Haiti Group Report

M. Eng. 2001

Daniele Lantagne, Farzana Mohamed,

Peter Oates, and Nadine van Zyl

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Acknowledgments

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Chapter 1: Introduction

1.1 Haiti Disinfection Project

Over one billion people in the world lack access to safe water, and over three billion lack access to adequate sanitation (WHO, 2001). In Haiti, only 45 percent of the rural population has access to safe water, only 16 percent of the rural population has access to safe sanitation, and the morality rate for children under five is 129 per 1,000 live births (UNICEF, 2001).

To address this need for safe water in Haiti, MIT Master's of Engineering (M. Eng.) students teamed with the Florida-based non-governmental organization (NGO) Gift of Water, Inc. (GWI). GWI has been working in Haiti on point-of-use rural household filtration since 1995. Four related projects were developed and researched by M. Eng. students during the 2000 – 2001 academic year. The projects researched included: (1) chlorine generation in Haiti, conducted by Nadine van Zyl; (2) disinfection by-product formation and critical factors for program success, conducted Daniele Lantagne; (3) solar disinfection, conducted by Peter Oates; and (4) program sustainability, conducted by Farzana Mohamed.

Chapters 2, 3, and 4 provide the background information for this report. Chapter 2 provides a socio-political background to the project, Chapter 3 continues by describing water resources in Haiti, and Chapter 4 finishes by describing Gift of Water and the purifier design. Chapters 5, 6, 7, and 8 are the four research chapters: chlorine generation, disinfection by-product formation, solar disinfection, and program sustainability, respectively. Chapter 9 provides the conclusions.

Chapter 2: Historical and Cultural Context

Haiti encompasses 27,750 square kilometers of the western third of the island of Hispaniola in the Caribbean Sea. It shares the island with the Dominican Republic, and is near Cuba, Jamaica, and Florida. Haiti's current population is about 8 million people, with the largest population center the capital, Port-au-Prince.

Isolated by culture and language from its neighbors, Haiti remains "the most African of Afro-American countries (USAID, 1985)." Haiti is also full of apparent contradictions. From being the second free state and the poorest country in the hemisphere, to the mixture of Vodoun and Catholicism, to a history that is both proud and contentious, to a people who are living in severe poverty but are welcoming and friendly, Haiti is both a vibrant and a difficult place.

Figure 2.1: Map of Haiti

2.1 Haitian History and Culture

Prince (1995) detailed the complexity of Haiti's complicated and tortuous history. Columbus first landed in the new world at Cap-Haiten, on the northern coast of Haiti, in 1492. He promptly exploited the native Taino population to mine for gold to send back to Spain. In 1548, 56 years after Columbus had landed, the population of Taino had dropped from 500,000 to less than 500 due to slavery, hunger, disease, and suicide. In 1519, with the gold mines worked out, sugar and cattle farming began to thrive. 864,000 slaves were brought to Haiti from Africa between 1519 and 1549. By 1559 only 400,000 slaves remained, due to the death rate of slaves in transport to, and hardship of life in, Haiti.

During this time period, French pirates landed at La Tortue, an island off the north coast of Haiti. The French began to fight with the Spanish over control of Hispaniola, eventually taking control of the western portion of the island in 1697. In 1801, slave leaders Francois-Dominique Toussaint L'Ouverture, Jean Biassou, and Jean Francois led a revolt that resulted in Haiti declaring independence on January 1, 1804. Thus, Haiti became the first black republic in the world and only the second free state in the western hemisphere. The current languages spoken in Haiti, French and Creole, reflect Haiti's historical connection with France. France officially recognized Haiti in 1825, on the condition that France would be compensated for lost income due to "confiscation" of property. Thus, Haiti began its existence with 150 million dollars of debt to France that was only repaid in full in 1922.

A number of different political leaders were in control of the country from 1804 to 1915. The political situation reflected the social tension between blacks and mulattos and between Haiti and the Dominican Republic. Leaders came into and out of power quickly, and established the precedent for dictatorships and "kleptocracies" in Haiti. In 1915, the United States occupied Haiti after seven different presidents were in power from 1910 to 1915. Ostensibly the U.S. occupied to stabilize the political system, but economic recognition of Haiti's strategic importance also played a role. The U.S. left Haiti in 1934, leaving behind a U.S. supported dictator, improved infrastructure, a U.S. trained police force, and increased tension between the mulatto and black communities.

A number of dictators held office in Haiti from 1934 to 1956. In 1956, Francois Duvalier, with support from the black middle class and isolated rural poor, won the presidency in the first election in Haiti that women were allowed to vote in. The Duvalier regime lasted from 1956 to 1986, with Duvalier's son, Jean Claude, succeeding him after his death in 1971. The Duvalier regime was characterized by excessive wealth at the expense of the Haitian people, rule by private militia, amendment of the constitution, and on-and-off support from the United States.

Maguire (1996) discussed Haiti's recent history. In 1986, a combination of popular uprising, supported by the liberation theology of the Catholic Church, and withdrawal of U.S. support, led Jean Claude Duvalier to flee to France in exile. In February 1991, after a period of civil unrest, a young priest named Father Jean-Bertrand Aristide was inaugurated into the presidency in what is widely regarded as the first democratic election in Haiti. His Lavalas (cleansing flood) party only survived until a coup in September of 1991. Aristide escaped to the U.S., and the army was again in power.

In October 1991, the U.S. established economic sanctions against the military regime governing Haiti that significantly hurt the civilian population. Responding to pressure from an increased number of "boat people," the U.S. occupied Haiti once again in 1994. On October 15, 1994 Aristide was reestablished as the Haitian president, with only one and a half years left in his constitutionally mandated five year term. Aristide was replaced by his successor, Rene Preval, in 1996. Aristide was then reelected President on November 26, 2000, with civil unrest, low voter turn-out, and the questioning of the legitimacy of the election all indicating that Aristide has lost popular support and the ability to effectively govern the country. His inauguration was February 7, 2001. The questioning and unrest surrounding his reelection does not lead to much hope for Haitian politics changing for the better in the near future.

2.1.1 Economics

Maguire (1996), detailed some economic indicators in Haiti as well. Seventy-five percent of the population of Haiti is involved in sustenance agriculture, although urban migration to Port-au-Prince has increased over the last few years. Poverty is widespread, with over 75 percent of the country in “absolute poverty.” Economic disparity is extreme, with one percent of the country owning 45 to 55 percent of the wealth. The foreign debt weight of Haiti is also extreme. Population growth is currently among the highest in Central America at 5 children per woman. The growing tourism industry of the 1980s was abruptly shut down when Haiti was, incorrectly, blamed for bringing HIV to the U.S. via Miami.

2.1.2 Religion

Courlander (1960) observed the following while investigating religion in Haiti. Haiti is predominantly Catholic, with a small 10 percent Protestant minority. Although the majority of the population is Catholic, Vodoun is extremely widespread throughout the country. Despite first appearances, this is not the anachronism that it seems. Vodoun and Catholicism are blended in a religion that sees the Catholic God as “destiny,” and the Vodoun *loa* (spirits) as responsible for the here-and-now.

Water is intrinsically tied to the Vodoun relationship with the *loa*. “The land where the loa live” is “the place below the water.” The route to *loa* worship is through water: “tales are heard everywhere of persons who, drawing water from the spring at night, heard the voices of loa or the sound of singing and drumming coming up from somewhere below,” and “virtually all the tales about human beings who visited the land of the *loa* describe them as descending into a river or disappearing into a waterfall.” Water is also used to entice *loa* to ceremonies, to call the cardinal points, and to bathe the *loa* in the ceremonies. The baptism of Catholicism integrates well with this water worship.

The Catholic and Protestant churches work extremely well together in Haiti. Due to the absence of government support for infrastructure, the churches have stepped into this role. In rural areas, churches are often the only organizations that support community development projects. Both Catholic and Protestant churches work with GWI to provide safe water.

Chapter 3: Haitian Water Resources

Water is the most ubiquitous compound in living cells and imperative to all forms of life. Haiti is the poorest nation in the western hemisphere and potentially faces catastrophe from lack of this essential resource. Overpopulated, Haiti's resources are exhausted and trends of further deterioration are readily apparent. Vast advancements in water resources are needed to improve the livelihood for the Haitian people.

3.1 Water Sources

Water in Haiti is generally available from precipitation, rivers and surface water, and groundwater. All of these resources are intimately related in the hydrologic cycle, which ultimately provides water for the Haitian community. The impacts of deforestation have adversely affected the amounts of water potentially available from each resource.

3.1.1 Precipitation

The majority of Haiti's precipitation is brought by the northeast trade winds with a slight contribution from easterly winds. Extreme patterns including storms, hurricanes, droughts, and floods are common. Annual Rainfall can range from less than 30 mm in the northwest to more than 3000 mm in the mountains of the southwest. Orographic factors greatly influence site-specific rainfall patterns creating the largest amounts of precipitation in highly mountainous areas (USAID, 1985).

3.1.2 Rivers and Surface Water

The majority of Haitians use surface water. Most of Haiti's rivers are short and swiftly flowing with the exception of the Artibonite River. The broken and steep landscape gives rise to numerous streams and rivers. However, most of these rivers only flow during periods of rainfall and few rivers have permanent flow (USAID, 1985).

3.1.3 Groundwater

Groundwater is Haiti's second most important water resource and could become the primary supply of freshwater in the future. Limestone underlies 80% of the nation, making groundwater readily accessible with well-drilling equipment. Water quality is high, although hard and slightly saline in some cases. Groundwater is especially abundant in the coastal plains and these aquifers can yield between 10 to 120 liters per second. Port-au-Prince and domestic areas such as Cul-de-Sac, Leogane, Carrefour, St-Marc, Cabaret, Grande-Riviere Du Nord, Limonade, Ouanaminthe, and Aquin widely use groundwater for domestic purposes (Library of Congress, 1979). Some regions of Haiti contain ample groundwater but they could be difficult to develop as they contain a karstic substratum (USAID, 1985). The onset of any future development of this resource must be carefully evaluated. If pumping rates exceed groundwater recharge rates, salinization of the freshwater could occur. Additionally, to obtain optimal benefits from groundwater, as well as surface water, the effects of deforestation must not only be considered but also remedied.

3.1.4 Impacts of Deforestation

A steady source of available water may not be possible with the current amount and trends of deforestation. Groundwater and surface water resources depend on the capacity of a watershed to store water and then gradually release it into rivers and recharge water tables. The ability of a watershed to retain water depends on its vegetative properties. Surface root structures, small plants, and dead leaf matter increase overland friction to flow and this allows more surface water to infiltrate. Deforestation causes a much larger portion of the water to flow overland, which decreases groundwater base flow. Thus river levels rise and fall dramatically as a function of precipitation events. This type of river flow provides a highly variable and ultimately unreliable source of water. Additionally, loss of vegetative cover results in significant soil erosion, degrading both upland and downstream areas and causing high maintenance costs.

At the beginning of the 16th century, Haiti was covered with lush forests. As of today, only about 7% of the land is forested. Twelve of thirty major watersheds were deforested by 1978. If the rate of deforestation continues, only one pine forest and its corresponding watershed will remain by the year 2008 (USAID, 1985). Significant actions need to be taken to protect and restore the vegetative cover, and thus the water resources of Haiti's watersheds. Although Haiti's water resources are not known in great detail, with the right care, they are believed to be adequate to meet all needs. One major task is harnessing these resources and delivering them to the Haitian people.

3.2 Haitian Water Supply

Two government sections are responsible for managing and developing water resources in Haiti. The Ministry of Agriculture, through the Services des Resources en Eau, is in charge of water resources studies, research, control, and protection. The Ministry of Public Works provides drinking water through two organizations: Centrale Autonome Metropolitaine d'Eau Potable (CAMEP) for the metropolitan area, and Service Nationale d'Eau Potable (SNEP) for the remainder of the country. In reality, there is little control over the use of water resources and several other government and non-government organizations administer water supply programs (USAID, 1985).

In 1978, there were 40 domestic water supply systems in the country serving 700,000 people, or roughly 15 percent of the population (HARZA, 1979). The existing water supply programs are the result of investments by government agencies, and bilateral and multilateral cooperation organizations. In 1984, the government devoted 4 percent of the budget to potable water projects and this contribution was financed at 84 percent by external assistance (USAID, 1985).

CAMEP serves Port-au-Prince, Petionville, Carrefour, and Delmas, supplying its customers from 17 springs and 3 wells from the Cul-de-Sac (USAID, 1985). The upkeep of these structures and associated distribution pipes leave much to be desired. Water loss from pipes is estimated to be between 50 and 70 percent (DATPE, 1984; Fass, 1982). All of these sources, with the exception of Doco Spring, have disinfection units but they are usually not operational. CAMEP nominally serves about 500,000 people through 40,000 connections and 80 functioning standpipes. In actuality, only about 80,000 people utilize CAMEP as their legal source of water. Approximately 300,000 people obtain water from private vendors, 100,000 share a connection with a subscriber, and about 40,000 illegally tap into CAMEP's pipes (USAID, 1985).

SNEP is responsible for the construction, operation, and maintenance of all water supply systems outside the metropolitan area. SNEP's finances are severely limited it but has received assistance from UNICEF, WHO, The World Bank, Inter American Development Bank, German Foundation for Technical Assistance, and USAID (USAID, 1985). SNEP has 185 water supply systems in operation, serving a total population of 700,000. Most of these systems are capped springs. Community systems range from a dug or bored well with a hand pump serving about 200 people, to house connections and public fountains serving about 60,000 (USAID, 1985). Several organizations helped finance or physically participated in the construction of these systems: IDB, Organization pour le Development du Nord, and Department de la Sante Publique et de la Population at the Ministry of Health. In addition, several non-governmental organizations made vital contributions: CARE, World Church Service, Missionary Church Association, German Foundation for Technical Assistance, and Canadian Agency for International Development. A major problem with these water supply systems is there are no national drinking water supply standards. The managers of CAMEP, SNEP, Public Hygiene Division, and Sanitation Office indicate that the main concern is bacteriological contamination. It is generally agreed that there is enough water for drinking purposes and the real issue is developing of the quality of the resource (DATPE, 1984).

3.3 Haitian Water Quality

Water-related diseases run rampant in Haiti. CAMEP and SNEP water is theoretically disinfected before distribution. However, treatment is very erratic due to breakdowns and lack of backup supplies. Surface water and groundwater from uncapped springs are considered unsafe due to the high risk of contamination. Water from private vendors can pose a risk of disease because it is not disinfected and the sources are unprotected. Even bottled water's safety cannot be guaranteed, as there is potential contamination during the shipping process. Essentially, there is no controlled potable water in Haiti and every source could contain pathogens (DATPE, 1984).

Waterborne pathogens are capable of causing illness depending on the dose and physical condition of the exposed individual. Infectious organisms found in water may be discharged by human beings who are carriers of a disease. Pathogenic organisms include bacteria, viruses, protozoa, and helminthes, which can all cause a wide array of diseases.

These infectious organisms can have highly deleterious impacts on community members. Table 3-1 shows there were several thousand cases of water related diseases reported in 1980 (CONADEPA, 1984).

Table 3-1. Some Reported Cases of Water Related Diseases in 1980 (CONADEPA, 1984)

Area	**Population**	**Diarrhea**		**Intestinal Infections**		**Typhoid**	
		Cases	**/1000**	**Cases**	**/1000**	**Cases**	**/1000**
Port-au-Prince	650,000	6608	10.2	4694	7.2	460	0.7
Gonaives	33,000	225	7.7	167	5.1	11	0.3
Port-de-Paix	15,000	455	30.3	2171	145	114	7.6
Hinche	10,000	694	69.4	738	74	100	10.0
St. Marc	23,000	851	37.0	314	13.7	266	11.6
Petit Goave	7,000	294	42.0	1357	194	2	0.3
Belladere	2,500	875	350.0	272	109	68	27.2
Jacmel	13,000	320	24.6	152	11.7	87	6.7
North Dept.	560,000	3145	5.6	6819	12.2	141	0.3
South Dept.	500,000	1909	3.8	2380	4.8	462	0.9

The actual numbers of diarrhea and intestinal infections are much higher as many occurrences are never reported. In 1979, diarrhea alone caused the death of 9% of babies less than one year of age (USAID, 1984). A study from 1994 to 1995 found nearly one-half of all deaths occurred within the first five years of life. Additional statistics indicate that approximately 74 out of 1,000 children die before one year of age and 131 never reach five years of age (PAHO, 1999). The National Health Survey conducted a study from 1987-1994 and found that the incidence of diarrhea was about 47.7% in 6-to-11-month-old infants. Diarrheal diseases are the leading cause of illness and death in children under five years of age, and are often associated with malnutrition and acute respiratory infections (PAHO, 1999). These daunting statistics make water quality the biggest water resource issue in Haiti. If correctly managed, there is an ample amount of water to meet the needs of the Haitians but they need an easy and economical way to destroy waterborne pathogens.

3.4 Point-of-Use Water Treatment

In developed countries, elaborate centralized water treatment plants typically destroy pathogens. Unfortunately, it is not financially possible to upgrade to conventional water treatment technologies in Haiti. As a more plausible alternative, low-cost point-of-use disinfection technologies can treat water and are more economically realistic. The choice of a point-of-use water technique should fulfill the following criteria (Lehr *et al.*, 1980; Shultz and Okun, 1984):

1. Should be effective on many types and large numbers of pathogens
2. Should perform regardless of water fluctuations
3. Must operate in appropriate pH and temperature range
4. Should not make the water toxic or unpalatable
5. Should be safe and easy to handle
6. Any chemical concentrations should be minor
7. Must provide residual protection against possible recontamination
8. Units must be affordable to all
9. Should be adaptable to local conditions and variations
10. Specialized equipment should be produced locally
11. Must be accepted by local traditions, customs, and cultural standards
12. Must comply with national sanitation and pollution policies

Current household disinfection methods include boiling water, filtering, and chlorination. Boiling water uses energy in the form of firewood, which is no longer possible in many areas of Haiti due to extensive deforestation. The current point-of-use disinfection approach in Haiti is filtration and disinfection. Our efforts will research point-of-use disinfection with respect to the criteria provided above.

Chapter 4: Gift of Water and the Purifier Design

4.1 Gift of Water, Inc. (formerly Industry for the Poor)

The general objective of Gift of Water (GWI) is: "Industry for the Poor empowers impoverished families in rural Haiti to purify their own water through the sustainable development of a maintenance network and small scale enterprises (GWI, 2000)."

4.1.1 Beginnings

In 1985, Thomas P. Warwick (Phil) became involved with a solar distillation project in Haiti that was large, impractical, and cost prohibitive. Later, in medical mission trips to the Dominican Republic, Phil worked on a water project for three years, and the beginnings of the current GWI purifier were developed (GWI, 2000).

In May 1995, Phil and his family decided to incorporate Industry for the Poor and work to provide safe drinking water in Haiti. In November 1995, GWI began by assessing medical conditions and health problems in Dumay, Haiti with Adopt-a-Village Medical Missions (GWI, 2000). This study recommended home-based water purification as the most economical of the alternatives considered.

GWI (2000) details the history of purifiers in Haiti. In August 1996, 52 families in Dumay purchased the first purifiers for H$2 (approximately US$0.40), and the first six Haitian technicians were trained to monitor the program. By March 1997, 96 percent of the families using the purifier chlorinated properly and 84 percent of the purifiers showed negative total coliform tests. The decision was made to expand and 229 purifiers were installed in Haiti in August 1997.

In August 1997, 13 Haitians were trained to assemble the purifiers in a factory facility in Dumay. By the end of 1999, approximately 4,000 purifiers had been shipped to Haiti.

In November 1997, the purifier was independently verified by Brevard Teaching & Research Laboratories (BTR). In July 1998, the newly independently verified purifier became the first Haitian-made purifier to be approved by the Haitian Ministry of Health (GWI, Undated). Gift of Water states in their literature that monitoring studies have shown greater than 90 percent correct use, greater than 98 percent consistent use of the purifier, and a 90 percent drop in water-related illnesses among children under five who use the purifier (GWI, 2000).

In January, 1999 GWI began working with a number of different sponsors to expand to additional rural communities. Seven communities, together with sponsors, now have established purifier programs (Table 4.1).

Table 4.1: Communities in Haiti with Purifier Programs

Village	Number of Purifiers	Data Begun	Sponsor
Dumay	1,800[1]	August 1996	Adopt-A-Village Bethel Foundation
Les Palmes	600	January 1999	Haiti Twinning Program Church
Barasa	50	January 2000	Catholic Center at Illinois University
Fon Verrettes	50	October 2000	Matt Cyr
Ferriere	50	July 2000	Catholic Church
Bas Limbe	50	August 2000	Medical Mission
Demiere	50	September 2000	Dennison University
Total:	2,650		

Of note is that 4,000 purifiers have been shipped to Haiti, but only approximately 2,650 are accounted for in the seven communities. Phil Warwick is working to investigate this discrepancy (Warwick, personal communication).

[1] Different technicians in Dumay quoted different total numbers of purifiers. 1,800 is an average number.

Currently GWI employs Trudi Onek as General Administrator, Sisi Towers as Workshop Manager, and two differently abled workshop employees. The President of the Board, Thomas P. Warwick (Phil), and the rest of the Board do not take a salary. Bill Gallo volunteers to lead the sampling trips to Haiti and also does not take a salary. In Haiti, GWI employs technicians in each community who visit homes with purifiers, solve problems, and implement the program on the ground. The technicians are supervised by a volunteer water committee of approximately ten people in each community. In addition, each community has one contact person, such as the priest or nun, who acts as the liaison between GWI and the community. Thus, a network of people support the program on the ground.

A recent donation appeal, sent by Phil Warwick, detailed GWI's (2000) continued vision, successes, concerns, and financial accountability. Phil details how water "remains the #1 killer of children today" and how "education and monitoring programs are *more important* than the actual number of purifiers shipped." He states "our vision provides education, monitoring, and growth." In program successes of the past year, Phil details how six out of seven areas in Haiti meet an 80 percent correct and consistent usage standard.

In summary, although there are a number of uncertainties, including: (1) the actual number of purifiers in Haiti; (2) data supporting the 90 percent correct usage statement; and (3) epidemiological data supporting the 90 percent drop in childhood disease statement (GWI, 2000), GWI clearly has developed a responsible organization that is promoting public health in Haiti.

4.2 Purifier Design

The purifier itself is two 15-liter buckets connected by a check valve. Above the check valve in the top bucket is a cotton filter. Below the check valve in the bottom bucket is a carbon filter. To use the purifier, water is collected in the top bucket, and bleach is added. The top bucket with the bleach in it is allowed to sit for 30 minutes. It is then placed on the bottom bucket and water flows through the cotton and then the carbon filter. Five drops of chlorine are added to the bottom bucket before filtration to form the residual.

Chapter 5: Chlorine Generation

5.1 Introduction

The seven Haitian communities with GWI programs have achieved significant measures of success regarding water treatment, however some problems continue to hinder initiative's progress. One critical issue involves drinking water disinfection, i.e. the sources of chlorine used in the filters are inconvenient and expensive, and current practices impede the program's self-sufficiency. The purpose of this section of the project is to provide a solution to the difficulties associated with the generation, transportation and longevity of chlorine sources used in GWI purifiers in Haiti.

Currently, commercial chlorine bleach is used as a disinfectant in the GWI filter, imported from the United States or the Dominican Republic. This practice is becoming increasingly problematic due to issues of bleach availability and stability, as well as problems associated with Haiti's dependence on foreign products. We propose generating sodium hypochlorite as a chlorine source within Haiti, replacing imported bleach thus alleviating the above problems. Moreover, in-country chlorine generation gives Haitians a greater stake in the GWI initiative, provides local jobs and skills, and represents the move towards a self-sufficient and sustainable water purification project.

In order to establish the most appropriate hypochlorite generator and implementation of it, we have structured the project so as to assess Haiti's particular needs and how they might realistically be met. We studied the context of the GWI project, i.e. the current situation in Haiti with respect to its economy, politics and environment. This involved a site visit in January 2001, where we visited six communities with GWI programs, including Dumay, the location of our generated sodium hypochlorite pilot project.

5.2 Disinfectant Generation in Dumay

A key benefit of sodium hypochlorite generation is its lessening of Haiti's dependence on imported products. A Haitian dollar is better spent on Haitian-made salt and labor than on imported commercial bleach. Because sodium hypochlorite generation gives Dumays residents the responsibility of disinfecting their water as well as producing the disinfectant, it progresses towards GWI's ultimate goal of putting the entire project under Haitian control.

Dumay is by far the most experienced and saturated with water filters, with estimates ranging from 1800 to well over 2000 purifiers in use. The local water committee is in charge of selling chlorine bleach to the community: ten stations throughout the area sell a 250 ml bottle of bleach for 3 gourdes (approximately $0.12 US). Generally, Nathan Dieudonné, a local pastor and community leader as well as GWIs coordinator of Haiti, buys bulk quantities of chlorine bleach from Port-au-Prince as is needed, with prices averaging at 6 gallons for 52 Haitian dollars (equal to 260 gourdes or $10.40 US). The strong community support, history with GWI and regulation of bleach distribution make Dumay ideal for the pilot hypochlorite generation project. Dumays system of community meetings should also be helpful in easing the transition to a different form of bleach.

5.2.1 Chlorination Fundamentals

Before chlorine, a strong chemical oxidant, can disinfect, the chlorine demand of the water must be satisfied, that being the difference between the added oxidant dose and the residual oxidant concentration. In water, free available chlorine can be found in one of three forms: chlorine (Cl_2), hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-). Hypochlorite is the most widely used active chlorine compound in disinfection, due to its powerful germicidal action, non-toxic nature at at-use concentrations, economic advantages and ease of use. Available chlorine is an empirical measurement of a compound's oxidizing power in terms of an equivalent quantity of pure chlorine; i.e. Cl_2 is 100% available chlorine. Sodium hypochlorite of high chlorine concentrations is impractical due to its increasing instability with chlorine concentration. At ambient air temperature, the half-life of sodium hypochlorite is approximately 60 days for an 18% available chlorine solution and 1700 days for a solution of 3% available chlorine (Lawrence and Block, 1968). Heat and light also significantly affect a hypochlorite solution's stability: its rate of decomposition nearly doubles with a temperature increase of 10 degrees Fahrenheit (approximately 5.5 degrees Celsius) (Sconce, 1962).

5.2.2 Mechanisms of Hypochlorite generation

The costs and benefits of drinking water disinfection by chlorination depend on site-specific factors such as power costs, availability of brine/sea water, safety and ease of use.
On-site sodium hypochlorite generators generally produce a solution of strengths between 0.6 and 0.8%. These concentrations are under the threshold for hazardous classification, therefore no containment requirements or process safety management concerns are necessary. The only raw materials required by the generator are salt and water (or seawater), and electricity. Haiti's climate poses challenges for chlorine storage, with its mean yearly temperature of 26 degrees Celsius (Dogget and Gordon, 1999). Sodium hypochlorite's low chlorine concentration and the reduced storage needs of on-site generation resolve such degradation concerns.

A standard generating system produces sodium hypochlorite through electrolysis. The generating cell itself consists of a series of electrodes contained inside a protective shell. With the application of an electric current, the electrodes start an electrochemical reaction where brine solution (or seawater) is converted into sodium hypochlorite and hydrogen. Salt impurities may increase calcium build-up on the cathode and necessitate more frequent maintenance, and household white vinegar can be used to clean the cell. Most generator models are available using either alternate current (AC) or direct current (DC) electricity. During the electrolysis of a brine solution, chlorine is generated at the anode and hydrogen at the cathode.

5.2.3 Assessment of Dumays Chlorine Demand

Selecting a generator capacity for Dumay, allowing for future expansion of GWIs filter distribution without making the project prohibitively expensive, was an extremely difficult task. The prediction of future water purifier use is problematic in itself, but the uncertainty was increased by the contradictory information collected on Dumays current demand. Technicians had differing estimates of the numbers of purifiers in the area, and as GWIs estimate was based on parts shipped to Haiti it was much higher. Further, GWI has manufactured parts for an additional ten thousand water filters for distribution throughout Haiti. The most common estimates for Dumay's filters currently in place were between 1800-2000. Frequency of filling ones dispensing bottle was assessed through surveys of individual purifier owners, and the response of once per month was the most common. In determining a capacity for the first generator to be installed in Dumay, we assumed that 2000 filters are currently in use, and in the relatively near future another 3000 would be distributed from the new GWI shipment. We explicitly acknowledge, however, that assumptions are worth little in Haiti, and the future of the country, including GWIs program, is uncertain. Optimistically, we predict that within the next few years, the number of filters in Dumay will be approximately 5000.

Currently, GWIs practice is to maintain a filter chlorine concentration much higher than that recommended by the Center for Disease Control and Prevention (CDC). In similar projects using generated sodium hypochlorite, the CDC encouraged a free available chlorine concentration of 0.5 to 2 mg/L (Center for Disease Control and Prevention, 2001), whereas GWI practice results in approximately 16 mg/L. This is done to satisfy the raw water’s chlorine demand, and as the chlorine was obtained from imported commercial bleach of 5.25% concentration, degradation interfered with its ability to disinfect and high doses were needed to compensate. Based on both the CDC and GWIs experiences, we recommend a trial period for a filter concentration of 5 mg/L, corresponding to adding 12 ml (2 capfuls) of generated sodium hypochlorite solution. (If the raw waters chlorine demand is not satisfied with this dose, it can readily be increased to 7 mg/L with the addition of another 6 ml per treatment (corresponding to 3 capfuls). This will require further study in Dumay.) We believe that the issues responsible for decreased clean water in GWIs previous tests will not be similarly problematic with the 0.8%

chlorine solution. Because sodium hypochlorite stability increases with decreased chlorine concentration, and the transportation and storage times are greatly reduced, degradation will not affect the disinfection capabilities of the solution. Thus raw water will be effectively treated with a 5 mg/L chlorine concentration, while still providing a margin of safety to account for chlorine demand.

The amount of available chlorine needed to maintain a 7 mg/L filter concentration (the conservative estimate, corresponding to the maximum amount of chlorine required) was calculated to be 1 kg/d, for 5000 filters using current practices. Ideally, the 5 mg/L concentration will be sufficient and chlorine requirements will be even lower, but as this is not certain we provided for assumed the conservative amount in our design calculations.

5.2.4 Brine in Hypochlorite Generation

Although some commercial units can generate sodium hypochlorite using seawater, the use of brine solution is more common and can achieve higher concentrations of available chlorine. Because of Dumays location on flat plains near a mountainous region, fresh water supply is sufficient for the communities use plus the generators requirements. In addition, GWI is exploring plans to collect rainwater for use in the sodium hypochlorite generator.

Haitian salt is produced by solar evaporation in semi-agricultural operations along the northern coast. Small units function with minimal organization or quality control, as producers have little financial means or access to technical assistance. The more fortunate Haitians dig holes into the shore where seawater will penetrate, and after a few months of drought salt is ready for piling and harvesting. In local markets, 3 kg of salt can cost 10 to 15 gourdes (Vil, 1999). Salt purity in developing countries tends to be low, with estimates ranging from 80-90%, often with visible contamination (Vil, 1999). Production statistics are generally unavailable, however; therefore such estimates have little basis. The presence of impurities in the Haitian-made salt will not be problematic with respect to sodium hypochlorite generation, however. In response to questions regarding the effects of impure salt on the generator, suppliers indicated that impurities would only affect the efficiency and maintenance schedule of the electrodes, and suggested adding an additional 10% salt to the brine solution as compensation.

5.2.5 Photovoltaic Power

The use of photovoltaic power is appropriate for the conditions of this project due to its lack of a highly specialized or technical nature, minimal polluting effects and ability to function in absence of infrastructure. Currently, solar power is used in some parts of rural Haiti, but diesel generators are more commonly found than photovoltaic panels. We wish to encourage solar power use to power the sodium hypochlorite generator because it is a sustainable, non-polluting energy source, and because it will prevent Haitians from needing to buy imported fuel. Dumay is located in an area that receives more than adequate sunlight to generate solar power, but despite its prime location no solar panels are currently used; the little community power that does exist comes from a diesel generator that provides up to 46.5 kilowatts. Some communities, including Ferriere and Fonds Verrettes, use photovoltaic power, with panels obtained from Port-au-Prince.

5.2.6 Economics and Generator Selection

The selection of a sodium hypochlorite generator for Dumay involves many factors, both quantitative and qualitative. Economic concerns play a significant role, however it is important not to emphasize these aspects over the social and environmental ones. Multiple criteria must be considered, such as safety, community attitudes, risks, and training requirements. Some of the above factors can be expressed in monetary terms, but others, such as community attitudes, are impossible to quantify, thus a multifaceted approach is needed. In determining a present or future value, the combined interest rate should reflect both the time value of money and inflation. USAID estimated Haiti's 2000 inflation rate to be 10% (USAID, 2001), but a Haitian interest rate has been much more difficult to find. A representative of the Haitian Consulate in Boston claimed that in February 2001, the Haitian interest rate was 18% (Haitian Consulate interview, 2001). Due to the great uncertainty surrounding Haitian rate information, we used the simple combined interest rate formula as in a comparable project in Nigeria, with the same range of interest and inflation rates (Adeoti, 2000). The Haitian combined interest rate was determined to be 7.3%.

The importance of non-economic factors in this project is great and they demanded careful consideration. Weighted factor comparisons are used in decision-making with multiple attributes, where each alternative is assigned a numerical value in proportion to a set of factors (e.g. operator safety, net present worth) according to specified degrees of importance (White *et al.*, 1998). Based on alternatives performances with respect to each factor, a numerical score is given. We selected fifteen factors against which to evaluate the generator models, based on the most important issues addressed by this project. Weights were assigned summing to 100, according to the relative importance of each factor.

5.2.7 Generator Specifications

During the initial search for a sodium hypochlorite generator, a number of companies were contacted about the manufacture of such machines. The two companies providing suitable units for this project are Exceltec International Corporation and Equipment & Systems Engineering Inc. Each firm manufactures potentially appropriate units for Dumay's needs: the SANILEC 6 unit by Exceltec and the AC100D generator from Equipment & Systems Engineering. The units are similar with respect to their technology and general requirements, and ability to use AC or DC electricity. Further specifications follow in Table 5.1:

Table 5.1: Specifications Comparison

	SANILEC 6	AC100D
amount/hr of available chlorine	113 g	100 g
equivalent chlorine concentration	0.8 %	0.6 %
water consumption per 24h cycle	455 L	400 L
salt consumption per 24h cycle	13.6 kg	12 kg
electricity consumption per kg chlorine	5.5 kW	8.3 kW
generator weight	4.1 kg	7.7 kg
generator dimensions	17.8 cm diameter 102.6 cm length	112 cm length
Warranty	2 years	1 year
electrode lifetime (vendor description)	depends on maintenance	several years
Cost	$2000	$2450

5.2.8 Weighted Factor Comparison

Based on the above criteria and unit specifications, we rated the two units individually to establish total scores for each one. The score is simply the weight of the factor multiplied by the unit's rate out of ten with respect to said factor, and the total score is their sum.

Table 5.2: Weighted Factor Comparison

	Factor	Weight	Sanilec-6		AC100	
			Rate	Score	Rate	Score
1	NPV / initial machine cost	14.6	0.8	11.7	0.6	8.8
2	Generator lifetime	6.6	0.7	4.6	0.7	4.6
3	Generator capacity	9.3	0.9	8.4	0.8	7.4
4	Energy usage	9.3	0.9	8.4	0.5	4.7
5	Water, salt usage	3.9	0.7	2.7	0.7	2.7
6	Supplier experience with developing countries	3.9	0.9	3.5	0.9	3.5
7	Generator durability	4.9	0.8	3.9	0.7	3.4
8	Ease of use	14.6	0.5	7.3	0.5	7.3
9	Maintenance needs	8.3	0.6	5.0	0.6	5.0
10	Chlorine concentration of solution	3.4	0.9	3.1	0.7	2.4
11	Manual & product information	5.4	0.6	3.2	0.8	4.3
12	Warranty	6.1	0.8	4.9	0.6	4.3
13	Size, space requirements	2.9	0.8	2.3	0.5	1.5
14	Portability	2.9	0.9	2.6	0.8	2.3
15	Supplier support	3.9	0.7	2.7	0.9	3.5
	sum	100.0		74.3		65.1

According to this comparison, the SANILEC-6 model is the most appropriate unit for Dumay. Its cost, particularly for a generator of this capacity, is an important factor in this selection, as is the experience of its manufacturer, Exceltec, with similar projects in Burkina Faso and Guatemala. This model clearly scores better using the weighted factor comparison, and as this method incorporates all key issues in generator selection, we recommend the SANILEC-6 for Dumay.

5.2.9 Project Implementation

As the household water disinfection program is already in place in Dumay, sodium hypochlorite generation should be fairly readily achieved. The most significant challenges will be establishing the generator in Dumay, and training its operators. Whether the generators initial costs are to be borne by GWI or a combination of it and Dumays benefactors will be decided by GWI. The basic needs of the generator include a well-ventilated room, electrical source of 110-220 V / 20 amps, and close proximity to a water source (Center for Disease Control and Prevention, 2001). Further details are provided in the CDC's Safe Water Manual. Detailed instructions from the manufacturer are needed, and three operators must be trained by GWI to run the generator and bottle the solution. We recommend that technicians or water committee members become the generator operators, as they are familiar with the program and GWI, and are more likely to understand French (manuals are not available in Creole). Most importantly, the new solution's concentration must be maintained at 0.8%.

The most efficient and cost-effective means of procuring a photovoltaic power system for Dumay is to obtain one from Port-au-Prince, guided by the experience of community leaders from Fonds Verrettes and Ferriere. The system must provide either 110V or 220V single phase power, AC or DC. In the case that solar panels are no longer available in Port-au-Prince, Sunwize Technologies, Inc. was recommended by Equipment & Systems Engineering, Inc.

The initial step in introducing sodium hypochlorite solution to Dumay is to select a group of families for the miniature pilot project. The purpose of a pilot project is to determine the best procedures and product, through trial and error, before expanding to the entire area. The test population will have a range of experience with the system, but have a good understanding of the necessity of adding chlorine to the filter. The Dumay project will eventually include approximately 5000 filters, and the pilot projects size must be representative but manageable as increased technician visits will be necessary to guide correct usage of the generated hypochlorite.

As a potential health concern exists due to the reduction of the filters' chlorine concentration, we recommend an initial case study of 60 filters. These households should be strictly monitored in order to assess the efficacy of both the generated hypochlorite and the 5 mg/L chlorine concentration. Two months should be sufficient to determine the success of both factors. Shortly after this test, presuming that it is successful, we propose a miniature pilot project involving 660 filters, 60 per each technician in Dumay. Using the same calculation as performed in assessing Dumay's chlorine demand, 660 filters will need 150 g/d of available chlorine. The SANILEC-6 may be run intermittently to provide this amount. Pilot projects of this nature generally last from 12 weeks to one year (Center for Disease Control and Prevention, 2001), and as this sample is small, we suggest a time frame of 3 to 4 months to obtain a sense of the feasibility of project expansion.

5.2.10 Cost Recovery

One of GWI's goals for sodium hypochlorite generation is to reduce the cost of disinfectant, putting these savings back into the program and leading it towards self-sufficiency. Costs associated with local generation of sodium hypochlorite involve the generator itself, power and salt. For simplicity and continuity, all expenses are calculated in US dollars. The SANILEC-6 unit, at $2000, is the most significant capital cost. According to solar panel owners in Ferriere, the approximate price of a series of panels is $800 to $1000, obtained through a Catholic priest in Port-au-Prince. Assuming that 5000 filters will be in use, based on Dumay's projected chlorine demand and the SANILEC-6s salt requirements per kg chlorine, 4 kg/d are needed, accounting for surplus salt used to compensate for impurities. At a cost of $0.2 per kilogram of salt, the monthly cost is $24.

At the January 2001 commercial bleach price of approximately $0.45 per liter, the monthly cost of bleach for 5000 filters is $570. Community bleach sellers bring in $0.12 (3 gourdes) per squeeze bottle of bleach, totaling $600 per month for the future 5000 filters. If sodium hypochlorite is sold to the community for half the amount per bottle as bleach, but two times more solution is needed per use, monthly income will remain at $600. These figures assume that

5 mg/L will be a sufficient filter chlorine concentration. We suggest keeping monthly disinfectant cost constant to encourage Dumays filter owners to accept the generated solution.

The pattern of monthly cash flows is shown in Table 5.3, where cash outflows point downward and inflows point upward. Initially, $3000 are required to purchase the generator and photovoltaic power source. Using generated solutions, $24 per month are needed for salt, while $600 are made from the sale of sodium hypochlorite to Dumay's 5000 filter owners. We have assumed that the generator is run properly and maintenance costs are minimal.

Table 5.3: Cash Flow Table

		$600	$600	$600	$600	$600	$600	$600
month 0								
	$2,000	$24	$24	$24	$24	$24	$24	$24
	$1,000							

In order to determine the time at which the generators capital costs will be recovered, a time value of money calculation was performed, using a simple relationship for a uniform series of cash flows (White *et al.*, 1998). Based on tabulated uniform series present worth values (White *et al.*, 1998), the costs of the generator will be recovered in slightly less than 6 months. This analysis applies to the larger scale case of the entire Dumay community numbering 5000 filters using sodium hypochlorite solution.

We performed a sensitivity analysis on the above calculations because of the significant uncertainty surrounding the Haitian interest rate. Based on the formula for a uniform series of cash flows, and containing the interest rate of 7.3% within a range from –80% to +80%, the present value of monthly investments varies from $3326 to $3441, compared to the initial value of $3384. Therefore the present value of monthly investments over a 6 month period is relatively insensitive to changes in the interest rate and the investment in a generator can be encouraged despite the lack of certainty regarding Haiti's discount rate.

5.3 Conclusions and Recommendations

The purpose of this project was to provide an alternative to the current GWI practice of chlorinating raw water with imported commercial bleach in its Haitian water filtration programs. Sodium hypochlorite generation will further the GWI initiative in providing economic benefits as well as the beginnings of self-sufficiency. Exceltec, Inc's SANILEC-6 hypochlorite generator is the most appropriate unit for Dumays conditions, and we recommend its procurement. The capital cost of this machine plus photovoltaic power, $3000 US, is perhaps more than what GWI had anticipated, yet when the current costs of buying imported bleach are considered, as well as the revenue to be gained from selling bleach to 5000 filter owners, these costs are readily recovered. Further, disinfection problems associated with bleach degradation will be alleviated due to the low chlorine concentration and short time between manufacture and use of the generated solution.

We do recommend further studies, however, to determine the exact relationship between the raw waters chlorine demand and the minimum amount of chlorine required for adequate disinfection. The suggestion of 5 mg/L as the chlorine dose for the generated hypochlorite, although significantly higher than the CDC's recommended 2 mg/L, may not be sufficient if raw water chlorine demand in Dumay continues to affect disinfection capabilities of the bleach solution.

Chapter 6: Trihalomethane and Critical Factors Project

This section investigates trihalomethane production in the GWI purifier system. Trihalomethanes (THMs) are disinfection by-products (DBPs) formed when chlorine reacts with natural organic matter in the source water. Studies have detailed potential human health effects from lifetime exposure to low levels of THMs. GWI is concerned about THMs because their purifier system chlorinates twice: once in the raw water for biological inactivation, and then again in finished water to form the residual necessary to prevent recontamination in unclean containers.

The purpose of the THM study was twofold: (1) to determine if THM concentrations were above the World Health Organization (WHO) and United States Environmental Protection Agency (USEPA) standards; and (2) to develop an equation based on easily measured source water parameters that GWI could use to estimate THM concentration in finished waters. An additional focus of the section was to observe the program "in action" and determine critical factors of program success.

6.1 Chlorination and the Formation of THMs

"The first documented drinking water treatment can be found in Egyptian hieroglyphics, describing procedures to purify water. The basic principles were the same then as they are today: boiling, chemical treatment, and filtration were recommended treatments (Calderon, 2000)." Until 1908, when chlorine was first introduced in the United States, the same mechanisms as mentioned in Egypt were utilized for drinking water treatment. Chlorine revolutionized water purification, is credited with the reduction of infectious disease, and is currently the most widely used chemical for disinfection in the U.S. (Gordon, 1987).

Gaseous chlorine (Cl_2) or sodium hypochlorite (bleach, NaOCl (aq)), reacts with water to form hypochlorous acid and hypochlorite ion. Hypochlorous acid and hypochlorite ion then react with water according to pH. Hypochlorous acid also reacts with bromide in the water according to the following reaction:

$$HOCl + Br^{-} \longrightarrow HOBr + Cl^{-}$$

In 1974, Rook discovered that hypochlorous acid and hypobromous acid react with naturally occurring natural organic matter to create four compounds, chloroform ($CHCl_3$), bromoform ($CHBr_3$), bromodichloromethane ($CHCl_2Br$), and chlorodibromomethane ($CHClBr_2$). These four compounds are collectively termed trihalomethanes (THMs). Early days of research into THMs and chloroform received much attention because chloroform was shown to be an animal carcinogen (Simpson, 1998). As time has passed, chlorination of drinking waters has become equated with increased mutagenic activity due to an array of halogenated compounds and has spurred much concern and research (Simpson, 1998).

The role of the bromide ion in the formation of THMs is critical. Without bromide in the raw water, the three brominated THMs are not formed. Bromide itself is a naturally occurring ion found most commonly in ocean water and waters near the ocean. While chlorine acts preferentially as an oxidant, bromine is a more effective halogen substituting agent, so bromide not only causes a shift towards the more brominated species, but also increases the total THM yield (Sketchell, 1995).

6.2 Toxicology and Standards

The identification of DBPs as ubiquitous in chlorinated drinking water led to a flurry of research into potential human health effects. The effects of the four THMs have been studied individually and synergistically. A number of studies in rats and mice have noted increased liver and kidney tumors in animals exposed to individual and mixed THMs.

In response to concerns about potential human health effects of THMs, both international and governmental organizations have established exposure standards. The WHO regulates the individual THMs separately and in total. The USEPA regulates only total THMs (TTHMs). The standards are as follows:

Table 6.1: THM Standards

Compound	Standard
WHO: Chloroform	200 μg/L
WHO: Bromodichloromethane	60 μg/L
WHO: Bromodichloromethane	100 μg/L
WHO: Bromoform	100 μg/L
USEPA: TTHM	100 μg/L

In addition to the individual guidelines, the sum of the four THMs' actual value divided by their guideline value cannot be greater than one.

In addition, the WHO specifically states in the standards that: "It is cautioned that, where local circumstances require a choice to be made between meeting microbiological guidelines or guidelines for disinfection by-products such as chloroform, the microbiological quality must always take precedence. Efficient disinfection must *never* be compromised (WHO, 1998)."

The Center for Disease Control (2001) agrees with the WHO and states the following:

> Another concern about chlorination of water is the health effects of trihalomethanes. Trihalomethanes are disinfection byproducts that are formed when hypochlorite is used to treat water with organic material in it. Research suggests that, over a lifetime, the risk of bladder cancer increases with chronic consumption of trihalomethanes. In populations in developing countries, however, the risk of death or delayed development in early childhood from diarrhea transmitted by contaminated water is far greater than the relatively small risk of bladder cancer in old age.

Thus, although some countries stringently regulate TTHM concentrations, both the CDC and WHO strongly state that the danger due to bacterial contamination of drinking water in childhood in developing countries is far greater than the risk of cancer later in life.

6.3 Field Sampling and Observations

To determine the amount of THMs generated in the GWI purifier, a two-pronged approach was taken: (1) raw source water was collected, analyzed before purification, and filtered through a purifier; and (2) finished water from the purifier was collected and analyzed at MIT. This data was also used to model the formation of the THMs mathematically.

Raw source water was analyzed for color, turbidity, pH, temperature, and nitrate in Haiti. Source water was then collected and transported to a nearby purifier. Finished water was collected into two 45 mL VOA vials from the spout and checked for the correct amount of chlorine using the pool test kit. Through a translator, the family was asked questions about how often they use the purifier and how old the filters in the purifier were.

6.3.1 Summary of Source Water Data

Analysis of the source water data shows that the purifiers are used, on average, daily, and the average carbon filter age is slightly under one year (Table 6.2). Nitrate levels were very high, for the WHO standard is 10 ppm, and the average was above this. Turbidity was low for standards of using the water in the purifier, and all water was clear in color. In addition, the average carbon filter age was significantly over six months, with one four years old.

Table 6.2: Source Water Quality Summary

Parameter	Average	Range	Standard Deviation
PH	6.6	4.7 – 8.0	1.0
Turbidity (NTU)	1.17	0 .00 – 4.21	1.19
Temperature (C)	21.7	15 - 29	4.67
Nitrate (ppm)	10.3	0 - 44	10.6
Size of family using purifier	8.2	1 - 20	5.0
# times / week purifier used	7.3	1 - 14	6.0
Age of carbon filter (weeks)	47.4	13 - 208	43.1

Lastly, four out of the five communities sampled using the GWI methodology reached the 70 percent correct usage rate, and two of five reach the 90 percent correct usage rate (Table 6.3).

Table 6.3: Percentage Correct Usage by Community

Village	Percent Correct Usage
Ferriere	100
Bas Limbe	20
Fonds Verrettes	75
Barasa	90
Les Palmes	77

6.3.2 Carbon Filter Records

While in Haiti, the number of times that the carbon filters are actually changed was investigated. Nuphie is the technician / secretary who collects the reports from the other technicians and maintains the record book on filter maintenance in Dumay. Nuphie mentioned that carbon is changed every six to eight months, when the color of the water changes to yellow on the bottom or the family can feel the taste of chlorine in the water. She estimated that 15 carbon filters are changed per month. This number was confirmed by her records and by analysis of the amount of carbon left in Dumay by Phil Warwick. If every one of the 1,800 purifiers in Dumay had their carbon changed once every six months, then there would be 300 changes per month. This is significantly more than the 15 recorded by Nuphie, and thus carbon changes are not occurring as often as they should.

6.4 Critical Factors for Project Success

The following common factors for successful program implementation were determined from the visit to the six communities. They are meant as observations and potential recommendations.

6.4.1 Staff

Dedicated, respected, and well-selected technicians are vital to the success of the program. In Ferriere, Mary-Marthe and Suzanne are greeted warmly on a home visit, and they perform the testing with ease. The success of the program in their community is partially due to their dedication. The importance of good hiring of technicians should be stressed to the project leader in the community. In addition, when the project leader in the community has a vested interest in water issues and is familiar with U.S. style paperwork, and with the English language, the program runs more smoothly. Bail in Les Palmes, Matt in Fonds Verrettes, Sister Pat in Ferriere, and Nathan in Dumay all supervise their projects well, and function as good cultural translators between GWI and the French / Creole speaking technicians.

6.4.2 Purifier Distribution

Staged, planned, and local distribution of purifiers is also critical. In Ferriere, where 50 purifiers were distributed in a small area, rounds were comfortable, and easily completed multiple times per week. In Les Palmes and Bas Limbe, rounds were difficult and time consuming because the purifiers were very far apart in mountainous areas. The addition of a small number of purifiers at a time to localized areas will simplify the project in many ways.

6.4.3 Purifiers as Part of the Community

A number of people we saw were sharing their purifier with neighbors. This is a simple and effective way for GWI to reach a greater number of people for less capital costs. In addition, the water program seemed to have more support when it was part of a larger community development plan. Sister Pat has sponsored many health related programs in Ferriere, and the GWI program ties well into her larger work with the community and education. This is a tenuous metric, but measuring the “readiness” of the community for the project seems vital to the success of the project.

6.4.4 Challenges

Although there are many successes in the GWI program, there are a few challenges that are of note.

1. A number of community leaders were not using their own purifier correctly (Sister Pat, Nathan, Father Bruni). This is a result of either the leaders or their staff not knowing the correct procedure.

2. Carbon filters were not actually being replaced. Generally, the technicians knew how to and when to, but it was still not happening.

3. In Barasa, the lack of available water indicates that the first priority there should be water access, rather than water treatment.

4. No one in GWI speaks fluent Creole. This makes effective communication difficult because many subtleties of feeling and opinion are likely missed. In addition, more contact with GWI could be a positive factor for communities. The hiring of a full-time, in-country, Haiti-wide organizer who is fluent in Creole could improve many situations.

5. Good technicians will not continue if they are unreliably paid. A system of effective distribution of salaries outside of Dumay should be determined.

The GWI program is an effective and vital project in Haiti. Although there are some challenges, there are also many successes. Some simple modifications to the project implementation could help the program achieve even more.

6.5 THM Results and Modeling

A total of 19 finished water samples were brought back to MIT from Haiti. Seventeen of these samples were analyzed for TTHM and provided the basis for the development of equations to model TTHM concentration in the GWI purifiers.

6.5.1 Sampling Methodology and Quality Assurance

Trihalomethanes were sampled using a Tekmar LSC 2000 purge-and-trap system connected to a Perkin Elmer AutoSystem XL gas chromatograph (GC). A number of QA / QC procedures were used to ensure accuracy of data in the THM analysis. This included the assembly of standard curves, the analysis of duplicate samples and lab splits of the same sample, and daily analyses of standard samples to ensure accuracy. In summary, percentage error can be considered to be less than 20 percent, for the standard curves, duplicate and split samples, and holding time analysis all (except one sample) show error less than 20 percent.

6.5.2 Results

THMs were observed in all seventeen of the finished water samples analyses (Figure 6.1). Two samples, one from Dumay (D-2) and one from Bas Limbe (BL-1) were dropped from the sampling procedures because of, respectively, leakage in the VOA vial and no chlorine residual in the bottom bucket.

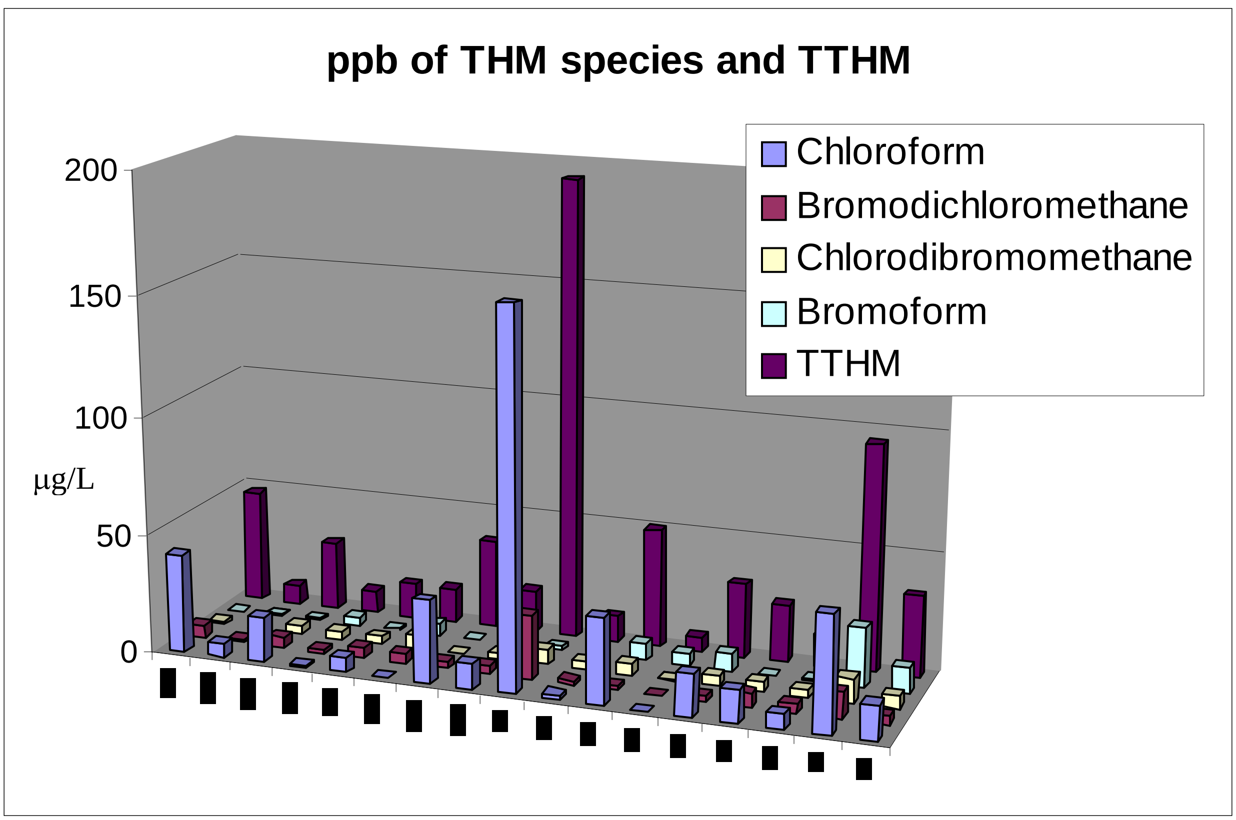

Figure 6.1: THM species and TTHM in 17 Haitian Samples

All samples met the WHO guideline values of 200 μg/L for chloroform, 60 μg/L for bromodichloromethane, 100 μg/L for chlorodibromomethane, and 100 μg/L for bromoform. However, sample D-1 exceeded the WHO guideline value that states the sum of the four THMs' actual value divided by their guideline value cannot be greater than one. The sum of the four THMs' actual value divided by guideline value in sample D-1 was 1.37. In addition, all but one, D-1, met the USEPA standard of 100 μg/L for TTHM.

Brominated compounds were commonly seen. Some samples, such as LP-1 and D-1, contained predominantly chloroform, with few brominated compounds. This was commonly seen when investigating THM production from freshwater sources. Other samples, such as LP-4 and D-5, were bromoform-dominated samples. This was more commonly seen in the literature with source water that is near the ocean or had been desalinated. Samples such as D-4 and F-1 are mixed. In the literature review, no study determined and developed a model from samples with the amount of variation in percent brominated compounds (5 – 100 percent) as found in the Haiti samples (Table 6.4).

Table 6.4: TTHM and Percent Brominated in 17 Haitian Samples

Sample	TTHM μg/L	TTHM mol/L	Percent Brominated	Source Type
LP-1	48	0.39	9	Cistern
LP-2	8	0.06	19	Captage
LP-3	29	0.21	24	Spring
LP-4	9	0.05	85	Spring
FV-1	15	0.10	48	Surface
FV-2	14	0.07	100	Cistern
BL-2	37	0.31	5	Well
BL-3	18	0.13	30	Spring
D-1	193	1.53	13	Well
D-3	11	0.06	70	Well
D-4	50	0.37	17	Captage
D-5	6	0.02	100	Captage
D-6	31	0.21	30	Well
B-1	24	0.17	33	Cistern
B-2	14	0.09	42	Surface

F-1	95	0.63	35	Well
F-2	34	0.21	43	Well

6.5.3 Brominated Compounds Investigation

To begin understanding why there was a large range of percent brominated compounds and their effect on finished water TTHM concentrations, characteristics of source water were analyzed at MIT.

The first step was to quantify the bromide ion concentration in the source water. To this end, conductivity and sodium concentration were measured in raw source water samples. These were measured because both of these parameters can correlate with bromide ion concentration. The results from these data were used to calibrate the mathematical model.

6.6 Mathematical Model

All of the source water data and the TTHM results were then used to create a mathematical model to predict the concentration of TTHM in finished, purified water.

6.6.1 Derivation of TTHM Model

After regressing all the variables against TTHM production to determine the best mathematical fit, the most accurate regression equation determined was using total usage and conductivity. The total usage / conductivity regression equation is:

$$\text{TTHM } (\mu\text{g/L}) = 0.14 \text{ (Total Usage)} + 21 \text{ (Conductivity)} - 9.6$$

$$R^2 = 0.780$$

with conductivity in μmho/cm and total usage an integral number.

Total usage was calculated by multiplying the number of times the purifier was used per week by the age of the carbon filter in weeks. 75 percent of the variance in the TTHM concentration in the finished water can be attributed to total usage of the carbon filter. This indicates that each time the carbon filter is used, more TTHMs breakthrough, which is a reasonable result. A certain volume of GAC can only adsorb a finite amount of a compound. The remaining three percent of the variance is due to the increased amount of brominated compounds present when the conductivity of the water is higher.

When the calculated value from this total usage / conductivity model was compared to the observed value from GC measurements of actual Haitian water there was a small amount of spread in the lower concentrations, but the fitted linear total usage / conductivity regression equation explains 78 percent of the total spread (Figure 6.2).

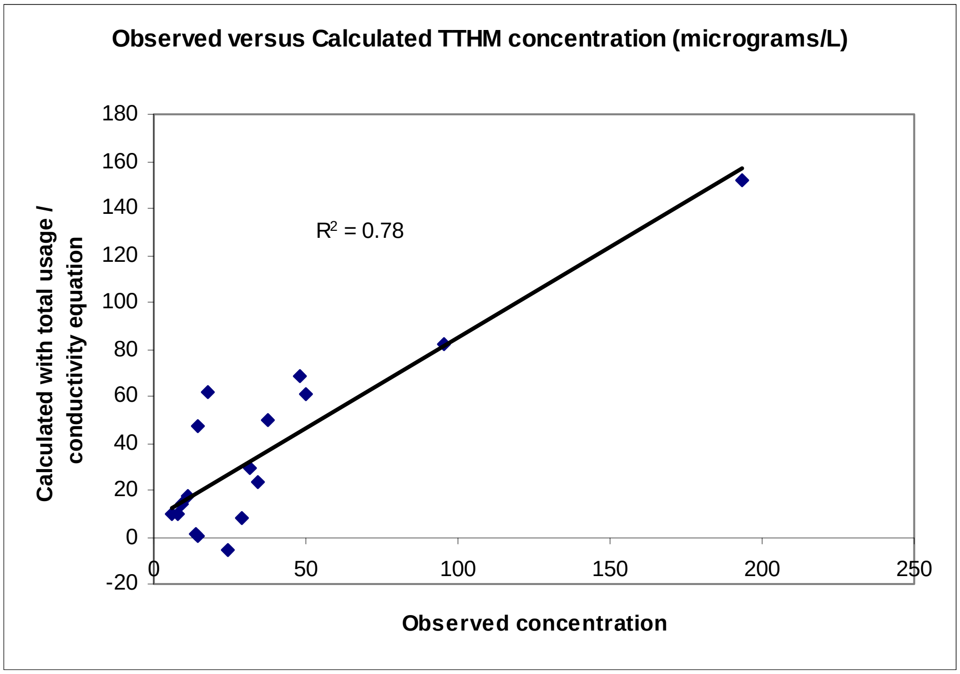

Figure 6.2: Comparison of Calculated and Observed TTHM Concentration

Thus, increased conductivity and increased carbon use can be used to model increased TTHM concentration (μg/L) in the finished water after filtration with a GWI purifier. This simple equation can be used to estimate TTHM production in water throughout Haiti, but only if GWI continues using the GAC currently purchased and distributed. Solving this equation for TTHM equal to the USEPA standard of 100 μg/L allows calculation of the total number of uses after which the purifier can be expected to exceed USEPA standards (Table 6.5). As can be seen, GWIs policy of changing the carbon every six months includes a safety margin against even the highest potential use of the purifier in areas with the highest conductivity.

Table 6.5: Average, Best, and Worst Case Carbon Change Scenarios

Scenario	Total Usage at USEPA Standard	Convert Total Usage to carbon age at USEPA standard
Average: Conductivity: 470 μmho/cm Usage: 7.3 times / week	712	97 weeks 1.9 years
Worst Case: Conductivity: 1.5 μmho/cm Usage: 14 times / week	552	39 weeks 0.75 years
Best Case: Conductivity: 40 μmho/cm Usage: 1 time / week	776	776 weeks 14.9 years

However, as was found in Haiti, carbon is not changed every six months. In addition, it would be more accurate for the carbon change to occur based on usage of the filter because of the large range (used 1 – 14 times per week) of usage. This would be instead of a time scale, which assumes the same use of the filter across Haiti. A usage criterion would complicate the carbon change process, however, and currently the first goal is to ensure the carbon is changed at all. Thus, it is recommended that GWI take one of two courses: (1) work with the technicians to implement the current policy of carbon changes every six months; or (2) implement a new two-step policy that includes the technicians assessing the number of times per day the purifier is used. If that number is greater than one, carbon should be changed every six months. If that number is equal to or less than one, carbon should be every year. This would ensure a safety margin, and necessitate fewer carbon changes. The two-step policy adds a complexity that, given the current carbon change rate, may not be feasible. Thus the simpler every-six-months policy may be the best option.

6.7 THM Mitigation Strategies

The main approaches currently used to prevent THMs reaching the tap are grouped into the following categories:

1. Disinfection by-product (DBP) precursor removal
2. Disinfection process control / alternative disinfection processes
3. Physical processes: Ultraviolet light, membrane filtration
4. Advanced oxidation processes
5. Removal of DBPs from finished water
6. Quenching agents

Of all of the mitigation strategies investigated, those with the greatest potential for application in Haiti are:

- Quenching by hydrogen peroxide: The addition of strong oxidizers could quench the production of THMs.

- Coagulation: The addition of a coagulation step prior to chlorination could reduce the THM precursors in the sample.
- Chloramination: The use of this alternate to chlorine could reduce the TTHM produced.

If THM levels become a problem in Haiti, or GWI determines they would like to investigate mitigation of THMs, then the use of hydrogen peroxide, coagulates, or chloramination are all viable options to investigate.

6.8 Further Studies

Three studies are recommended for further study:

1. Epidemiology Study: A full scale study to determine the actual health benefits of the purifier is needed. Although these studies are difficult to implement in the developing world, the full benefit of the purifier will not be known without one.

2. Chlorine Demand Study: Currently significantly more than the CDC recommended amount of chlorine is added to the purifier. Although this may be necessary, a new study to investigate chlorine demand across Haiti will help to optimize chlorine addition.

3. GAC Study: This study clearly shows that the GAC is critical in THM removal. Studies to determine the characteristics of the actual GAC used by GWI would be a valuable addition to this study. If the type of GAC is changed, the equations mentioned herein are no longer valid.

Chapter 7: SODIS (Solar Disinfection)

7.1 Introduction

SODIS harnesses the suns energy to provide an economically feasible means of supplying safe drinking water. This treatment process produces disease free water by filling transparent containers and exposing them to sunlight. This technology was pioneered in the late 1970s by Acra at the American University of Beirut, Lebanon, to find an inexpensive disinfection method for oral rehydration solutions (Acra *et al.*, 1984). His exciting results gave birth to a new disinfection technique. Subsequently, a workshop on SODIS was held in Montreal in 1988 (Lawand *et al.,* 1988), and SANDEC/EAWAG (Swiss Federal Institute for Environmental Science and Technology/Eidgenossische Anstalt fur Wasserversorgung Abwasserreinigung und Gewasserschutz) started to investigate the SODIS process in 1991. The most alluring aspect of this technology is the minimal investment costs of plastic bottles.

7.1.1 Solar Radiation and Disinfection

SODIS uses the destructive power of different bands of the electromagnetic spectrum to destroy pathogens. The sun emits energy in the form of electromagnetic radiation that covers the ultraviolet, visible, and infrared range. The most important bandwidths for SODIS are the UV-A, red, and infrared. Recent studies have shown that UV-A light is the main bandwidth involved in the eradication of microorganisms (Acra *et al,* 1984; Acra *et al.,* 1990; Reed *et al.,* 1997; McGuigan *et al.,* 1998). UV-A has direct effects on DNA and forms highly destructive oxygen species as a secondary product. In addition, water strongly absorbs red and infrared light creating heat, which results in pasteurization. The synergistic UV-A and water temperature mechanisms that inactivate microorganisms will be discussed further.

7.1.1.1 DNA Alterations by UV

UV absorbance by DNA causes mutagenesis and results in death (Raven and Johnson, 1996). UV light is absorbed by microbial DNA and causes adjacent thymine bases to covalently bond together, forming thymine dimers (Figure 7.1). When DNA replicates, nucleotides do not complementary base pair with the thymine dimers and this terminates replication. Organisms may also replace thymine dimers with faulty base pairs and cause mutation. Mutations lead to incorrect protein synthesis that blocks metabolism. To ensure adequate disinfection, at least 5 hours of 500 W/m^2 sunshine to should be available (SODIS News No. 1, 1998).

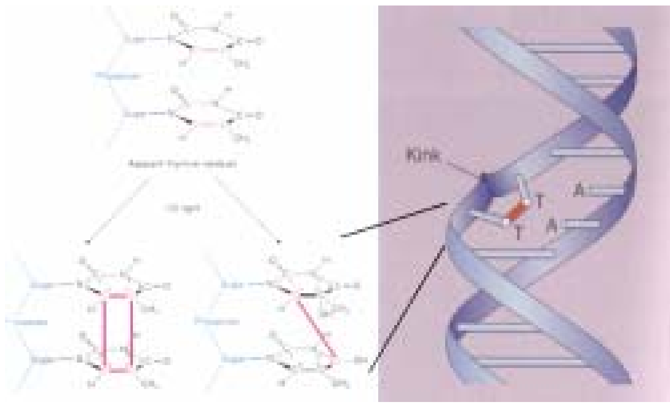

Figure 7.1 Formation of Thymine Dimers (Raven and Johnson, 1996; Mathews and Van Holde, 1996)

7.1.1.2 Photo-Oxidative Disinfection

UV-induced reactive oxygen species can prove to be lethal. Natural dissolved organic matter can absorb ultraviolet radiation to induce photochemical reactions (Miller, 1998). The energy transfer of a high-energy photon to absorbing molecules produces highly reactive species such as superoxides (O_2^-), hydrogen peroxides (H_2O_2), and hydroxyl radicals ($OH\cdot$) (Stumm and Morgan, 1995; Miller 1998). These highly reactive species in turn oxidize microbial cellular components such as nucleic acids, enzymes, and membrane lipids (McGuigan *et al.*, 1998; Reed, 1996; Reed, 1997). This oxidation kills microorganisms.

The above reactions depend on the presence of oxygen in the water. On a practical level, aeration can be achieved by vigorously shaking the SODIS containers before sunlight exposure. This is especially important for stagnant water drawn from ponds, cisterns, and wells where dissolved oxygen levels maybe inadequate (EAWAG/SANDEC Technical Notes, 1998).

7.1.1.3 Thermal Inactivation

Thermal inactivation is an important part of the synergistic inactivation process. As temperatures rise past the maximum growth value, it becomes difficult for proteins to form their proper structures and the high temperature causes already formed proteins to unfold. Denatured proteins do not function properly and may eventually kill the organism (Brock, 2000). It has been observed that water temperatures between 20°C and 40°C do not affect the inactivation of *E. coli* by sunlight (Wegelin *et al.*, 1994). However, synergistic effects are observed at a water temperature of 45°C (McGuigan *et al.*, 1998). Compared to lower water temperatures, only one-third of the UV-A fluence was required to inactivate E. coli at 50°C (Wegelin *et al.*, 1994). To increase thermal effects, bottles are painted black at the bottom. Black by definition is the absence of color and therefore it absorbs many wavelengths from the electromagnetic spectrum, which converts light energy into heat. The half-blackened SODIS bottles increase the temperature by approximately 5°C. Additionally, placing the bottles on dark surfaces will also help heat the water and produce thermal effects (EAWAG/SANDEC Technical Notes, 1998).

The combined effects of sunlight-induced DNA alteration, photo-oxidative destruction, and thermal inactivation are responsible for the inactivation of microorganisms, which is well documented.

7.1.2 Inactivation of Indicator Organisms and Pathogens

SODIS efficacy is usually established through the inactivation of indicator organisms, but effects on actual pathogens have also been investigated. Table 7.1 is a list of microorganisms that have been inactivated by the SODIS process. The table is not comprehensive and the references for coliform bacteria are far more extensive. However, it demonstrates that many different microorganisms are sensitive to the SODIS process.

Table 7.1. SODIS Inactivation of Microorganisms

Microorganism	**Reference:**	**Microorganism**	**Reference:**
E. coli	Wegelin *et al.*, 1994	*Str. Faecalis*	Wegelin *et al.*, 1994
Fecal Coliform	Sommer, 1997	*Penicillium*	Acra *et al.*, 1984
Vibrio Cholera	Sommer, 1997 *New Scientist Magazine*, 2000	Polio Virus	Cubbage *et al.*,1979
P. aerugenosa	Acra *et al.*, 1984	Bacteriophage MS2	Kapuscinski and Mitchell, 1982
S. flexneri	Acra *et al.*, 1984	Enterocci	Wegelin *et al.*, 1994
S. typhi	Acra *et al.*, 1984	Bacteriophage f2	Wegelin *et al.*, 1994
S. enteritidis	Acra *et al.*, 1984	Encephalomyocarditis virus	Wegelin *et al.*, 1994
S. paratyphi	Acra *et al.*, 1984	Rotavirus	Wegelin *et al.*, 1994
Aspergillus niger	Acra *et al.*, 1984	Cryptosporidium∗	Bukhari *et al.*, 1999; Clancy *et al.*, 1998
Aspergillus flavus	Acra *et al.*, 1984	Cryptosporidium	*New Scientist Magazine*, 2000
Candida	Acra *et al.*, 1984	Giardia Muris∗	Craik *et al.*, 2000

∗Found under a UV lamp measured in the UV-C range. Although UV-C is not found in sunlight, it suggests these organisms would be sensitive to the UV-A portion of sunlight.

While this list does not address all of the important pathogens, there is active research to investigate infectious organisms such as *Giardia* (SODIS Conference Synthesis, 1999). Some additional insight to other microorganisms could be gained by examining their thermal sensitivities, as thermal inactivation of microorganisms is a very important process in SODIS (Table 7.2).

Table 7.2. Thermal Destruction of Microorganisms (Feachem *et al.*, 1983)

	Time and Temperature for 100% destruction		
Microorganism	**1 min**	**6 min**	**60 min**
Enteroviruses			62 °C
Rotaviruses	63 °C for 30 min		
Salmonellae		62 °C	58 °C
Shigella		61 °C	54 °C
Vibrio Cholera			45 °C
Entamoeba Histolytica cysts	57 °C	54 °C	50 °C
Giardia Cysts	57 °C	54 °C	50 °C
Hookworm eggs and larvae		62 °C	51 °C
Ascaris eggs	68 °C	62 °C	57 °C
Schistosomas eggs	60 °C	55 °C	50 °C
Taenia eggs	65 °C	57 °C	51 °C

The inactivation of microorganisms by the SODIS process is well established. However, microbial inactivation is highly dependent on a number of variables.

7.2 Important SODIS Variables

SODIS operates on the principle that sunlight-induced DNA alteration, photo-oxidative destruction, and thermal effects will inactivate microorganisms. For these parameters to be effective, the environment must be sunny and hot enough, the water must be clear enough to allow the light to penetrate, and the type of bottle being used must not substantially hinder these processes. In addition, for this technology to become a reality, people must be able to afford it, and they must believe in it, or it would never be applied. Haiti's climate as it relates to SODIS will be presented, including the results of simulated sunshine intensities. This will be followed by a discussion of the social acceptance observed in different parts of the world along with economic considerations.

7.2.1 Haitian Climate

Assuming there is adequate oxygen to mix into the water, the two most influential variables affecting SODIS efficacy are sunshine and temperature. These two parameters are a function of seasonal and geographical climate variation. Haitian sunshine and temperature will be examined followed by influences of topography.

7.2.1.1 Haitian Sunshine

SODIS efficacy depends on an adequate duration of sunshine radiation. It has been deduced that an intensity of 500 W/m^2 should be available for 3 to 5 hours for effective disinfection (SODIS News No. 1, 1998). A value of at least 5 hours of sunshine above 500 W/m^2 will be used as a conservative threshold. Many areas of the world in need of SODIS are developing countries, and consequently, do not have meteorological data on sunshine intensity profiles. However, NASA Langley Atmospheric Sciences Data Center provides web accessible data on the 10-year average, minimum, and maximum amount of total energy received for a representative day of each month (NASA Langley Research Center Atmospheric Sciences Data Center, 2001). This data has a spatial resolution of one-degree latitude and longitude for the entire world. Using this data, Oates (2001) develops, calibrates, and implements a mathematical model to simulate the monthly average, minimum, and maximum daily sunlight intensity profiles for the degree latitude and longitude grid overlaying Haiti. From these results, a general sunshine intensity envelope of the average, minimum, and maximum peak five hours is obtained by examining the spatial averages across Haiti. These monthly values are compared to the intensity threshold (Figure 7.2). Haitian sunshine is on average above the recommend 5-hr average disinfection threshold and SODIS should be effective year-round in Haiti. However, it is important to note that these results are based on the discretization per degree longitude and latitude. The total energy values used to generate the intensity profiles are an

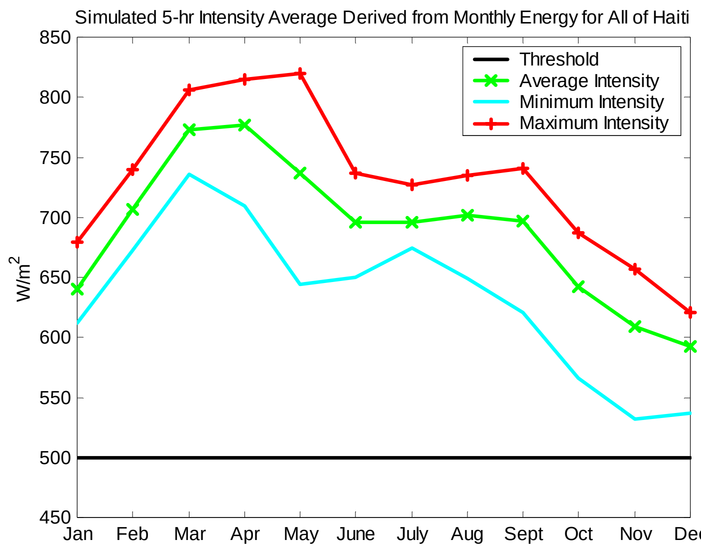

Figure 7.2. Yearly Five-Hour Average, Maximum, and Minimum Intensity Profile of Haiti (NASA Langley Research Center Atmospheric Sciences Data Center, 2001)

average for each one of the grids and there could be substantial variation within the spatial resolution of the model (which will be discussed further in the topography section). This method of sunshine simulation is considered a good first approximation to assess the possible application of SODIS throughout the year in Haiti. The other important variable in the SODIS process that warrants investigation is temperature.

7.2.1.2 Haitian Temperature

To have synergistic sunlight and thermal effects in the SODIS process, water temperatures should reach at least 45°C (McGuigan *et al*., 1998). Bottle temperature mainly depends on the amount of sunlight received and ambient temperature conditions. It has already been estimated that there is sufficient sunlight for the SODIS process, so ambient temperature conditions will be examined. Haiti has a warm tropical climate with average temperatures over the country ranging from 24°C in the winter to 28°C in the summer. The average yearly temperature and average daily range for all of Haiti is given by Figure 7.3.

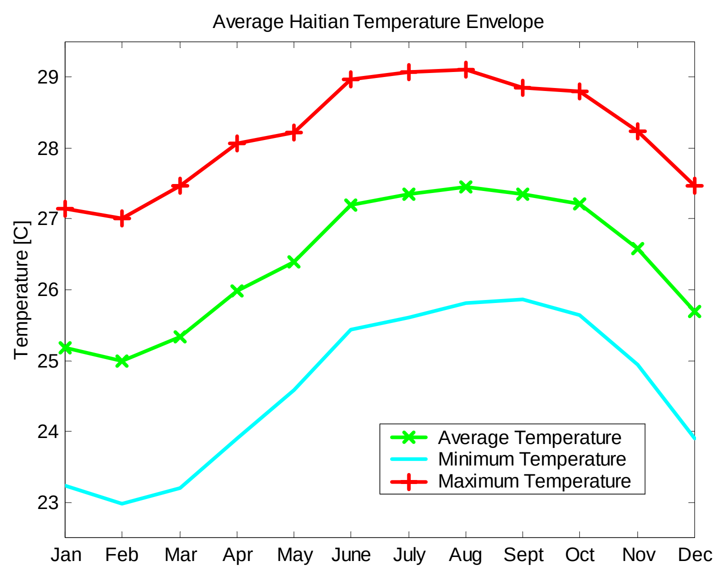

Figure 7.3. Yearly Average, Maximum, and Minimum Daily Temperature in Haiti (NASA Langley Research Center) Atmospheric Sciences Data Center, 2001)

The high amount of sunshine Haiti receives and Haiti's consistent warmth suggest that bottle temperatures should usually exceed the synergistic threshold. However, topographical effects can have strong influences on both local sunshine and temperature.

7.2.1.3 Haitian Topography

The Native American Indian inhabitants called the island Ayti, meaning "Mountainous Land." Approximately 63% of all land in Haiti have slopes greater than 20% and only 29% have slopes of less than 10% (USAID, 1985). Haiti's heterogeneous terrains create highly variable microclimates with a large range of sunshine, temperature, and rainfall. A contour map of Haitian elevation in relation to its latitude and longitude grid used for the NASA sunshine and temperature data is shown by Figure 7.4.

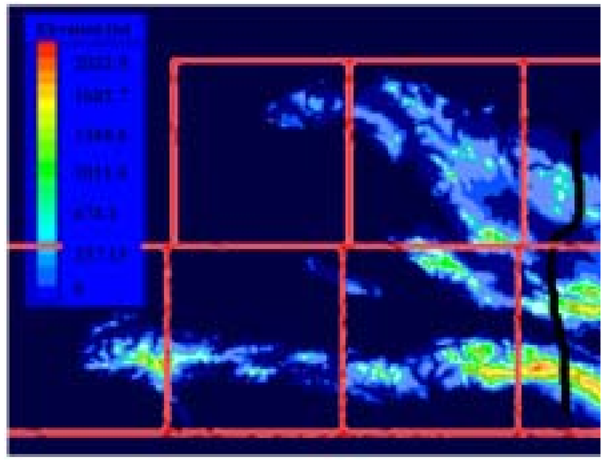

Figure 7.4. Haitian Topographical Map (Generated by GEOVU, Matlab, and TECPLOT using NOAA data)

Haiti's extreme topography in proximity to the ocean causes heavy cloud cover in the mountainous areas due to orographic lifting. Essentially, this is where the mountains physically force air to rapidly rise and cool. When the air cools enough to reach the dew point, clouds and precipitation occur. This phenomenon is verified by the increase of precipitation in the mountainous areas (USAID, 1985). However, higher altitude can increase the amount of UV radiation incident to the surface by decreasing the atmospheric path (Acra, 1990). It will be assumed that any enhanced UV radiation due to altitude will be dwarfed by orographic lifting effects on average. Furthermore, temperatures can decrease greatly with altitude. For example, the village of Kenscoff at an elevation of 1,432 meters has an average temperature of 16 °C, while Port-au-Prince, at sea level, has an average temperature of 26 °C. These observations suggest that SODIS could have limited effectiveness in the mountainous regions of Haiti but would need further research. Aside from how Haitian climate affects the water, the physical properties of the water, namely turbidity, are extremely important.

7.2.2 Turbidity

Turbidity measures the optical properties of liquids. Suspended particles can absorb and scatter light as it passes through. Consequently, highly turbid solutions can severely limit the amount of light penetration, thus reducing the efficiency of the SODIS process. For effective solar disinfection, waters should be less then 30 NTU (Nephelometric Turbidity Units) to ensure safe drinking water (SODIS News No. 3, August 1998). When the water turbidity is higher than 30 NTUs, it must be treated by allowing coarse solids to settle for one day, inducing flocculation/sedimentation, or filtering.

7.2.3 SODIS Bottles

Plastic mineral water and soft drink bottles are gradually replacing glass. Plastic bottles are made of either PET (polyethylene terephthalate) or PVC (polyvinyl chloride). Both types of plastics contain UV-stabilizers to protect the material from UV radiation and oxidation. There is some concern, which needs further research, that some of these stabilizers may be a potential health risk. These additives are used much less in PET compared to PVC making PET the preferred SODIS material. PET is also a good transmitter of light in the UV and visible range. Simple comparison methods have been developed to determine whether a plastic material is PVC or PET. PVC has a distinct bluish gleam, which is especially noticeable around the edges. Additionally, PVC smells caustic when burned, whereas PET smells sweet (SODIS Technical Notes).

Another important characteristic of the PET bottles is they have an appropriate depth to make the SODIS process effective. Sommer *et al.* (1997) demonstrated that UV radiation is dramatically decreased by water depth. At a depth of 10 cm and a moderate turbidity level of 26 NTUs, UV-A radiation was decreased by 50%. The black bottom of the SODIS bottles induces a temperature gradient, which increases circulation. However, the water depth should be less than 10 cm to ensure efficient disinfection, which is why bottles of less than 2 liters are typically used.

SODIS bottles that are used daily and over long periods get scratched. This scratching leads to a reduction of UV transmittance and can decrease disinfection effectiveness over time. For these reasons, SODIS containers eventually have to be replaced. Consequently, PET bottles make the best choice as SODIS containers because they are usually the most locally available and are relatively inexpensive. The cost of PET bottles will be given more attention in the next section. Furthermore, field studies have shown the majority of people like the PET bottles because they are easy to handle, sturdy, and durable (SODIS News No. 3, 1998).

7.2.4 Acceptance of SODIS

In 1997, Environmental Concern carried out demonstration projects in seven countries by local institutions to assess the socio-cultural acceptance of SODIS. The participating countries include: Columbia, Bolivia, Burkina Faso, Togo, Indonesia, Thailand, and China. A survey was then conducted to see how people felt about using SODIS to treat their water. This survey revealed that 84% of the users would definitely use SODIS in the future while 12.6% said they might use it in the future. The background for SODIS has been presented. The next section involves the materials and methods that were used to see if SODIS would work in Haiti.

7.3 Materials and Methods

7.3.1 Materials

To test the efficacy of SODIS in Haiti, the following measurements were made: turbidity, sunlight intensity, and bottle water temperature. These disinfection parameters were then coupled to microbial analysis, which consisted of presence-absence testing for total coliform, *E. coli*, and H_2S-producing bacteria. While it would have been useful to enumerate the amount of bacteria present, the most important question is: are there harmful bacteria present, and if so, can SODIS destroy all of them. For this reason, in addition to more simplistic testing procedures, presence-absence tests were run in parallel for total coliform, *E. coli*, and H_2S-producing bacteria. The specific materials used for each parameter are summarized in the following table:

Table 7.3: SODIS Materials

Parameter	**Material**
Sunlight Intensity	Kipp and Zonen Solrad kit
Temperature	Enviro-Safe® thermometers
Turbidity	Hach Pocket Turbidimeter
Total Coliform and *E. coli*	Hach's Presence-Absence Broth
H_2S-Producing Bacteria	Hach's PathoScreen™

The precise experimental setup and procedure for making these measurements will now be described.

7.3.2 Methods: Experimental Setup and Procedure

Field Measurements were made on January 12th and 13th in Dumay, and from January 15th to the 21st in Santo. Nine 1.5-liter PET bottles were collected from a home, local garbage, and a local store. PET bottles were readily available in Santo. Black paint was applied to the bottom horizontal half of each of the bottle to enhance thermal effects. Several coats were required to ensure an opaque finish. During January 12th and 13th, six bottles were used. Three bottles were placed in the dark to serve as controls and three were left out in the sun for one day. In addition, samples from the first day were kept for the duration of the study to test for possible bacterial regrowth. From January 16th to the 21st, nine bottles were used to assess the effects of both one and two-day exposure. This bottle arrangement was divided into three groups with three bottles per group: 1-Day, 2-Day_1, and 2-Day_2. The two 2-Day groups were exposed in an overlapping staggered arrangement, which allowed for the effects of both one and two day exposure to be measured every day.

Water was collected from various sources in the early morning using the SODIS bottles. Bottles were initially filled up about two-thirds and shaken vigorously for 30 seconds to provide aeration for photo-oxidative disinfection. They were then completely filled. Additional samples were taken for raw water turbidity and microbial analysis. The Turbidimeter® was calibrated each day and every bottle was measured (six or nine bottles per day) at the beginning of each experiment. Total coliform, *E. coli*, and H_2S-producing bacteria tests were run in triplicate both before and after setting the bottles out in the sun. A blank was used for each type of test and every time a batch was run. All of the microbial samples were incubated in a cooler for two days prior to analysis. The incubation temperature was kept constant at 35°C using different proportions of hot and cold water. The 100 ml and 20 ml glass vials used for Hach's Presence-Absence Broth and PathoScreen™ respectively, were sterilized in boiling water for reuse.

The bottles were placed on a dark surface on top of a roof and where hourly sunlight intensity and bottle water temperature measurements where made. Sunlight intensity measurements were taken so that the hourly averages are representative for each chronological hour. Hourly temperature measurements were simultaneously made on three bottles and the thermometers were allowed to equilibrate with the bottle water temperature before readings were made. Most of the nights were spent completing the microbial analysis for the daily group of designated bottles. A summary of results of these experiments will now be examined.

7.4 Summary of Results

The general results for turbidity, sunlight intensity, and the overall microbial analysis will be presented.

7.4.1 Turbidity

All realistic water sources were very clear with an average turbidity of 1.3 ± .6 NTUs. This is consistent with Lantagne (2001), who found an average turbidity of .88 ± .84 NTUs collected from several other places in Haiti.

7.4.2 Sunshine and Temperature

The average sunshine from January 12th through January 21st, 2001 had a 5-hour average peak intensity of 651 W/m^2 and received 4537 Wh/m^2 per day. On average, the bottle water temperature hovered around the synergistic temperature for about 3 hours. Two of the nine days were under the cover of thunderclouds. For these two stormy days, the 5-hour average peak intensity was 445 W/m^2, and the total amount of energy received was 2958 Wh/m^2. The bottle water temperature never reached the synergistic threshold. Subtracting these two stormy days from the rest, paints a better picture of a typical day of Haitian sunshine and bottle water temperature (Figure 7.5).

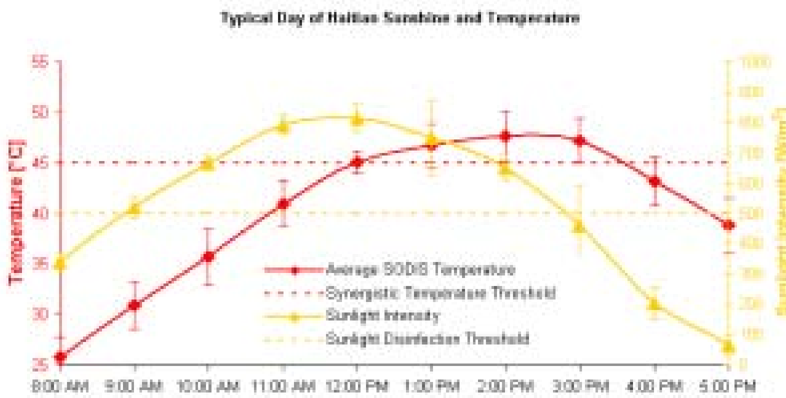

Figure 7.5. Average Non-Stormy Day Profile for Partly Cloudy to Mostly Sunny days (7 of 9).

For the average of the non-stormy days, the 5-hour average peak intensity was 735 W/m^2, and the total amount of energy received was 5061 Wh/m^2. The bottle water temperature rose past the synergistic threshold for over 4 hours.

7.4.3 Overall Microbial Analysis

Microbial testing was conducted using total coliform, *E. coli*, and H_2S-producing bacteria to assess how SODIS performed under various conditions. No bacterial reactivation was observed and all of the dark controls tested positive for all types of organisms. The total results for the raw water, 1-day exposure, and 2-day exposure are given by Table 7.4.

Table 7.4. Overall Microbial Analysis

Initial Raw Contamination %, (Positive/Sampled)	**1-Day Kill** %, (Negative/Sampled)	**2-Day Kill** %, (Negative/Sampled)
97.2%, (70/72)	**52.8%, (38/72)**	**100%, (53/53)**

The three types of microbial tests showed good agreement between one another for both positive and negative results for all tests made (Table 7.5).

Table 7.5. Percent Agreement between Different Microbial Tests

Type of Agreement	Total Coliform and *E. coli*	Total Coliform and H_2S Bacteria	*E. coli* and H_2S Bacteria
Positive	92.7 %	95.1 %	97.4 %
Negative	91.2 %	96.9 %	94.1 %

7.5 Discussion

Every point source that people used for potable water in Dumay and Santo had very low turbidity. Lantagne (2001) sampled several other locations in Haiti to find that they all had minimal turbidity. Based on the measurements made in January, it would be reasonable to say that most places would not need a prefiltration step and SODIS could be directly applied. However, to make a broader conclusion, additional samples would have to be taken in the rainy seasons (around October and May) to investigate how increased runoff would affect turbidity.

The intense Haitian sunshine and warm climate appear to provide conditions suitable for effective SODIS. This research was conducted during Haiti's winter, implying shorter and colder days compared to most of the year. However, "the rainy months like October and May, could receive less sunshine, but you could easily count the days on your fingers in Haiti that receive no sunshine because they are so few" (Nathan Dieudonné, personal communication, 1/14/01). It would be important to conduct further SODIS testing around October when there is less sunshine and increased cloudiness. The highly heterogeneous nature of Haiti's climate makes general conclusions difficult to formulate. At higher altitudes, the orographic enhanced cloud cover and the colder temperatures could compromise the effectiveness of SODIS. If the mountainous regions are too cold to realistically incorporate synergistic thermal effects, the bottles should not be painted black and could be placed in solar reflectors. This would have the SODIS process rely solely on optical inactivation, which could be very effective given there is more UV radiation at higher altitudes. If this technique were ineffective, an alternative disinfection method would have to be used in the mountainous regions.

SODIS efficacy was evaluated by the inactivation of total coliform, *E. coli*, and H_2S-producing bacteria. The different tests were in strong agreement indicating the raw water had all of the target organisms present and that the SODIS process had roughly the same effect on the different types of indicator bacteria. The microbial testing verified that Haiti does have water problems with microbial contamination as 97% of the samples tested positive for all indicator organisms. Impacts of exposure duration varied significantly between 1-day and 2-day periods. Under various sunshine intensities, bottle water temperatures, and initial bacterial concentrations, 1-day exposure completely inactivated all of the bacteria half of the time, while the 2-day exposure period achieved 100% inactivation for all conditions experienced. A major drawback of this study is two consecutive stormy days were not observed and SODIS efficacy for these conditions in Haiti is unknown.

Guidelines that differentiate between 1-day and 2-day exposure have been suggested in the literature. However, it is considered more practical to have every bottle exposed for a 2-day duration. It was observed that 100% bacteriological inactivation is mainly a function on sunlight, temperature, and initial microbial concentration (the effects of turbidity and wind are considered less important for Haiti). These parameters are highly variable and the right conditions for 100% inactivation with 1-day exposure were only met half of the time. To ask a villager to gauge how much sunshine a specific day has received takes away from the simplistic beauty of this technology. First, it is distracting for villagers to have to constantly think about how much sunshine a bottle is receiving. Second, this judgment is prone to large errors (I met a man who told me he was 177 years old), which could ultimately cause illness or death. If the 2-day exposure results that were observed in January hold true, leaving every bottle out in the sun for 2-day exposure would take the guess work out of this technology and would always lean towards the conservative side of disinfection. A practical way of providing people with cold water every morning that has undergone a 2-day exposure period can be termed “a SODIS triangle.” Essentially, it consists of three groups of bottles that are rotated every morning, so two groups are out in the sun and one is being used for consumption. This process is explained in more detail in the next section. From the experiences and the results produced in Haiti, a set of practical application guidelines has been constructed.

7.6 Practical Application Guidelines

The SODIS disinfection process is simple to apply but would require training at the community level to ensure optimal benefits. These guidelines are a product of what was experienced in Haiti along with some adaptations from the SODIS Technical Notes (EAWAG/SANDEC), and should be applied to those areas deemed suitable for SODIS.

7.6.1 Practical SODIS Procedure

7.6.1.1 Bottles

- Collect clear 1-2 PET bottles from home or local market. Enough bottles should be obtained to sustain a household level of consumption. PET bottles can be easily identified as they will say PET or have the number "1" on the bottom.
- Make sure the bottles are not to scratched up so light can easily penetrate.
- Make sure the bottles do not leak and have caps that seal watertight.
- All labels should be removed and both the inside and outside of the bottles should be washed to ensure optimal light transmittance.
- Paint half of the bottles black (if paint is available):
  - The side with any residual label glue should be painted. This eliminates the hassle of trying to remove it and prevents future dirt build up, which would reduce light transmittance.
  - Use as many paint coats as necessary to create an opaque finish.
  - Hold the bottle up to light and make sure light does not come through the paint.

7.6.1.2 Water

- Water should be obtained from a common village supply: well, stream, pond, reservoir, etc.
- Water must be clear enough for SODIS to work. Turbidity can be checked by placing a copy of the SODIS logo under the bottle and checking its readability.

Place logo under a bottle

Put in sun (<30 NTUs)

Have to filter or let settle until logo is legible (>30 NTUs)

If the logo is legible, then turbidity is low enough for SODIS. If not, the water must be left to settle or processed with a filter if available.

- When collecting water, rinse the outside of the bottle to remove any buildup that would block sunlight transmission.
- Fill the SODIS bottles about two-thirds full and screw on the cap. Shake the bottles vigorously for about 30 seconds to ensure the water is sufficiently oxygenated. The bottles are now ready for exposure.

7.6.1.3 Exposure

- An area must be chosen that receives sunshine throughout the entire day.
- Place bottles on dark surfaces to enhance thermal inactivation such as black plastic or tire pieces. Corrugated metal rooftops reach high temperatures and they would be excellent SODIS areas if they receive full sunshine during the day.
- Bottles should be sheltered from high winds to decrease thermal depletion by convection (wind blowing the heat away from the bottles). Make sure that any objects use to shelter wind do not shelter sunshine.

- To make things simple, routine, and conservative, groups of bottles should be set out for two days, regardless of the weather conditions. This takes out the guesswork as to whether conditions are right for SODIS. A practical approach to this exposure guideline would be to set up a “SODIS Triangle.” This involves three groups of bottles: A, B, and C; and two designated SODIS areas: SODIS Area 1 and SODIS Area 2. The two areas could simply be adjacent spots on a roof. The SODIS Triangle is set up as follows:

    - Morning of Day 1:
        - Collect water with group A
        - Place group A in SODIS Area 1
    - Morning of Day 2:
        - Collect water with group B
        - Place group B in SODIS Area 1
        - Move group A from Area 1 to Area 2
    - Morning of Day 3:
        - Collect water with group C
        - Place group C in SODIS Area 1
        - Move group B from area 1 to Area 2
        - Bring group A home from Area 2 to drink

This now establishes an indefinite loop where a person goes out in the morning to fill up a group of bottles and returns the same morning with a group of bottles that have undergone two days of SODIS treatment. This has the added advantage that the bottles have been allowed to cool over night.

7.6.2 Anticipated Mistakes

- Some bottles are placed in sunny areas in the morning but the areas become shady after a few hours.
- Many people like to place their bottles on chairs, but the chair backs shade bottles after a few hours.

- Some users expose the bottle with the black side on top.
- Users don't plan well, become impatient, drink the water prematurely, and get sick.

7.7 Summary and Conclusions

SODIS is a simple technology that operates on the principle that sunlight-induced DNA alteration, photo-oxidative destruction, and thermal effects will inactivate microorganisms. The treatment process consists of filling plastic bottles with water and exposing them to sunlight. Using this technique, 100% inactivation of total coliform, *E. coli*, and H_2S-producing bacteria was achieved after a 2-day exposure period under a variety of conditions. Based on these results in January, it is recommended that a "SODIS triangle" be applied to ensure every bottle receives 2 days of the SODIS process. Mathematical sunshine simulations suggest that SODIS would be applicable, on average, throughout Haiti year-round. However, this model does not take into account microclimates and mountainous areas that may have limited success due to lower sunshine and temperature. This aspect needs further research. Overall, the results are encouraging and it is strongly recommended that SODIS be further investigated for at least some parts of Haiti. It is hoped that this extremely affordable point-of-use treatment technology can help alleviate the water quality problems that currently plague Haiti. To evaluate SODIS as a point-of-use treatment technology, it will be compared to the point-of-use water treatment criteria established in the introductory section and summarized in Table 7.6.

Table 7.6. Point-of-Use Water Treatment Compliance Criteria (Lehr *et al.*, 1980; Shultz and Okun, 1984)

Criteria	**Compliance**
Should be effective on many types and large numbers of pathogens	X†
Should perform regardless of water fluctuations	√
Must operate in appropriate pH and temperature range	√
Should not make the water toxic or unpalatable	√
Should be safe and easy to handle	√
Any chemical concentrations should be minor	√
Must provide residual protection against possible recontamination	X‡
Units must be affordable to all	√**!**
Should be adaptable to local conditions and variations	√
Specialized equipment should be produced locally	√
Must be accepted by local traditions, customs, and cultural standards	√
Must comply with national sanitation and pollution policies	√

†Although SODIS has been effective on large number of pathogens, there is still no data for many organisms

‡ Indirectly provides some protection against recontamination because the disinfected bottle stays closed until consumption

EAWAG/SANDEC is currently studying the effects on other pathogens and the issue of providing residual protection is easily offset by the low cost of this technology. Every point-of-use treatment technology has it strong points and setbacks. SODIS would have the following advantages and disadvantages in Haiti.

Advantages:

- Inactivates or destroys pathogenic organisms.
- Requires plastic bottles which are inexpensive, easy to handle, transport, and store.
- Extremely low cost technology since its investment costs are low and its running costs are negligible.
- Has simple application which is ideal for the household level.
- Does not require chemical addition, which could be carcinogenic, have questionable availability, or change water taste and smell.
- Makes use of locally available resources.

Disadvantages:

- Does not improve the chemical water quality.
- Requires favorable climate conditions: 5 hours of radiation above 500 W/m^2 and warm ambient temperatures, which may not be available in mountainous regions.
- Should not be applied to raw water of turbidity higher than 30 NTUs.
- Offers limited production capacity.

Along with good point-of-use treatment methods, the population needs to be educated about water problems and potential solutions. Community health will not improve just because they have point-of-use technologies available to them; they must use them. SODIS would most likely only be applied if the target population were convinced it works. To stay healthy, and benefit from SODIS, users would need to become aware of the bacteriological routes of water borne diseases and how to avoid them. One of the biggest problems witnessed in Haiti is most people, especially children, do not know or care that their water contains pathogens. Even at locations with water purification systems, children were constantly drinking from contaminated sources. These types of action negate the effects of any water treatment technology.

Ultimately, this point-of-use treatment option is very attractive as it could provide a safe source of water at the cost of a plastic bottle. It is hoped that this relatively new disinfection method will produce an economically feasible technology to improve water quality and public health in Haiti.

Chapter 8: Best Practice and Program Sustainability

8.1 Introduction

GWI has achieved commendable results in educating and changing drinking water practice in households in rural Haiti. Additionally, the organization has helped create meaningful employment opportunities and sow seeds for capacity building through its technician and filter assembly programs. Nonetheless, GWI's growth and learning as a non-profit development organization has not been without its challenges. While GWI has achieved high rates of successful filter use in almost all of the communities it works with, a few of its project sites have been problematic. Filters are used inappropriately in some homes, taken apart and used for alternate purposes in others, and have, at times, gone missing. Technicians in some communities are highly respected members of the community, and well-received in homes. In others, the rapport between families and technicians is not as congenial; not surprisingly, projects in these communities do not do as well as those in the first set. Certain communities have a dire water-supply problem, which impairs the ability of families to use the GWI filters consistently. Timelines for achieving desired success levels also vary from one project site to another. The first section of this chapter aims to establish a set of "best practice" guidelines for project implementation that draw from the range of experiences at different sites with varying degrees of success.

The second component of this chapter explores future directions for GWI, looking specifically at scenarios for program sustainability. As projects grow and mature across the country, GWI is undergoing its own rapid growth and change. For the first time in the organization's history, its ability to produce filters is far outstripping its ability to train technicians and prepare communities to receive them; 10,000 new filters await distribution, well over three times the number of filters GWI has placed in homes over the past five years. Additionally, GWI is branching out into other countries. Program growth is not necessarily accompanied by an attendant growth in the resources, financial or human, needed to support it. Continued funding for maturing programs may become problematic; at this stage, no mechanisms exist to guard against sponsor pullout, or lack of continued support. This change of scope and concerns, in addition to a desire to build local capacity, necessitate a revision of the organization's project implementation structure, and an exploration of ways in which programs can become financially and managerially self-sufficient.

8.2 Best Practice: Guidelines for Program Implementation

The best practice component of this research grows primarily out of observation, comparison, and analysis of GWI's field operations at different sites, contextualized by a broad literature review of effective frameworks for program operation in developing regions.[2] In January 2001, we visited six of GWI's seven project sites: Ferriere, Bas Limbe, Fonds Verrettes, Barasa, Les Palmes, and Dumay. At the time, the projects at these sites ranged in age from 3 months to four and a half years, covering a range of 50 – 1800+ households at each site. We did not visit the program's youngest project site, Demier. It has therefore been left out of the best practice analysis. However, it is important to note that Demier is the only site at which the project has been set up entirely by Haitian technicians without the assistance of GWI. The project in Demier thus marks a critical step towards program sustainability, and is likely to present key lessons for future program implementation.

[2] This review is informed by the following literature sources: Smout and Parry-Jones *ed.* (1999), Smout *ed.* (1996), Okun (1982), Grover (1981).

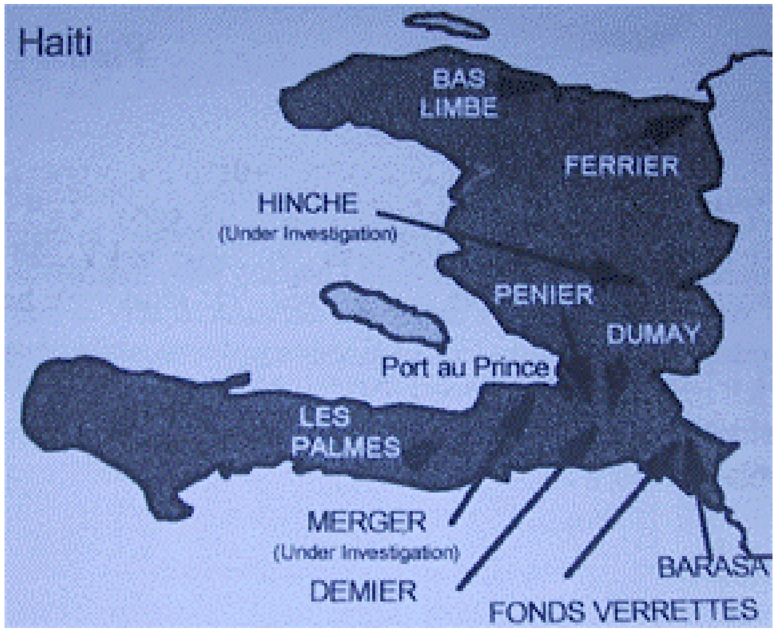

Figure 8.1: Map of Project Locations

(*Source: GWI Newsletter, March 2001)*

Best practice, as used in a development context and in this document, refers to a set of practices that produce desired objectives. Two objective assumptions underlie our recommendations. First, we assume that GWI would like to provide access to its programs to as many households as need it – in Haiti, well over 60% of the population lacks access to safe drinking water, about 3.6 million people (World Bank, 2000). Second, given that GWI has a relatively large pool of demand for its services, we assume that GWI would prefer to site filter projects in areas where chances of project success are stronger. Additionally, we assume that GWI's overarching goal and intention for its projects is to build sufficient capacity for the programs eventually to be run locally.

Program success at each of the sites was judged by a composite variety of qualitative and quantitative indicators: GWI's own sense of satisfaction with the progress of the program, consistency and accuracy of filter use, rapport between technicians and project households, and general level of water awareness in the community. The recommendations that follow in this section are drawn from past successes of and lessons learnt from the six project sites visited, and grounded on the assumptions outlined above.

Grover (1981) breaks down the process of program development and implementation into four stages: identification and preparation, appraisal and negotiation, implementation and supervision, and operation and evaluation. The first two stages can be loosely lumped to create a broad "program setup" category; he suggests that effectiveness and thoroughness of program setup is the one of the strongest indicators of program success. It is additionally often the most overlooked.

This correlation between thoroughness and attention paid to program setup and program success appears to hold true for GWI's projects in Haiti; through our review of project sites, three key factors appear to link most strongly with program success:

- Effectiveness/thoughtfulness of program set-up process (who was involved in program setup, length of time invested in program setup, and degree of local information and input considered in program setup)
- Selection of effective technicians who have a respected stance within a community
- Presence of other community development programs/activities

GWI's program setup stage may be broken down into five elements: community selection, water committee and technician selection, technician training, community education, and filter distribution. After the program setup stage comes the ongoing support, operations and maintenance stage. The success of this second stage derives largely from the success of the first. For GWI, this stage includes continued technician support and training, monitoring, community education, and general troubleshooting activities. A third stage of the program, as yet undeveloped and untried for GWI, would consist of some form of exit strategy and paced turnover of project control to local hands; suggested scenarios for the first steps of this process are presented in the subsequent section. The following recommendations are drawn from the successes and lessons of the six project sites, and, we believe, will improve GWI's project delivery and chances of success.

8.2.1 Program setup

Overall, because of the importance of this stage to program success, GWI needs to play a more consistent and much more hands-on role in facilitating, advising, and providing stricter guidelines for the entirety of the program setup stage, from site, water-committee, and technician selection to household filter distribution. Two primary factors pose a significant barrier to GWI's ability to play this role optimally:

- First, not a single person on the US contingent of GWI's staff speaks fluent Creole, seriously hampering GWI's ability to communicate with project staff and households. While two of GWI's Master Technicians speak English, their level of fluency and comfort with the language is still not developed enough to translate fine nuances of communication.
- Second, administering GWI programs is not a full-time position for either Thomas (Phil) Warwick or William (Bill) Gallo, the key people involved in and authorized to make decisions about program setup from GWI's US end; neither Bill nor Phil draws a salary from GWI.

8.2.1.1 GWI Staffing

Because of the rapid expansion of GWI's programs in Haiti, and of the increasing need for communication among projects across Haiti, as well as between Haiti and the US, we recommend that GWI hire an in-country manager for each country in which it has projects. Ideally, this person would have a Bachelors degree or equivalent, good understanding of the relationship between water and health, strong community organizing skills, diligent record keeping capacities, strong team management, leadership, and troubleshooting skills. The ideal candidate would have experience working in or be able to function effectively in a multi-cultural environment. The manager must have a high degree of fluency in common working languages of the country – English and Creole, and preferably some French in Haiti, as teaching materials are in French – and, for optimal impact, an intimate understanding of local customs, culture, and social structure. The responsibilities of this manager should include new-program setup and program expansion, overseeing program monitoring, liaising regularly with GWI's Florida and Dumay headquarters, and, as time allows, meeting volunteer groups. Additionally, the manager should have the authority and approval to make key decisions regarding staffing and user fees, in consultation with the local water committee. Because of the responsibilities the manager is expected to assume, suggested salary should at a minimum be equal to that of Emmanuel, the head master technician. Additionally, the manager should have sufficient resources at his/her disposal to travel around program sites, make random, unannounced checks, and retain the ability to initiate communication with GWI headquarters.

In addition to hiring in-country managers for each program country, it may be prudent for GWI's key non-salaried staff, Phil Warwick in particular, to consider drawing a salary. The presence of an in-country manager may alleviate some of the need for Phil to travel to Haiti, but it is likely that organizational needs will become more complex as the programs grow and spread to other countries. It is important for the organization's and programs' health that key figures within its administrative levels be fully available to deal with concerns as they crop up and evolve. Average salary levels for the Executive Directors of non-profits fall in the general range of $45,000 to $70,000 plus benefits. (Idealist.org 2000)

Adequate staffing and solid cultural and language interpretation capacity will go a long way towards helping establish successful programs based on the guidelines recommended below.

8.2.1.2 Community selection

Currently, GWI's site selection process is largely sponsor-led, rather than based on particular criteria built around community-driven needs or an exploration of the resources and opportunities available at particular sites. This sponsor-led process, whilst it ensures that programs are supported to some degree for at least some period of time, has resulted in two immediately apparent impacts – first, GWI's sites are spread out across the country, posing significant difficulty and expense in communicating and moving among the different sites; second, the level of local resource availability and support for the water projects varies significantly from site to site. These impacts make it challenging at best to provide consistent support across programs, and hamper the degree of learning that can be gained through site-to-site interaction. The sponsor-led process, if unaccompanied by an intensive field site exploration, might also result in the siting of a project in conditions where it may be inappropriate, or where resources simply do not exist to support the project. In Barasa, for instance, water scarcity is high, and people often lack access to sufficient water to use the filter consistently. In Bas Limbe, support for and interest in the project is low at the local leadership level, making it difficult to gain momentum in the local community. Up until this stage, however, GWI has had to rely on sponsor financing to build up support and recognition for its programs. Given current trends in demand growth, however, and the possibility of novel financing schemes (explained in greater detail in section 8.3), GWI can now afford to and should be more selective in its choice of project sites.

Based on our review of project sites, we believe GWI should ask the following set of questions as part of an expanded and more intensive field exploration period, at the end of which it should decide whether or not to start or expand an existing project in a particular area:

- Are enough resources available in the community, in terms of financial and time commitments on the part of households and local leaders, and sufficient water availability?
-Are there contact people in the community who are willing to commit to the program as a priority?
-Are there other organized development activities taking place? How can these existing networks of people and resources be drawn upon for implementing the water program?

While we do not have specific facts to support the link between water project success and presence of other development activities, it is our impression that this linkage exists, andwas visible during our visits to project sites. Fonds Verrettes and Ferriere in particular have leveraged this linkage well, and the water committees in both cases have invested in exploring local initiatives outside the strict boundaries of the program; exploring communal cistern-building, and a continuous community-wide education program respectively. Ferriere has provided its technicians with uniforms, to add to their recognition in the community, and Fonds Verrette is exploring the same.

There are no clearly right answers or cut-off points for these questions; they are simply intended to flag issues that deserve consideration, and which seem linked in some way to project success.

We did not spend enough time at each site in Haiti to be able to produce clear rankings of the sites with regards to the availability of various resources. However, these questions provide a starting point from which to develop rough benchmarks for judging whether to start or expand a project in a given community. The benchmarks would best be tailored further by a person who is more intimately familiar with Haiti than we are.

8.2.1.3 Water committee and technician selection

The water committee and technician selection process is one of the most crucial factors in the fate of a project. To command the respect of the community that may yet need to be taught about the importance of safe water practice, water committee members and technicians need to be trusted and known widely within their communities. Additionally, they need to agree to make the project a priority in their activities, and to commit the necessary time and attention required by their responsibilities. The technicians in Ferriere, Fonds Verrettes, and Dumay appear to be highly respected and recognized individuals within the community. In contrast, the Bas Limbe technicians seemed to be neither recognized, even by households they are supposed to service, nor respected. In Barasa, while one of the technicians, Monsieur Dondon, is a highly respected local, he is unable to commit the time necessary to effectively administer the responsibilities of that program. The difference between project successes at the sites speaks for itself. GWI is not unaware of the importance of technician selection, but, because it frequently operates in initially unfamiliar communities, added to language and cultural barriers, we suggest the adoption and replication of a successful framework, used by Matt Cyr[3] in Fonds Verrettes, for improving selection.

Prior to selecting members for the water committee, Matt researched, through contacts at the local church and schools, existing local organizations whose networks could be drawn on for leveraging local support for the program. He drew up a list of people from two organizations, Kommunite Development (KD) and Foundacion Economique Assistance Societe (FAES),

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[3] Matt Cyr is a young American teaching in Fonds Verrettes. He learnt of GWI's program in neighboring Barasa, where he spent a year, and raised funds to sponsor a new project in Fonds Verrettes. Matt's fluency in Creole, local knowledge, and community organization skills have enabled him to assemble a very competent team in Fonds Verrettes.

actively involved in community development activities in Fonds Verrettes. In addition, because he was familiar with locals, and in the area, he asked people that he knew to recommend community members who they felt were reliable, approachable, respected by people in the neighborhood, had a good sense of ethics, and were usually around and reachable. From the initial list, Matt invited three members from each of the five districts in Fonds Verrette, making sure that at least one female was represented on each group of three. He also invited representatives from the local medical institutions, and any other organizations or individuals that would form natural stakeholders in the filtration project. The 15-member group then elected voting water committee officers: a president, vice president, treasurer, secretary, two advisors, and a *delege* (Creole word for a runner. The *delege* is responsible for ensuring that all committee members are kept informed of meeting times, and generally functions as the communication "hub" of the committee.). It was simply luck of the draw that all five districts were represented within this seven-member committee, which has one female member.

The non-voting members of the committee were then invited to apply for the two available technician positions, once the responsibilities of that position had been explained to the committee. Three people applied for the two slots – one female and two males. At the beginning of the information process, Matt had explained the importance to potential project donors of female representation on the committee and in the technician pool. The female, Helene, therefore automatically received one of the technician slots. However, she too had to prepare a statement of interest in the position, as did the two other technician applicants. Each applicant delivered a statement to the water committee on why he or she was interested in the position, and what he or she would bring to it. The voting members of the committee then voted to select between the two male applicants, and settled on Dieumaitre, the second Fonds Verrette technician. This selection process ensured that the technicians are not only respected by local folks and hold the mutual respect of the water committee, but are also actively interested in being technicians. Additionally, it allows for a more thoughtful and staged selection process that then mirrors itself within the water committee's future deliberations.

Matt's explanation of the requirement for some sort of gender balance in both the water committee and technician mix before the actual selection process, and his presence through it, probably helped avoid the problem recently experienced in Les Palmes, where four of the eight male technicians were fired so that female technicians could be appointed (Warwick, personal communication). This fact adds further import to the need for GWI to set stricter guidelines upon which to base these processes, and to be present in a facilitative or advisory role through program setup.

Water committees should have significant decision making power that should be weighted more strongly than program sponsor desires. GWI needs to dance a fine line between ensuring this is the case and facilitating and advising decision-making. One way to ease this challenge is to present firmer guidelines for operation ahead of the process, and staying intimately involved through the set up process, rather than simply at the end of it, at the decision-making stage. The cost of overriding local decisions is high, as indicated by the Bas Limbe project. During a rather agitated community meeting in Bas Limbe in January, Father Dubois, the head of the local water committee, communicated his frustration with the program to the master technicians who were acting as translators for the meeting. He had wanted to charge a $10 leasing fee for the filters, but his decision was over-ridden by the project sponsor, who wanted to charge $6. Adequate quantities of chlorine, as a result, were not available in the community. More importantly, Father Dubois felt that his decisions and input were not of value to the committee, and has therefore not taken on a much-needed leadership role within the program. It is also our impression that this fact was not communicated fully in the translation to Bill Gallo who was running the meeting, a problem that could be avoided in the future by bringing on a staff member who is fluent in Creole.

Based on the approximate time frame – three to four weeks – it took Matt to carry out this exploration and set-up process, and on suggested time frames for pre-project feasibility studies (Grover, 1981; Goethert, R., 2000), this process is estimated to take on the order of six to eight weeks to perform effectively. This time includes time spent gathering information from and about the local community, time spent getting voting systems in place, and basic community education or initial social marketing time.

8.2.1.4 Filter distribution

GWI presently provides few guidelines for distribution of filters among households, aside from requiring that disbursement be equitable, without regard to religious preference, socio-economic status, or similar criteria. This lack of more specific guidance has resulted in poor placement of filters from a project manageability standpoint. In Les Palmes, 400 filters were distributed on a first-come first-served basis; the distances between houses are vast, exacerbated by the fact that Les Palmes is a mountain-top community, and houses are spread out over several steep peaks to begin with. The Fonds Verrettes water committee, on the other hand, made a deliberate decision to contain filter distribution within a manageable pre-set boundary before they assigned filters to households. Additionally, the Fonds Verrettes committee made a conscious decision to site filters in homes where it knew, from local experience, that household members would make a commitment to using the filters and set an example for other households. Faced with a decision between two households, all else being equal, the household with the greater degree of literacy, or “smartness,” was chosen to receive a filter. We recommend that similar criteria be presented and used to distribute filters in all sites, and particularly in new ones, where placing filters in conditions amenable to success might lead to better adoption and growth of the project. Local knowledge, in the form of input from water committee members, is invaluable at this critical stage.

8.2.2 Ongoing program support

8.2.2.1 Community education

In Dumay, we had the opportunity to observe a monthly community meeting. These meetings are an effort to provide continued community learning and reminders of water-health relationships, and are conducted as follow-ups to meetings that interested households are required to attend prior to being given a filter. The meeting that we attended was conducted in a manner that is probably not dissimilar to the ways classes are conducted in schools, where a teacher stands in front of the classroom and gives a lecture. The meeting started with a prayer, as do most gatherings in Haiti, and continued on in lecture format, with first Joliette, one of the female technicians in Dumay, then Emmanuel, the head master technician, presenting. Each of them repeatedly stressed the importance of filter use, the relationship between drinking bad water and getting sick, and made repeated reference to the fact that a lot of Americans were spending a lot of money to come to Haiti to help on this important project. About 70 people were in attendance at the meeting, roughly 50% of whom were women, with older children making up the bulk of the remaining attendants. A number of people appeared distracted and bored, and there was no opportunity for questions and answers. However, we recognize that it might be culturally inappropriate and uncomfortable to have a question and answer session at a Haitian gathering; people do also get a chance to ask questions of their technicians during household visits. It is unclear whether or not regular large group meetings of the same kind might produce effective changes; smaller group meetings, with some opportunity for interaction through group exercises and appropriate demonstrations, that are targetted at particular groups – children's, women's, school groups – might provide effective avenues for learning interchange.

We saw few other forms of community education, with the exception of the project in Ferriere, which had developed a couple of colorful and simple posters, displayed below. In Dumay, Fonds Verrettes, and Ferriere, children are taught about good water practice in schools, an initiative spurred in most places by the same actors responsible for initiating GWI programs in those communities. GWI would benefit from more active initiation or support of programs such as those that encourage keener awareness of good water-related behavior. Increased awareness of and demand for filtration will help ensure program sustainability and sustained behavior change. Postering, word of mouth, and other forms of continued education and social marketing practices are therefore essential.

Figure 8.2: Water education posters in Ferriere

8.2.2.2 Technician support

Technician funding

When we visited project sites and spoke with technicians in Fonds Verrettes and Dumay specifically, they indicated strong dissatisfaction with salary disbursement. In January, the Fonds Verrettes technicians had not received payment for over three months worth of work, a fact that the water committee members were irked by and disappointed with. Salaries are paid out every three months, for work done in the previous three months, by checks that need to be personally picked up from GWI's headquarters in Dumay by all but the Ferriere and Bas Limbe technicians, whose checks are routed through Sr. Pat Downs, the head of the water committee in Ferriere. In a country where disposable income is low, and salaries are generally paid monthly, this practice creates significant problems for the technicians. Additionally, it sets a poor precedent for future program sustainability and self-financing, where project success will depend to a large degree on the timely payment of technicians and other project costs. It appears that some of the glitches surrounding payment disbursement are a result of local banking practice, which for some unknown reason necessitates the three-month payment frequency. If that is the case, then payments should be forwarded to Dumay three months in advance, rather than retroactively, from where they can be dispersed monthly. Technician salary disbursement could be further simplified by clustered project sites, so technicians would not be required to travel great distances to pick up their checks, another plus for heightened site selectivity.

Route management

Technician routes need to be more dynamically managed to ensure that they are manageable. This step is particularly important to revisit when new households are added to the project. In Dumay, households are presently configured into close clusters. Technician routes, however, are spread out over more than one cluster, a legacy from original route assignments that have not been revamped as new households are added. Routes need to center around household clusters for them to be more manageable, and be reviewed as projects grow.

8.2.2.3 Emergency funds and spare parts

A number of households in the various project sites have had problems with cracked buckets, where the top bucket of the two bucket system develops a crack along its bottom surface around the check valve. Some households, particularly those further away from Dumay, had to wait extended periods of time without bucket replacements, because purchasing new buckets is expensive, and would have required the drilling of a hole to fit the check valve. While technicians have access to some parts, it is unclear that each of the project sites has a well-stocked inventory of spare system parts sufficient to deal with multiple simultaneous system breakage. Each project site should have easy access to such an inventory. The actual size and mix of inventory should be based on past records for that particular community, and can probably be developed with the input of local community and master technicians.

In addition to a spare parts inventory, each project site should have some funds available to cover unforeseen expenses – for instance, the costs of new buckets if they are needed fast, or part of a technician's salary if payment is delayed for any reason might be good enough reasons to draw on this emergency fund. The exact size of the fund should vary proportionally to the costs of the project, largely a factor of the number of technicians serving a particular site, and should at any time be equivalent to at least 10% of technician cost. The fund should be maintained by the water committee, controlled by a committee-elected treasurer, and should require around a 2/3-committee vote to authorize its use. Some project sites do have a small reserve fund, created by charging a small additional fee over the $6 that the water committee is required to collect from each household and send to Dumay to cover filter assembly and transportation costs. In practice, water committees often do charge a small premium on the one-time filter lease cost, with costs ranging from $6 to $10. {Need to check on upper figure with Trudi, but I think that's the highest amount} The specific source of this emergency fund can vary from community to community; it is best for project sustainability and self-sufficiency reasons if the funds are sourced from users, but because the creation of the fund is a one-time rather than ongoing expense, its source is not critical. Funds used should be replenished through charges administered to recover the cost of what they are used for, however.

8.2.2.4 Carbon changeout

As discussed in Chapter 6, the carbon in the carbon filters is not being replaced on a regular basis, despite the fact that technicians are aware that it needs to be changed every 6 months on average for a regular Haitian household. The GWI filter is intended to be self-correcting: when the carbon filter is past its useful life, chlorine from the top bucket flows through into the bottom bucket, thereby increasing the concentration of chlorine in the lower bucket. The community technicians who regularly conduct chlorine presence tests should notice this increased concentration. In practice, however, based on our observations of the testing procedure, when chlorine concentrations are higher than expected, the common tendency is to assume that the household simply puts too much chlorine into the water. To eliminate this source of uncertainty, we recommend that a simple system be devised and implemented that involves households in the process of tracking filter use and carbon change-out. One device might be a retrofitted mechanical spring device, similar in design and function to the newly developed Brita® Filter Replacement Indicators that now ship with new households filters of the same brand in the US, but adapted to work with the GWI filters. The filter indicators snap on to the top of the carbon filter in the Brita filter. As water passes through the indicator over the life of the filter, an easy-to-read dial on the indicator moves from "new" to "reset" making it simpler to keep track of when to change filters. Alternatively, a color-coded indicator strip, similar to the blue toothbrush bristle colorants might be developed. A simpler, albeit more prone to human error, system would be to provide sticker labels with the appropriate number of grids of allowable runs before filter change, say a hundred, that should be placed on the bucket. A separate set of small individual stickers can be provided, and household members can be taught to place a sticker in a grid each time the filter is run. Alternatively, a simple pen-and-paper system can be used, again with a gridded label and pen fastened to the bucket. To ensure the integrity of such a monitoring system, one of the things a technician should note down during each household visit is the number of new runs; if the number changes significantly from an established average, the technician can consult with household members to assess the source of discrepancy. A filter-use tracking system has the added advantage of simplifying the process of gathering data on use, should GWI ever decide to carry out a program evaluation for any purpose.

8.2.2.5 Record-keeping

There is a range of difference in the kinds of records being kept at each project site. In his August 1999 trip report, Bill Gallo notes that each of the then-four technicians in Les Palmes, which at the time had about 400 filters, maintained a list of the houses in his circuit, but no central list of project households existed, or could be found at the time. In the same report, he suggests the use of uniform blank forms for all technicians, to facilitate the record-keeping process. Bill's trip report from October 1999 indicates that the central list problem was solved, but that it also brought to light the fact that well over fifty filters of the initial four-hundred shipment were unaccounted for. During our trip to Haiti, we noticed that not all technicians were using these forms; for the most part, the technicians were using notebooks, but some technicians were writing on pieces of paper that did not seem to have complete information on their circuits or households. Buckets were labeled with a circuit- and household-number in most places, but this practice was not uniform. Technician and project monitoring would likely be simplified by some degree of uniformity in practice across sites. We recommend that blank forms, bound into a notebook, be provided to every technician. The forms should contain columns for collecting information by circuit- and household-number – which all buckets should be labeled with – on chlorine presence results for the top and bottom buckets, and number of filter runs, if the sticker label system suggested above is being used. The book should also have an index that lists circuit and household numbers along with their corresponding household names. A brief description of household location might be desirable, but difficult to provide.

Other than providing uniform and comparable information about the progress of each project site, good record-keeping might also help dissuade technicians from falsifying records, particularly if records are required to be presented in Dumay as a condition of pay. Copies of these records, kept in Dumay over say a six-month period, could also be compared to results obtained from random testing procedures. Sustained significant differences between the two sets of results might provide grounds for technician dismissal.

8.3 Program Sustainability

Program sustainability is quickly becoming a critical objective for GWI's projects, particularly as demand for filters continues to grow, programs get older and more settled, and the economic condition of Haiti's rural poor remains uncertain. Sustaining current community sponsorship levels, which cover all community project costs save chlorine purchase, over the long term is difficult at best, and new methods of financing project costs need to be explored.

In addition to fiscal incentives for developing program sustainability scenarios, there are a number of development-oriented reasons for creating mechanisms to enhance the financial and managerial self-sufficiency of programs. First, the ability of programs to become self-financing means that GWI can retain a greater degree of autonomy, hence a greater chance of project success, in site selection, because alternatives to donor financing are available. Second, it gives GWI the ability to extend its filter program to a larger number of people. Third, a self-financing mechanism builds its own layer of accountability into a system – people are more likely to correctly utilize something that they consciously pay for, and will ensure, too, that technicians perform the tasks they are required to perform. Fourth, and more importantly, moving to a self-financing scheme encourages self-reliance, and places the program further in the hands of local community members. It also sets the stage for the development of additional collective projects, allowing the local community in general, and the water committee in particular, to develop its own management and training capacity so that it can become an effective motivator of change agents in the community and catalyze further development (Aga Khan Foundation, 2001).

A number of program sustainability strategies are already in place – moving some of GWI's filter assembly functions from the factory in Florida to a new one in Dumay enables local production of filters, and builds additional forms of capacity. The organization's recent exploration of in-country hypochlorite generation is another step in the right direction. Full program sustainability, however, will require paced shifting of responsibility for project costs from GWI to the households that benefit from the filter program. It will also require the creation of some form of bill collection mechanism, as well as disincentives for defaulting on project cost payment.

Popular resistance to setting up cost-recovery or any sort of financing mechanisms for servicing the poor includes concerns about their willingness and ability to pay for services. Whittington *et al.* (1990) and Okun (1992) dispel this myth using a number of examples that prove that, for the most part, the poor can and do pay for water services. In fact, they often pay a larger amount and a higher proportion of income for such services than their economically better-off counterparts living in areas served by piped networks (Whittington *et al.,* 1990; Whittington 1991; Whittington *et al*., 1992, Okun 1992). While in Haiti, we had neither the resources nor the time to conduct conventional contingent valuation surveys (which tend to provide problematic indications at best), but an informal survey of project household members revealed that a large number of households purchase a small amount of water daily. Purchase amounts increase during the dry season, but it appears that on average most households tend to purchase five gallons of water per household per day, at a cost ranging between 3 and 5 gourdes per 5-gallon bucket[4]. Household expenditures on water therefore range from approximately $0 to $25 Haitian per month, depending largely on seasonable variables. This indicates at least some amount of elasticity in price-demand for water.

One of the largest ongoing project costs is technician salaries. Monthly local community technician salaries range from $200 to $300[5], depending on whether a technician has passed

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[4] 5 gourdes make $1 Haitian. The Haitian dollar tends to fluctuate at a currency exchange rate of roughly 4:1 to the US dollar. At the time of our Haiti visit, $1 US was roughly equivalent to 22 gourdes. All dollar figures from this point on, through chapter 8, will be Haitian dollars, unless otherwise specified.

[5] For the sake of comparison, a good (higher level) salary for a local teacher ranges around $170 Haitian/month. GWI's salary, therefore, is competitive and generous. The technician positions are intended to be full-time day jobs.

GWI's certification process or is still in training, and on a salary level decision made by the local water committee. Two out of the three Master Technicians, Wilberne and Remis, make $400, and the third Master Technician, Emmanuel, who directs training programs, makes $450. In new committees, two technicians serve 50 projects. Once a community program is on its feet, roughly three new technicians are brought on board for every 200 filters added. Technician load levels therefore range from about 25 to 70 households. It is GWI's goal that every technician be able to service 250 households, once a program is established, communities know how to and consistently use the filters accurately, and technicians are trained and experienced – the actual ability of a technician to cover 250 households would depend on project household cluster patterns. If responsibility for technician salaries, at an average figure of $250 for simplicity's sake (for the purposes of this option exploration) were shifted entirely to project households, the households would have to pay between $1 and $10 per month, depending on technician load levels. That would increase monthly water expenditures to $1 to $35 per household. This figure does not include chlorine purchase expenditures, which fall between $1 and $2 for an average Haitian household. By comparison, the cost of bottled water, available in urban areas and larger centers, for similar consumption levels would range around $120 (Dieudonne, personal communication). When people develop an awareness of the relationship between water and health, even in rural areas, they are willing to pay for bottled water. In fact, GWI will not site a project in areas where bottled water is readily available (Phil Warwick, personal communication). This fact indicates that willingness and ability to pay for water might be relatively high, caps at $120, and depends strongly on community education and social marketing endeavors.

Moving from the current practice of close to full project subsidization to charging households for services is not a simple task[6]. Project households will need to be informed of the change in advance, convinced of the need for such a change, and given plenty of time to communicate their concerns and provide input into the specific phasing of cost shifting. The cost shifting is more

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[6] Similar transitional situations do not appear to be well documented in the literature; the recommendations provided, therefore, are an attempt to synthesize good practice drawn from a range of sources. We have also attempted to think through the ways in which the move to cost recovery might fail, and provide suggestions for preventive measures for the same.

likely to work if people actually receive a tangible product in return for their payments, rather than service-oriented visits from a technician. For this reason, it is desirable to lump chlorine, parts, and technician service into a basket of products that the households pay for, rather than simply technician service. Consequently, technicians will also need to take on the responsibility of distributing chlorine. Monthly charges for this basket, assuming that GWI continues to initially subsidize the cost of parts, will range between $2 and $12, the cost of technician salary plus chlorine. We recommend that GWI begin phasing cost transfer at the point where each technician is able to service one hundred households, but no later than 18 months into a particular project, at a monthly cost to households of around $5, a figure that seems affordable given current practice. The exact figure to charge will vary, depending on technician salary levels in the area, and on what GWI and the local water committee decide is an appropriate float buffer to cover additional unforeseen project costs. As additional savings are realized from increasing technician load levels and from local chlorine production, the community can also begin to assume responsibility for the cost of parts. Excess funds, if there are any, could either be returned to households at the end of the year, used by the water committee to invest in communal water resources, or be provided as incentive bonuses to technicians who perform above expectations.

In a country where disposable income is low and income streams are uncertain, it is necessary to explore mechanisms that will assist and encourage households to make regular and timely payments, without which any self-financing scheme is likely to fall apart. In this case, if technician payments become irregular or uncertain, technician retention could become a concern. While the actual figure to charge households can and will vary from site to site, depending on local conditions, a similar self-financing framework can be adopted for each site. Much of the literature in the area of self-financing mechanisms for water supply and treatment projects focuses on capital cost recovery on and operation and maintenance for capital-intensive and often centralized, or at least community-wide, treatment systems. Consequently, we have drawn lessons and ideas from a range of self-financing mechanisms, including those used for women's micro-credit schemes and small-scale agricultural assistance programs, which have more in common in scope with GWI's programs. Some improvisations have been made on water-related self-financing mechanisms to come up with a sustainability scenario that makes sense for the particular circumstances of the program in Haiti.

Based on a review of farmer cooperative practices, Coulter *et al.* (1999) identify four elements for discouraging default on program payments:

- Lending through groups
- Good communication and close monitoring
- Range and quality of services offered
- Incentives for repayment, and strict treatment of defaulters

Session proceedings of the Governing Body of the International Labor Organization (1994) further indicate that the sustainability of self-financing schemes and mutual-savings based organizations depends on:

- reciprocal trust and supervision among members/borrowers
- their location near users [accessibility]
- transparency and ease of management
- Good communication of rules

The above factors need to be enveloped within the design of any financing mechanisms for GWI programs. Group-based or group-insured financing, the basic gamut of most micro-credit organizations and rural cooperatives, works by creating a system of peer pressure, where the actions of an individual affect a group's ability to gain future financing. For the group-pressure system to function, there must be clear, understandable, and agreed-upon rules about individual and group expectations and abilities, as well as some degree of reciprocal trust or self-interested cooperation among the group's members. Monitoring of individual member activities with regards to group resources must be transparent to all members of the group, and strong incentives or disincentives must exist to reward or reprimand individuals who act outside a group's interest.

The Massachusetts Water Resources Authority (MWRA) employs an interesting and importable self-enforcing financing insurance mechanism. The 46 communities that purchase water from the MWRA each pay a small fee in addition to their monthly water charges. This fee is collected into a central account, which can then be drawn from to cover charges if a particular community does not make its monthly payment by a pre-established date. This fact is announced to the fund contributors. To keep the fund at a constant level, each community is then charged a little extra the following month (Levy, 1998). Naturally, if say the town of Chelsea were to default on its monthly payment to the MWRA, it would face a tremendous amount of pressure from upset politicians in 45 other communities. To date, no MWRA-served community has defaulted on its water bill payments, a significant change since the central insurance fund was introduced. A variation on a similar self-enforcing, self-insuring funding mechanism could be created for GWI's project communities.

We recommend that households be grouped in units of no larger than 25 households to form a single self-financing unit that pools together funds in the same way that the MWRA communities do. Ideally, the households within the unit should be clustered close together, and household members should know one another to some degree. Each household should nominate one member to act as its representative in the unit – the experience of microfinance organizations indicates that all-female groups have a higher rate of project cost recovery than all-male or co-ed groups. Every few months, the unit members should elect a treasurer, who will be responsible for collecting GWI's fees from the unit households each month, maintaining and monitoring the unit's central fund pool, and paying technicians by a certain date. As a unit's central fund pool builds up, the unit may decide to loan money to the household at a certain interest rate as an alternative measure to requiring all households to pay in extra, if a particular household has a genuine need for such a loan. The fund may also be used for other water-related activities within the units; paying for a cistern fill from a water-vending truck, for instance. In addition to the group pressures and opportunities created by organizing such financing units, this framework also creates a simple structure for rate collection – rather than having to collect individual household payments from the 250 households he or she serves, a technician simply collects ten payments from designated persons from each of the self-financing units. Moreover, because this system makes a technician directly accountable to households he is required to service, there is less likelihood that that a technician will skip out on his responsibilities, or falsify progress results, a practice that is presently suspected in a few cases.

In this self-financing scheme, the water committee acts as a final arbitrator. A self-financing unit may, after giving it a pre-specified number of chances to shape up, report a household that repeatedly defaults on its payments to the water committee. The committee should then decide on an appropriate sanction for that household; in extreme cases, a household's filter can be taken away and allocated to another household that is willing to take on the responsibility it entails. The severity of this action strongly depends on how valued the filters are, which in turn is a function of the effectiveness of social marketing and community education carried out by GWI. A highly visible program is also likely to attach status value to owning a filter, thereby increasing the chance that households will value the system enough to consider paying costs associated with its use a priority.

While creating this structure undeniably invents an additional layer of complexity in an already elaborate program, its benefits are well worthwhile. The suggested framework provides two established layers of security against non-payment: peer pressure, and loss of service. The latter is relied upon solely as a last resort measure, because it runs counter to the primary goal of providing people with safe drinking water. It is our sense that these mechanisms will work to some degree, but will probably require local adaptation. We recommend that pilot projects be initiated, perhaps using a couple of different self-insuring mechanisms in different segments or clusters of either Dumay or Les Palmes, where projects are more established. Dumay, as GWI's headquarters, might be an ideal site to start with. We also recommend starting a small pilot project where technician salaries are funded entirely by the local community, ideally in a site that is close to an existing site. Meillac, Madame St. Ville's village just outside Ferriere, might provide an ideal site for such a pilot, simply because it will be able to draw on support from the well-established program in Ferriere, and can be supervised to some degree by the capable hands of Marie Marthe Francois and Suzette, the Ferriere community technicians. Program setup and requirements for that site should be no different than those for conventional sites.

8.4 Conclusion

The purpose of this project was twofold: First, we intended to develop a set of project guidelines that draw upon the successes and challenges GWI has encountered in its six years of operation in seven different project sites in Haiti. Second, we hoped to develop the beginnings of an effective strategy that would allow GWI to share the burden of project costs with participating households over time, slowly weaning projects off donor funding and creating channels for the development of financially and managerially self-sustaining projects.

Our program implementation recommendations span the program setup stage through GWI's provision of sustained support to project communities and their technicians. We recommend that GWI exercise higher selectivity in site selection and play a stronger facilitative and advisory role during the project setup stage, from guiding water committee member and technician selection to suggesting tighter patterns of filter distribution. Hiring a staff member who is fluent in the local language and can be present through this vital stage is an important factor in ensuring effective project setup that can pave the way for improved performance. We suggest improvements in technician support, ranging from timely payment to better route management within tighter household clusters, monitoring and continuous community education.

The program in Haiti has begun to establish firm roots and sow the seeds for its own growth, as well as that of local capacity in the communities that is serves. The program sustainability scenarios are designed to provide GWI with an avenue for better managing and channeling its growth, and to help create an effective exit strategy for GWI, a necessary component of any sustainable development project that intends to build and catalyze local capacity. For about a $5 monthly cost, which includes the cost of chlorine and technician service, GWI can begin to shift the lion's share of its project costs to households participating in the filtration program. A self-insuring, self-enforcing group-based cost collection mechanism helps provide the necessary structure to ease cost collection and reduce default on payments. In addition to building local self-reliance and control, this project frees up GWI's resources so that the program can be expanded to other communities without the need to conduct ever-increasing fundraising efforts.

More importantly, it places the project further in the hands of local people, and allows the community to take control of its own destiny.

Chapter 9: Conclusions

This report details conclusions from four separate research projects. We have enclosed recommendations on the disinfection process in Haiti. We hope that the combined result of our research can be used to ameliorate the drinking water condition in Haiti.

References

Acra, A. Raffoul, Z., and Karahagopian, Y. (1984). Solar Disinfection of Drinking Water and Oral Rehydration Solutions. UNICEF. Paris.

Acra, A., Jurdi, M., Mu'allem, H., Darahagopian, Y. and Raffoul, Z. (1990). Water Disinfection by Solar Radiation: Assessment and Applications. International Development Research Center. Ontario, Canada.

Adeoti, O., Ilori, M. O., Oyebisi, L. O. and Adekoya, L. O. Engineering design and economic evaluation of a family-sized biogas project in Nigeria. Technovation, 20.2, 103-108.

Aga Khan Foundation. Special Report. http://ww.akdn.org/agency/akf_special.html (cited May 20, 2001)

American Society for Testing and Materials. (2001). Test Method 534-98 Standard Test Methods for Chemical Analysis of Sodium Chloride. West Conshohocken: American Society for Testing and Materials.

Brent, R. J. (1998). Cost-Benefit Analysis for Developing Countries. Cheltenham: Edward Elgar Publishing Ltd.

Brock, T., Madigan, T., Martinko, J., and Parker, J. (2000). Biology of Microorganisms. Prentice Hall.

BTR Labs (November, 1997). Laboratory Analysis Report for Thomas Warwick, Industries for the Poor (sic). Signed by Michael F. Helmstetter, Ph.D, Brevard Teaching & Research Laboratories.

Bukhari, Z., Hargy, T. M., Bolton, J. R., Dussert, B., and Clancy, J. L. (1999). Medium-pressure UV for oocyst inactivation. J Am. Wat. Wks. Assn. 91(3), 86-94.

Cabral, A., Cosgrove-Davies, M. and Schaeffer, L. (1996). Best Practices for Photovoltaic Household Electrification Programs. World Bank Technical Paper, 34, Asia Technical Department Series. Washington D.C.: World Bank.

Calderon, R. L. (2000), The Epidemiology of Chemical Contaminants of Drinking Water, Food and Chemical Toxicology, 38, S13 - S20.

Centers for Disease Control and Prevention, Department of Health and Human Services. (2001). Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects. Atlanta: CARE/CDC Health Initiative.

Clancy, J. L., Bolton J. R., and Dussert, B. (1998). Inactivation of Cryptosporidium parvum oocysts using medium-pressure ultraviolet light in bench and pilot scale studies. In American Water Works Association Water Quality and Technology Conference. American Water Works Association, San Diego, CA.

Chlorine Chemistry Council. Chlorine Knowledge Centre. <http://www.c3.org> (cited 1 Nov. 2000).

CONADEPA. (1984). Bulletin de Statistiques et d'Epidemiologie, Departement de la Sante Publique et de la Population.

Coulter, J., Goodland, A., Tallontire, A., and Stringfellow, R. (1999). Marrying Farmer Cooperation and Contract Farming for Agricultural Service Provision in Sub-Saharan Africa. In ODI Natural Resources Perspective No. 48

Country Report: Dominican Republic, Haiti, Puerto Rico. (1999). London: The Economist Intelligence Unit.

Courlander, Harold (1960). The Drum and the Hoe: Life and Lore of the Haitian People. Berkeley and Los Angeles: University of California Press.

Cubbage, C. P., Gannon, J. J., Cochran, K. W., and Williams, G. W. (1979.) Loss of Poliovirus 1 in river water under simulated field conditions. Wat. Res. 13, 1091-1099.

DATPE. (1984). Regions et Strategies de Developpment Regional, Ministere du Plan, Port-au-Prince.

Davidson, E. (2000). You Can't Eat GNP - Economics as if Ecology Mattered. Cambridge: Perseus Publishing.

de Oliveira Jr, A. and Tavares Pinho, J. (1993). An Alternative Water Disinfecting System for Amazon Rural Communities. Waterfront, 3, 14-15.

Doggett, S. and Gordon, L. (1999). Lonely Planet: Dominican Republic and Haiti. Hawthorn: Lonely Planet Publications Pty Ltd.

EAWAG/SANDEC. (1999, March). SODIS Conference Synthesis. http://www.sodis.ch/synthesis_e.html (cited 5 Nov. 2000).

EAWAG/SANDEC. (1997, August). SODIS News No. 1.

EAWAG/SANDEC. (1998, August). SODIS News No. 3. http://www.sodis.ch (cited 5 Nov. 2000).

EAWAG/SANDEC. Technical Notes. http://www.sodis.ch (cited 5 Nov. 2000).

Encyclopaedia Britannica. Salt. <http://www.britannica.com/eb/article.html> (cited 7 Feb. 2001).

Equipment and Systems Engineering, Inc. Aquachlor. <http://www.quakepro.com/aqua/indes.htm> (cited 13 Feb. 2001).

Exceltec International Corporation. SANILEC On-Site Generators. <http://www.sanilec.com/products/sanilec/index.html> (cited 1 Nov. 2000).

Fass, S. (1982). Water and Politics: The Process of Meeting a basic need in Haiti. Development and Change. London: Sage Publ.

Faust, S. D. and Aly, O. M. (1998). Chemistry of Water Treatment, 2^{nd} Edition. Michigan: Sleeping Bear Press.

Fawell, J. (2000). Risk assessment case study - chloroform and related substances. Food and Chemical Toxicology, 38, S91 - S95.

Feachem R., Bradley, D., Garelick, M., and Mara, D. (1983). Sanitation and Disease, Health Aspects of Excreta and Wastewater Management. UK: John Wiley and Sons.

Gallo, W.K. (1999). GWI Trip Report (August 17-22, 1999).

Gallo, W.K. (1999). GWI Trip Report (October 11-16, 1999).

Gift of Water, Inc (January 31, 2001). Newsletter. Written by Phil Warwick.

Gift of Water, Inc. (March 2001). Newsletter. Written by Phil Warwick and Trudi Onek.

Gift of Water, Inc. (May 1, 2000). A Collaborative Project for Rural Water Purification in Haiti: General Information for Traveling Volunteers.

Gift of Water, Inc. (Undated). Haitian Water Purification Project: Spiral Bound Data Book. Assembled by Trudi Onek.

Gift of Water, Inc. (1999). Water Purifier Assembly Instructions. Gift of Water, Inc.: Satellite Beach.

Goethert, R. (2000) Class notes. 11.465 Special Interest Group in Urban Settlements. Spring 2000, Massachusetts Institute of Technology.

Gordon, Gilbert, William J. Cooper, Rip G. Rice, and Gilbert E. Pacey (1987). Disinfectant residual measurement methods. AWWA Research Foundation, American Water Works Association.

Green, Martin A. (2000). Power to the People: Sunlight to Electricity Using Solar Cells. Sydney: University of New South Wales Press Ltd.

Grover, B. (1981). The Process of Project Preparation. In Schiller, E.J., and Droste, R.L. (Ed.) Water Supply and Sanitation in Developing Countries (pp. 269-285). Ann Arbor Science.

Haitian Consulate of Boston. Telephone interview. 5 April 2001.

HARZA. (1979). Water Resources Study for Haiti. Final Report. HARZA Engineering Co. Chicago.

Idealist.org. Job listings. http://www.idealist.org (cited May 2001)

International Labor Organization. (1994). Governing Body, 261st Session Proceedings. http://www.ilo.org/public/english/standards/relm/gb/docs/gb261/tc3-4c.htm (cited 15 May, 2001)

Ionics, Incorporated. The Cloromat System. <http://www.ionics.com/products/consumer/elite/cloromat.html> (cited 1 Nov. 2000).

Kapuscinski, R. B., and Mitchell, R. (1982). Sunlight-Induced mortality of viruses and *Escherichia coli* in coastal seawater. Env. Sci. Technol., 17, 1-6.

Kreider, J. F., Hoogendoorn, C. J. and Kreith, F. (1989). Solar Design: Components, Systems, Economics. New York: Hemisphere Publishing Corporation.

Lantagne, D. (2001). Trihalomethane Production in Household Water Filtration Systems in Rural Haiti. Massachusetts Institute of Technology Masters Thesis. Cambridge, MA.

Lawand T. A., Alward R., Odeyemi, O., Habn J., Kandpal, T. C., and Ayoub, J. (1988). Solar Water Disinfection. *Proceedings of a work-shop held at the Brace Research Institute. Montreal, Canada.* International Development Research Center, IDRC-MR231e, Ontario, Canada.

Lawrence, C. A. and Block, S. S. (1968). Disinfection, Sterilization, and Preservation. Philadelphia: Lea & Febiger.

Lehr, J. H., Gass, T. E., Pettyjohn, W., A., and DeMarre J. (1980). Domestic Water Treatment. New York: McGraw-Hill.

Letterman, Raymond D. (1999). Water Quality and Treatment, 5th ed. McGraw Hill Handbooks: New York.

Levy, P. Class Notes. 11.362 Environmental Management. Spring 1998. Massachusetts Institute of Technology

Library of Congress. (1979). Draft environmental report on Haiti. Science and Technology Division. Washington, D.C.

Lin, Tsair-Fuh and Shih-Wen Hoang (2000). Inhalation exposure to THMs from drinking water in south Taiwan. The Science of the Total Environment, 246, 41-49.

Maguire, Robert, Edwige Balutansky, Jacques Fomerand, Larry Minear, William G. O'Neill, Thomas G. Weiss, and Sarah Zaidi (1996). Haiti Held Hostage: International Responses to the Quest for Nationhood: 1986 – 1996. Providence, RI: The Thomas J. Watson Jr. Institute for International Studies and the United Nations University.

Marciniak, A. J., Imes, P. V., and Marcy, V. M. (1960). Analytical Methods. In D.W. Kaufman (Ed.) Sodium Chloride (pp. 318-359). New York: Reinhold Publishing Corporation.

Masters, Gilbert M. (1998). Introduction to Environmental Engineering and Science, Second Edition. New Jersey: Prentice Hall.

Mathews, C. K., and Van Holde, K. E. (1996). Biochemistry Second Edition. The Benjamin/Cummings Publishing Company Inc.

McGuigan, K. G., Joyce, T. M., Conroy, R. M., Gillespie, J. B., and Elmore-Meegan, M. (1998). Solar Disinfection of drinking water contained in plastic bottles: characterizing the bacterial inactivation process. J. Appl. Microbiol., 84(6), 1138-48.

McGinnes, R. (2001, Apr. 1). NASA Surface meteorology and Solar Energy Data Set. <http://eosweb.larc.nasa.gov> (cited 1 Apr. 2001).

Miller, W. L. (1998). Effects of UV radiation on aquatic humus: Photochemical principles and experimental considerations. In D. O. Hessen and L. J. Tranvik (Eds.) Aquatic Humic Substances – Ecology and Biogeochemistry. (pp. 125-143).

Munasinghe, M. (1993). Environmental Issues and Economic Decisions in Developing Countries. World Development, 21.11, (1729-1748).

NASA Langley Research Center Atmospheric Sciences Data Center. (2001). Surface Meteorology and Solar Energy Data Set. http://eosweb.larc.nasa.gov/sse/ (cited 6 Feb. 2001).

Neville, R. C. (1995). Solar Energy Conversion: The Solar Cell. 2nd ed. the Netherlands: Elsevier Science B.V.

New Scientist Magazine. (2000). Safe to Drink. vol. 167 issue 2253.

NOAA. (2001). http://www.noaa.gov (cited 6 Feb. 2001).

Oates, P. M. (2001). Solar Disinfection for Point of Use Water Treatment in Haiti. Massachusetts Institute of Technology Masters Thesis. Cambridge, MA.

Octave, F. (2000, April). MediaNET Bulletin: Haiti - Water management and difficulties of supply. <http://www.panosinst.org/island/IB29e.html> (cited 15 Feb 2001).

Okun, D.A. (1982). Financing Water Supply Systems. In Schiller, E.J., and Droste, R.L. (Ed.) Water Supply and Sanitation in Developing Countries (pp. 251-267). Ann Arbor Science.

PAHO (Pan American Health Organization). (1999). Haiti: Basic Country Health Profiles, Summaries 1999. http://www.paho.org/english/sha/prflhai.htm (cited 9 Feb. 2001).

Pires, C. (1998). Sustainability and Cost-Benefit Analysis. Environment and Planning A, 30.12, 2181-2194.

Prince, Rod (1985). Haiti: Family Business. Great Britian: Latin American Bureau.

Ramsdell, L. S. (1960). Mineralogy of Salt. In D.W. Kaufman (Ed.) Sodium Chloride (pp.13-22). New York: Reinhold Publishing Corporation.

Raven P. H., Johnson G. B. (1999). Biology Fifth Edition. McGraw-Hill

Reed, R. H. (1996). Sol-Air Water Treatment. 22nd WEDC Conference: Discussion paper. New Delhi, India. 295-296.

Reed, R. H. (1997). Solar inactivation of fecal bacteria in water: The critical role of Oxygen. Lett. Appl. Microbiol., 24, 276-280.

Reed, R. H. (1997). Sunshine and Fresh Air: A practical approach to combating water-borne disease. Waterlines. 15(4), 295-296.

Rook, J.J. (1974). Formation of haloforms during chlorination of natural waters. Water Treatment Examination, 23, 234-243.

The Salt Institute. (2001, Feb). What you always wanted to know about salt. <http://saltinstitute.org/4.html> (cited 7 Feb. 2001).

See, D. (1960). Solar Salt. In D.W. Kaufman (Ed.) Sodium Chloride (pp.96-109). New York: Reinhold Publishing Corporation.

Shultz, C. R., and Okun, D. A. (1984). Surface Water Treatment for Communities in Developing Countries. New York: John Wiley and Sons.

Simpson, Karen L. and Keith P. Hayes (1998). Drinking water disinfection by-products: An Australian perspective. Water Resources, 32, Number 5, 1522-1528.

Sketchell, Joanne, Hans G. Peterson, and Nick Christofi (1995). Disinfection by-product formation after biologically Assisted GAC treatment of water supplies with different bromide and DOC Content. Water Resources, 29, Number 12, 2635 - 2642.

Smout, I. (Ed.) (1996) Water and NGOs. Proceedings of an ODA Workshop. WEDC Loughborough University.

Smout, I. and Parry-Jones, S. (Ed.) (1999) Lessons learned from NGO Experiences in the Water and Sanitation Sector. WEDC Loughborough University.

Solar Energy Industries Association. Powerful Solutions with Photovoltaics. <http://seia.org/OldWeb.pvapps.htm> (cited 13 Feb. 2001).

Sommer, B., Marino, A., Solarte, Y., Salas, L. M., Dierolf, C., Valiente, C., Mora, D., Rechsteiner, R., Setters, P., Wirojanagud, W., Ajarmeh, H., Al-Hassan, A., and Wegelin, M. (1997). SODIS – an Emerging Water Treatment Process. J. Water SRT-Aqua. 46(3), 127-137.

Stumm W., and Morgan, J. J. (1995). Aquatic Chemistry. Chemical Equilibria and Rates in Natural Waters. 3rd ed. New York: John Wiley and Sons.

Tiwari, D. N. (2000). Sustainability criteria and cost-benefit analysis: an analytical framework for environmental-economic decision making at the project level. Environment and Development Economics, 5.3, 259-288.

United Nations International Children's Education Fund (UNICEF) (2001). Haiti. <http://www.unicef.org/statis/Country_1Page73.html> (cited May 8, 2001).

United States Agency for International Development (USAID) (1985). Haiti: Country Environmental Profile. USAID. USAID. (1985). Haiti, Country Environmental Profile: A Field Study

USAID. (2001, January). Haiti Overview. <http://www.usaid.gov/country/lac/ht/index.html> (cited 1 May 2001).

United States Environmental Protection Agency (USEPA) (2001). National primary drinking water standards. <http://www.epa.gov/safewater> (cited May 6, 2001).

United States Environmental Protection Agency. Drinking Water. <http://www.epa.gov/ebtpages/wdrinkingwater.html> (cited 20 Oct. 2000).

Vil, P. (1999, August). MediaNET Bulletin: Suzanne - or the ordeal of a deported family. <http://www.panosinst.org/island/IB11e.html> (cited 15 Feb 2001).

Wegelin, M., Canonica, S., Mechsner, K., Pesaro, F. and Metzler, A. (1994). Solar Water Disinfection: Scope of the process and analysis of radiation experiments. J. Water SRT-Aqua. 43(3), 154-169.

White, J. A., Case, K. E., Pratt, D. B. and Agee, M. H. (1998). Principles of Engineering Economic Analysis. 4th ed. New York: John Wiley & Sons, Inc.

Whittington, D., Briscoe, J., Mu, X. and Barron, W. (1990). Estimating the willingness to pay for water services in developing countries: A case study of the use of contingent valuation surveys in southern Haiti. Economic Development and Cultural Change 41, 75-87.

Whittington, D., Lauria, D.T., and Mu, X. (1991). A Study of Water Vending and Willingness to Pay for Water in Onitsha, Nigeria. World Development 19, No. 2/3.

Whittington, D. (1992). Possible Adverse Effects of Increasing Block Water Tariffs in Developing Countries. Economic Development and Cultural Change 38, 293-311

World Bank. Haiti Data Profile. <http://worldbank.org/data/countrydata/countrydata.html> (cited 15 Feb. 2001).

World Health Organization. Global Water Supply and Sanitation Assessment 2000 Report. <http://www.who.int/water_sanitation_health/Globassessment/Global8-2.htm> (cited 1 Apr. 2001).

World Health Organization (1998). Guidelines for drinking-water quality, 2nd edition. <http://www.who.int/water_sanitation_health/GDWQ> (cited March 16, 2001).