HOUSEHOLD WATER CHLORINATION FOR THE DEVELOPING WORLD
A CASE STUDY IN LUMBINI NEPAL

By

Hannah B. Sullivan

S.B. Civil and Environmental Engineering
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ABSTRACT

This thesis examines the CDC's Safe Water System program as an approach to the provision of microbially safe water in the developing world and evaluates a pilot study of household chlorination established in January 2001 in Lumbini, Nepal based on the Safe Water System approach. The evaluation of the Lumbini Household Chlorination Pilot Study presented here is based on field visits conducted in Lumbini, Nepal in January 2002. During this field-study period, households participating in the chlorination pilot study were visited to assess the level of effectiveness and acceptance of household chlorination in the region. Assessments of the effectiveness of household chlorination were based on bacterial removal and measured free chlorine residuals in stored household water supplies, as well as on health data collected over the course of the pilot study by the International Buddhist Society. Assessments of the acceptance of household chlorination were based on user interviews conducted during household visits. In addition to the pilot study evaluation, a microbial water quality survey was conducted on public tubewells installed in Lumbini by the International Buddhist Society.

This thesis presents recommendations for the expansion of household chlorination in Lumbini, including the establishment of a formal user education program and the introduction of user contributions and cost-recovery for household chlorination products. In addition, it presents recommendations for the establishment of a well inventory in Lumbini and suggests standard surveying and microbial testing procedures to facilitate future well surveying efforts in Lumbini.

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“A healthy individual is a person who is well balanced bodily and mentally, and well adjusted to physical and social changes, so long as they do not exceed normal limits, and contributes to the welfare of society according to this ability. Health is therefore, not simply the absence of disease, it is something positive, a joyful attitude towards life and a cheerful acceptance of the responsibilities that life puts upon that individual.”

Posting at a Nepali NGO
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CHAPTER 1 INTRODUCTION

1.1 The MIT-Nepal Water Project

This thesis is part of the 2001-2002 MIT-Nepal Water Project, a group of eight Masters of Engineering Students from the Civil and Environmental Engineering Department at Massachusetts Institute of Technology who have devoted their year to the study of point-of-use water treatment technologies, with the hope of providing relief for the people of Nepal and developing nations around the world who lack access to safe, high-quality drinking water sources.

The 2001-2002 team represents the third year of the MIT-Nepal Water Project, a program initiated in 1999 by Susan Murcott, a Lecturer at MIT, after her participation in the 2nd International Women and Water Conference held in Nepal in 1998. Local women attending the conference implored Murcott and other presenters to help them find a solution to the water quality crisis currently faced by rural villagers in Nepal. The MIT-Nepal Water Project was formed in response to their requests.

Over the three years of its existence, the project has sent twenty MIT students to Nepal. The work conducted by these students has progressed from field assessments of microbial and arsenic contamination in drinking water sources, to laboratory and field tests of point-of-use treatment technologies, to pilot implementation programs of these point-of-use technologies. This thesis evaluates one pilot project implementation program conducted between January 2001 and January 2002 in Lumbini, Nepal based on the Centers for Disease Control and Prevention's (CDC) Safe Water System Program. This program incorporates household drinking water chlorination, safe water storage, and behavior modification techniques as a means for providing microbially safe water to populations throughout the developing world who lack assess to high-quality drinking water sources.

1.2 The Current State of Drinking Water Supply and Sanitation Provision in Nepal

Landlocked between China and India, the Kingdom of Nepal covers an area of just over 140 thousand square kilometers. Blessed by eight of the world's ten highest peaks and revered by the mountaineering community since the opening of its borders in 1951, the mountainous landscape of Nepal lies in stark contrast to the extreme poverty of the Nepali people (Moran, 1991). The average annual income in Nepal is less that US $240, and the majority of Nepal's population relies on subsistence agriculture, operating largely outside the cash economy (World Bank, 2002). The country's formal economy is largely dependant on tourism, with over 200,000 foreigners entering Nepal each year during the 1980s and 1990s (Moran, 1991). Recent political instability, largely due to conflicts between the Maoist revolutionaries operating out of western Nepal and the national government, and the declaration of a national state of emergency in November 2001, have lead to severe declines in tourism, and have further weakened Nepal's economic status.

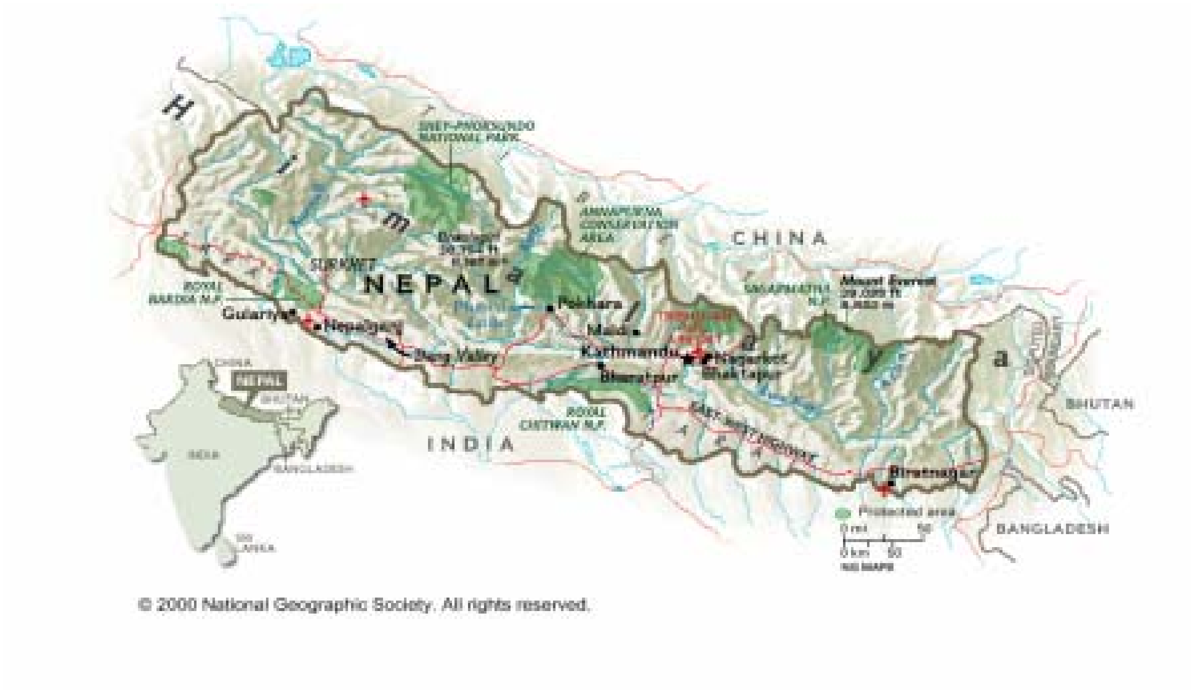

Figure 1.1: Map of Nepal

Nepal currently spends less that three percent of its national budget, and less than one percent of its GNP, on the provision of drinking water and sanitation for its citizens. In spite of these low levels of government investment, water supply coverage in Nepal has increased substantially over the 1980s and 1990s. The majority of the capital improvements occurring during this period were financed through foreign aid infusions spurred by the declaration of the United Nations International Drinking Water Supply and Sanitation Decade (IDWSSD) in 1980. Eighty-one percent of Nepal's population now has access to either piped municipal water supplies or tubewell water sources (UNDP, 2002). These high levels of coverage do not necessarily ensure the provision of safe water in Nepal. Municipal water supplies in Kathmandu are rarely chlorinated to adequate levels and bacterial contamination in tap water is commonplace as a result. Widespread bacterial contamination problems have also been identified in tubewell water in rural regions of Nepal. These water quality problems are frequently exacerbated by unsafe water storage practices in both urban and rural regions of the country (Shreshra, 2001). The sanitation situation in Nepal is even more troubling. Less than one percent of foreign capital investments are devoted to sanitation provision and the proportion of people in Nepal with access to sanitation facilities, at twenty-seven percent, is lower than any other nation in South Asia (UNDP, 2002).

As a result of this failure to provide safe water and adequate sanitation, the effects of waterborne disease weigh heavily on the Nepali people. The average life expectancy in Nepal is only 59.5 years, the infant mortality rate is 77.2 per 1000 life births, the under 5 mortality rate is 108.4 per 1000 live births, and over 50 percent of children under age 5 show signs of growth stunting which can be attributed to the inability to retain essential nutrients due to the effects of waterborne disease (UNDP, 2002). A survey conducted by Nepal's ministry of health in 2002 revealed than 20 percent of children under age 5 were affected by diarrhea in the two weeks prior to the interview day.

Figure 1.2: Water, Sanitation, and Health Indicators in Nepal

Percent of Population w/Access to Improved Water Sources	81
Percent of Population w/Access to Basic Sanitation	27
Life Expectancy (years)	59.5
Infant Mortality (per 1000 live births)	77.2
Under Age 5 Mortality (per 1000 live births)	108.4
Percent of Children w/Growth Stunting	50.5

(UNDP, 2002)

1.3 Water and Sanitation in the Developing World

Nepal is not unique in its struggles with water and sanitation provision and waterborne disease. Throughout the developing world, 1.1 billion people lack access to improved water supplies, and 2.4 billion people lack access to basic sanitation. Because of these deficits, 3.4 million people, most of them children, die each year from water-related disease (WHO, 2002).

The situation is quite different in the developed world. Each year in the United States, less than one percent of the population is affected by waterborne disease and these outbreaks have resulted in less than one death per year over the last thirty years (Viessman, 1993). These achievements can be attributed to the use of water treatment processes, such as chlorination. When chlorination was first implemented in1919 in Wheeling, West Virginia, typhoid cases dropped dramatically from 155-200 cases per year to just seven cases. Similar reductions were seen for other waterborne diseases (Hawkins, 1997).

One of the goals of the International Drinking Water Supply and Sanitation Decade was to bring these achievements in drinking water treatment and their associated health benefits to the developing world. In spite of investments of over $133 billion since the beginning of the decade, water supply and sanitation coverage levels have tapered off since 1990, and large numbers of people remain unserved (Mintz, 2001). Clearly the large-scale infrastructure improvements mandated by the decade have failed to meet the needs of the developing world in the timescales that these improvements are required. While the construction of piped water supplies, deep wells, and treatment facilities may one day be able to provide safe drinking water for all people around the globe, many segments of the world's population are facing severe health risks in the interim.

1.4 Point-of-Use Water Treatment and Household Chlorination

Point-of-use water treatment provides an alternative approach to safe water provision. This thesis examines one approach to household water treatment, the Centers for Disease Control and Prevention's Safe Water Systems program. This simple intervention attempts to bring the benefits of drinking water disinfection to the developing world through the household-scale application of chlorine disinfection. This thesis examines the Safe Water Systems approach to drinking water provision and evaluates a pilot study of household chlorination established in Nepal based on this program. The goal of this work is to evaluate the Safe Water Systems approach and determine if household chlorination is an appropriate approach to safe water provision in Nepal.

CHAPTER 2 THE CHEMISTRY OF WATER CHLORINATION

"Today, a simple turn of the tap provides clean water - a precious resource. Engineering advances in managing this resource - with water treatment, supply, and distribution systems - changed life profoundly in the 20th century, virtually eliminating waterborne diseases in developed nations, and providing clean and abundant water for communities, farms, and industries."

-National Academy of Engineering, 2001

2.1 Disinfection Theory

Disinfection of drinking water or wastewater refers to the destruction of disease-causing organisms. Disinfection does not necessary result in the complete sterilization of a water supply but rather in the destruction of bacteria, viruses, and amoebic cysts, the principal organisms responsible for waterborne disease. Disinfectants, such as chlorine, destroy these organisms by several means including

- damage to cell walls
- alteration of the cell membrane, destroying selective permeability
- alteration of the colloidal nature of the protoplasm, causing protein denature
- and, the inhibition of enzyme activity (Metcalf & Eddy, 1991).

It is valuable to make a distinction between two forms of disinfection that serve distinct purposes in a water treatment facility and distribution system. *Primary disinfection* refers to the initial inactivation of bacteria, viruses, and protozoa. *Secondary disinfection* refers to the maintenance of a disinfection residual that prevents against the recontamination and growth of microorganisms during the transportation or storage of treated water (Spellman, 2000).

Disinfection and the removal of drinking water pathogens can occur through the use of chemical, physical, mechanical, or irradiative techniques. Metcalf and Eddy (1991) identify a number of chemical agents that can be used as disinfectants, including (1) chlorine and chlorine compounds, (2) bromine, (3) iodine, (4) ozone, (5) phenol and phenolic compounds, (6) alcohols, (7) heavy metals and related compounds, (8) dyes, (9) soap and synthetic detergent, (10) quanternary ammonium compounds, (11) hydrogen peroxide, and (12) various alkalies and acids. Physical disinfectants include heat in the form of water boiling or light in the form of solar radiation (Mintz et al, 2001). Mechanical agents for disinfection include screening, sedimentation, and filtration. To date irradiative techniques for disinfection have made use of gamma rays to sterilize water supplies (Metcalf & Eddy, 1991).

Although numerous option exist for drinking and wastewater disinfection, chlorine continues to be the disinfectant of choice and commands nearly universal use at water treatment facilities in the developed world. A study conducted in the late 1980s by the American Water Works Association (AWWA) Disinfection Committee revealed that over 90% of American water utilities used chlorine or hypochlorite as their primary disinfection agent (AWWA, 1999).

2.2 Chorine Chemistry

2.2.1 Forms of Chlorine

Chlorine disinfectant is commonly applied in one of three forms; gaseous elemental chlorine (Cl_2), liquid sodium hypochlorite (NaOCl), or solid calcium hypochlorite ($Ca(OCl)_2$) (AWWA, 1999). Because of its low cost per unit available chlorine and highly concentrated form, the most commonly used form of chlorine in large treatment plants in the United States is chlorine gas. Sodium hypochlorite and calcium hypochlorite are more commonly used in small treatment facilities where safety considerations outweigh the cost of using these hypochlorite salts (Metcalf & Eddy, 1991).

Gaseous chlorine is a greenish-yellow toxic gas typically supplied to water treatment facilities in liquid form in high-pressure steel cylinders ranging in size from 100 to 1000lbs (Cepis, 2001). Although commonly used in large treatment facilities in the United States, gaseous chlorine is not suitable for small-scale disinfection because of the severe health hazards that it presents. Chlorine gas can be lethal at concentrations as low as 0.1% by volume and therefore must be handled only by highly trained personnel (Spellman, 2000).

Sodium Hypochlorite is a water-based solution containing sodium hydroxide and chlorine (CEPIS, 2001). Commercially prepared sodium hypochlorite solutions, such as household bleach, typically contain 5 to 15% available chlorine (Spellman 2001) . Sodium hypochlorite is corrosive in nature and should be handled with care and diluted prior to application. Sodium hypochlorite is more costly per unit available chlorine than chloride gas, but its use in larger water treatment facilities is increasing due to OSHA worker health and safety regulations that have encouraged these facilities to discontinue the use of chlorine gas (AWWA, 1999).

Calcium hypochlorite, or bleaching powder, is not as dangerous as gaseous chlorine but it is still highly corrosive and must be handled properly to prevent direct skin contact or inhalation. Commercially available calcium hypochlorite in powdered or tablet form typically contains 65% available chlorine and can be used to create dilute solutions for disinfection, though dissolution can be difficult and often produces large volumes of hazardous concentrated waste. In solid form, calcium hypochlorite is more stable than sodium hypochlorite, but once dissolved in solution, its shelf life becomes limited (Spellman, 2000). Solid calcium hypochlorite is also difficult to store in humid, tropical climates because of its hydroscopic nature (CDC, 2001).

2.2.2 Hydrolysis and Ionization

When chlorine disinfectants are added to drinking water two reactions occur to facilitate disinfection, hydrolysis and ionization. Hydrolysis reactions of chlorine gas, calcium hypochlorite, and sodium hypochlorite can be written as follows,

$$Cl_2 + H_2O \Leftrightarrow HOCl + H^+ + Cl^- \quad (1a)$$

$Ca(OCl)_2 + 2H_2O \Leftrightarrow 2HOCl + Ca(OH)_2$ (1b)

$NaOCl + H_2O \Leftrightarrow HOCl + NaOH$ (1c)

The hypochlorous acid (HOCl) created through these hydrolysis reactions is a weak acid and partially dissociated to H^+ and OCl^-, through the following ionization reaction,

$HOCl \Leftrightarrow H^+ + OCl^-$ (2)

Although both hypochlorous acid and hypochlorite possess disinfection power, hypochlorous acid is up to 80 times more effective, depending on concentration and contact time (Figure 2.1). The combined quantity of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) that is present in disinfected water is referred to as the *free available chlorine*. Disinfection power also exists in *combined available chlorine* which refers to the chlorine present as chloramines formed when chlorine reacts with ammonia and nitrate in natural waters. Three types of chorinamines, monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and nitrogen trichloride (NCl_3), are typically formed in successive reactions:

$NH_3 + HOCl \Rightarrow NH_2Cl$ (monochloramine) $+ H_2O$ (3)

$NH_2Cl + HOCl \Rightarrow NHCl_2$ (dichloramine) $+ H_2O$ (4)

$NHCl_2 + HOCl \Rightarrow NCl_3$ (nitrogen trichloride) $+ H_2O$ (5)

Monochloramines and dichloramines are generally the dominant species and possess some disinfection power, through they are typically less effective than hypochlorous acid and hypochlorite and react much more slowly to destroy pathogens (Figure 2.1).

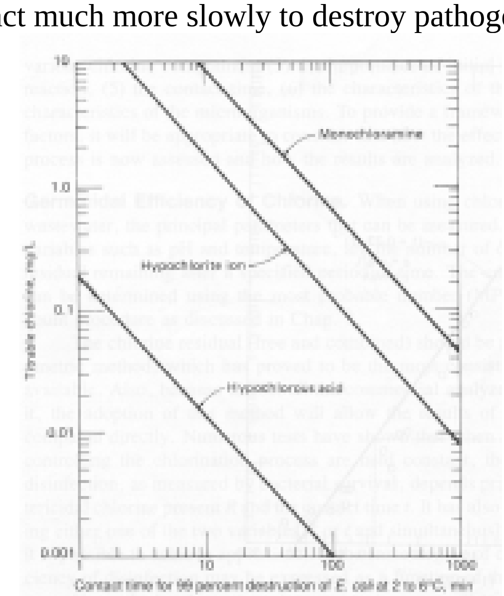

Figure 2.1: Germicidal Efficiency of Hypochlorous Acid, Hypochlorite Ion, and Monochloramine for 99% Destruction of E.coli (Metcalf and Eddy, 1991)

2.2.3 Breakpoint Chemistry

The effectiveness of a particular chlorine dose depends on the chlorine demand of the water supply being treated and on the proportion of free available chlorine and combined available chlorine. When chlorine, in the form of chlorine gas or hypochlorite salt, is added to natural waters, a stepwise series of reactions occurs as chlorine reacts with oxidizable substances present in the water and combines with ammonia to form chloramines. This progression of reactions and chlorine speciation can be explained through the use of a simple breakpoint curve (Figure 2.2). This curve shows the four stages of reactions that occur as chlorine is added to the system.

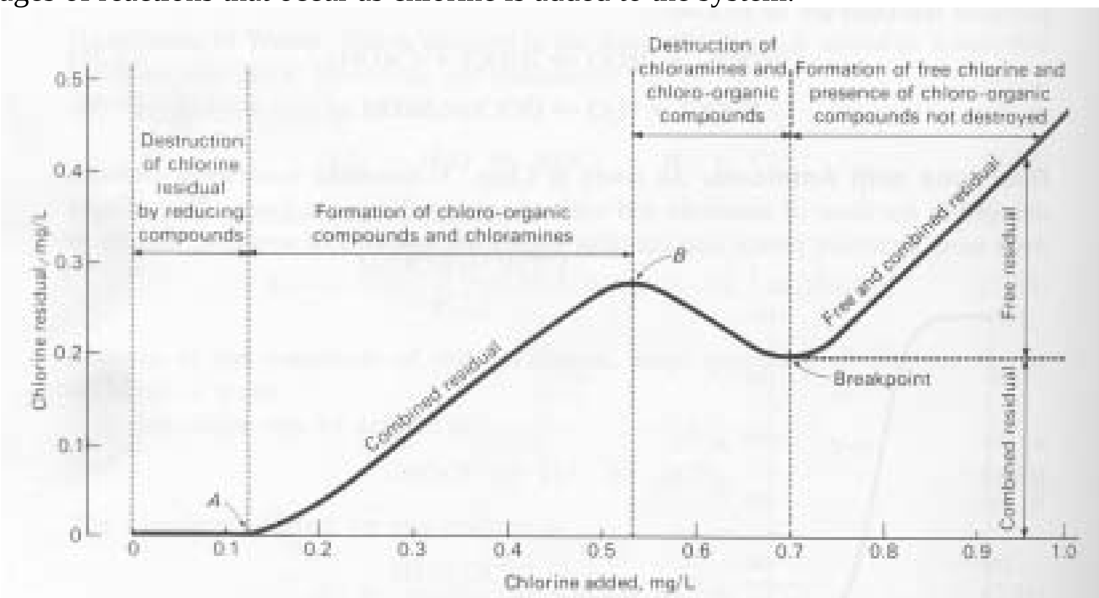

Figure 2.2: Chlorine Residual Curve for Breakpoint Chlorination (Metcalf and Eddy, 1991)

The stages of breakpoint chlorination occur as follows:

(1) Initially added chlorine reacts with oxidizable material in the water including Fe^{+2}, Mn^{+2},H_2S and organic matter. This chlorine demand reduces any added chlorine to the chloride ion making it unavailable for disinfection. Chlorine residual remains at zero throughout this stage.

(2) Once all oxidizable substances have been consumed, chlorine begins to reacts with ammonia to form chloramines, raising the combine chlorine residual.

(3) When all available ammonia has been consumed, a free available chlorine residual begins to develop and oxidize the previously produced chloramines to nitrous oxide (N_2O), and nitrogen (N_2), and nitrogen trichloride. This oxidation process results in a reduction of chlorine residual.

(4) Once all of the produced chloramines have been oxidized, the continued addition of chlorine will result in directly proportional increases in free chlorine residual. The point at which this occurs is referred to as the *breakpoint.*

The addition of chlorine beyond the breakpoint is usually desirable in a treatment system to ensure proper disinfection. Although the combined residual chlorine provides some disinfection power, the presence of unreacted hypochlorite, or free chlorine residual will provide much more significant disinfection power (Figure 2.1). The chlorine demand of a water source refers to the amount of chlorine that must be added to reach breakpoint and establish a free chlorine residual.

2.3 Chlorine Efficiency

2.3.1 CT Concept

Chlorine dose is typically measured in terms of concentration and contact time. In general, the longer the contact time the greater the level of disinfection. This is demonstrated numerically by Chick's Law (Metcalf and Eddy, 1991):

$$\frac{dN}{dt} = -kN_t \qquad (6)$$

where N_t = number of organisms at time t
t = time
k = constant [time^{-1}]

Similarly the higher the concentration of chlorine available for disinfection, the greater the level of disinfection. The concentration of chlorine available for disinfection is not equivalent to the amount of chlorine applied, but rather to the free chlorine residual present after chlorine is applied, as chlorine demand can vary widely among water sources.

The CT concept is widely used in US regulation of disinfection practices and refers to the relationship between chlorine concentration (C), contact time (T) and effective disinfection or inactivation of pathogens. In the United States, the Surface Water Treatment Rule (SWTR) mandates that a certain level of filtration or disinfection be maintained in all surface water treatment facilities. In terms of disinfection, this requirement is usually represented by a CT factor that must be reached by the treatment plant (AWWA,1999). CT factors are calculated as

$$\text{CT factor (mg/L·min)} = \text{C (mg/L) x T (min)} \qquad (7)$$

where C = residual concentration (mg/L)
T = contact time between disinfectant application and residual measurement

2.3.2 Other Factors affecting Chlorine Efficiency

The CT concept is an oversimplification because it discounts other factors that can affect the efficiency of chlorine disinfection. In addition to residual concentration of chlorine and contact time, pH, temperature, and turbidity can all affect the level of disinfection achieved by a particular chlorine dose (Spellman, 1999).

pH

Source water pH affects the efficiency of chlorine disinfection through its effect on the ionization reaction given in Equation 2. This affects the partitioning of chlorine into hypochlorous acid (HOCl) and hypochlorite (OCl^-). As discussed in Section 2.2, the disinfection power of hypochlorous acid is much greater than that of hypochlorite, making the relative distribution of these two species an important consideration. The disinfection power of chlorine declines significantly as source water pH rises above 8, and hypochlorite develops as the dominant species (Figure 2.3).

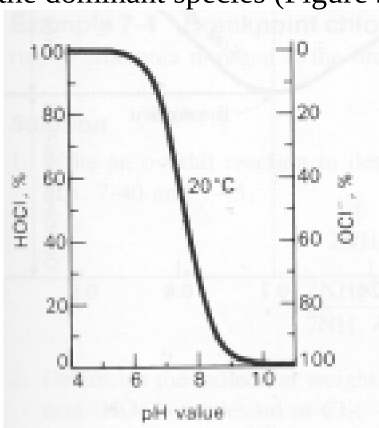

Figure 2.3: Effect of pH on the Distribution of Hypochlorous Acid and Hypochlorite (Metcalf and Eddy, 1991)

Temperature

Higher temperatures can lead to faster rates of disinfection or pathogen inactivation in chlorinated water. The relationship between temperature and time required to give a certain "percentage kill" is given by the Van't Hoff Arrhenius relationship,

$$\ln \frac{t_1}{t_2} = \frac{E(T_2 - T_1)}{RT_1T_2} \qquad (8)$$

where t_1, t_2 = time to reach given percent kill at temperatures T_1 and T_2 (°K) respectively
E = activation energy (J/mol)
R = gas constant, 8.314 (J/mol°K)

The activation energy (E) for chlorine varies with pH, and is equal to 34,338 J/mol at a neutral pH of 7.0 (M&E, 1991).

Turbidity

Turbidity refers to the degree of light scattering by a water column. It is typically measured in Nephelometric Turbidity Units (NTU). Turbidity in source water is caused by the presence of suspended solids and other particulate matter. Microorganisms that are adsorbed to or embedded in this particulate matter are often protected from disinfection (WHO, 1993). The precise relationship between turbidity and chlorine efficiency is difficult to quantify and is also affected by the organic content of the source water. One commonly cited model suggests that an increase in turbidity from 1 NTU to 10 NTU, causes an 8-fold reduction in disinfection efficiency (LeChavaller, 1981). Because of this effect on disinfection efficiency, source waters that demonstrate high turbidity should undergo primary treatment steps such as settling or filtration prior to chlorine disinfection. Ideally pretreatment processes should strive to produce waters with median turbidity levels less than 1 NTU (WHO, 1993). Alternatively chlorine dose or contact time can be increased when source water presents high-level turbidity.

Character of microorganisms

The nature of the microorganisms in source waters can also affect the efficiency of chlorine disinfection. Different pathogenic species require different levels of chlorine residual and different contact times to achieve inactivation. In general, bacterial species exhibit the lowest resistance to chlorine disinfection, followed by viruses, protozoa, and helmith eggs. The ability of specific microorganisms to be inactivated by chlorine disinfection can be represented by organism-specific CT values. Microorganisms, such as *Gardia lamblia*, with high CT values exhibit higher resistance to chlorination. CT values typically range from less than 0.01 mg/L·min to greater than 100 mg/L·min. This implies that complete disinfection can take anywhere from less than one minute to over 100 minutes at free chlorine residual levels of 1.0 mg/L (Viessman,1993). Table 2.1 gives inactivation information for various microorganisms of significance in waterborne disease. Note that a free chlorine residual of 0.5-1.0 mg/L at water temperatures of 25°C and pH 7.0 should be sufficient to inactivate most bacteria and viruses after thirty minutes of contact time. In general, protozoa are only slightly more resistant to chlorine disinfection with the notable exception of *Cryptosporidium. Cryptosporidium* cysts are highly resistant to chlorination and the use of chlorine in the absence of filtration or alternative removal techniques will not result in effective *Cryptosporidium* inactivation (CDC, 2001).

Table 2.1: Inactivation of Selected Microorganisms by Chlorine Disinfection (CDC, 2001)

	Cl_2 Residual (mg/L)	*Temperature (℃)*	*PH*	*Time (min)*	*Reduction (%)*
Bacteria					
Campylobactor jejuni	0.1	25	8.0	5	99.99
Escherichia coli	0.2	25	7.0	15	99.99
Legionella pneumophila	0.25	21	7.8	60-90	99
Mycobacterium chelonei	0.7	25	7.0	60	99.95
Mycobacterium fortuitum	1.0	-	7.0	30	99.4
Mycobacterium intracellulare	0.15	-	7.0	60	70
Pasteurella turarensis	0.5-1.0	10	7.0	5	99.6-100
Salmonella typhi	0.5	20		6	2 orders of magnitude
Shigella dysenteriae	0.05	20-29	7.0	10	99.6-100
Staphylococcus aureus	0.8	25	7.2	0.5	100
Vibrio cholerae (smooth strain)	1.0	20	7.0	< 1	100
Vibrio cholerae (rugose strain)	2.0	20	7.0	30	> 5 orders of magnitude
Yersinia enterocolitica	1.0	20	7.0	30	92
Viruses					
Adenovirus	0.2	25	8.8	0.7	99.8
Coxsackie	0.16-0.18	27-29	7.0	3.8	99.6
Hepatitis A	0.42	25	6.0	1	99.99
Norwalk	0.5-1.0	25	7.4	30	Not Complete
Parvovirus	0.2	20	7.0	3.2	99
Poliovirus	0.5-1.0	25	7.4	30	100
Rotavirus	0.5-1.0	25	7.4	30	100
Protozoa					
Cryptosporidium parvum	80	25	7.0	90	90
Entamoeba histolytica	1.0	22-25	7.0	50	100
Giardia lambia	1.5	25	7.0	10	100

2.4 Disinfection Byproducts

Since its introduction in 1908, chlorine has proved effective in inactivating pathogenic microorganisms and ensuring the safety of drinking water supplies throughout the developed world, but in recent years the use of chlorine for drinking water disinfection has come under intense scrutiny due to concerns about cancer risk associated with disinfection by-products (DPBs). Chlorination byproducts include chloroform ($CHCl_3$), bromoform ($CHBr_3$), bromodichloromethane ($CHCl_2Br$), and chlorodibromomethane ($CHClBr_2$) and are collectively referred to as trihamomethanes (THMs). THMs are formed when hypochlorous acid reacts with organic matter in source waters. Concern over THMs was spurred by the release of a 1974 study identifying a link between the use of Mississippi River Water, which contained chlorinated sewage effluent, and the incidence of cancer (Melosi, 2000). Subsequent studies have produced conflicting findings on the carcinogenicity of THMs and other disinfection byproducts and have often relied on animal data that cannot be directly transferred to humans (Veissman, 1993).

Several organizations have come forward with statements on this issue, generally emphasizing that any potential health risks from THMs and other disinfection byproducts should be carefully weighed against the known health effects of microbially contaminated drinking water supplies. The US Center for Disease Control and Prevention makes the following statement about trihalomethanes in chlorinated drinking water:

> "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 (CDC, 2001)."

The WHO supports this view, making the following statement about disinfection byproducts in their Guidelines for Drinking Water Quality:

> "Where local circumstances require a choice be made between meeting microbiological guidelines or guidelines for disinfection byproducts such as chloroform, the microbiological quality must always take precedence. Efficient disinfection must never be compromised (WHO, 1993)."

2.5 Applications for Chlorination in the Developing World

The Centers for Disease Control and Prevention and the National Academy of Engineering recently named water treatment as "one of the most significant public health advancements in the 20th century (EPA, 1999)." Water treatment and chlorination have reduced the number of waterborne disease outbreaks in the United States to less the 20 per year, affecting less than 1% of the US population and resulting in less than one death per year due to waterborne disease (Viessman, 1993). Yet worldwide over 3 million people, most of them children, die of diarrheal disease each year (CDC, 2001). The majority of distribution systems in the developing world either do not make use of chlorine or do so intermittently. Furthermore a large percentage of the world's population live in rural areas where distribution systems have not been established, making it impossible for them to realize the health benefits of treatment plant scale chlorination.

The chemistry presented here seems to imply that chlorination is a complicated technology, best left to large-scale water treatment plants in the developed world. But there are alternatives to this large-scale treatment plant and distribution system approach. Chlorination can be used for household scale drinking water disinfection without complicated application systems or dosing regimes. Simple methods exist for extending the health benefits of chlorination to the developing world. Starting in the early 1990s, the Centers of Disease Control and Prevention (CDC), in association with the Pan American Health Organization (PAHO), began to explore the use of chlorine to combat cholera epidemics affecting Latin America. The CDC has since expanded this initiative into a Safe Water Systems Program that emphasizes household chlorination, safe water storage, and hygiene behavior modification as a means to reduce waterborne disease in the developing world. Since 1990, the Safe Water Systems program has brought the benefits of chlorination to communities in Africa, Asia, Latin America, and Eastern Europe.

CHAPTER 3 SAFE WATER SYSTEMS

"Approaches that rely solely on time and resource intensive centralized solutions will leave hundreds or millions of people without access to safe water far into the foreseeable future; a radical reorientation towards interventions to support these people is urgently required"

- Eric Mintz MD, Centers for Disease Control and Prevention

Today, waterborne disease has been virtually eliminated in the developed world, largely due to water treatment processes such as chlorination. The Safe Water System Program is an attempt to bring the benefits of chlorination to the developing world through a small-scale household level disinfection approach. It was developed in 1992 by the Centers for Disease Control and Prevention (CDC) and the Pan American Health Organization (PAHO) in response to the cholera epidemics affecting Latin American. The programs reach has since expanded to Asia, Africa, and Eastern Europe. Safe Water System programs have been implemented in numerous countries throughout the world including Guatemala, Nicaragua, Bolivia, Ecuador, Peru, Cote d'Ivoire, Guinea-Bissau, Kenya, Madagascar, Malawi, Uganda, Zambia, Pakistan, and Uzbekistan.

The overarching goals of any Safe Water System Program are "to improve water quality in homes by means of a sustainable technology, to decrease death and diarrhea from contaminated drinking water, and to improve hygienic behaviors related to water use (CDC, 2001)." Although SWS developers support current infrastructure projects designed to meet these goals, such as the construction of deep wells and piped water systems, they fear that immense shortages of the time and resources needed to complete these projects will leave many people in the developing world without access to safe water sources. Due to these concerns, the Safe Water System approach relies on point of use water disinfection and safe water storage to meet its goal of safe water provision and waterborne disease reduction. The program has three key components:

(1) ***Point-of-use treatment*** of contaminated water using locally produced sodium hypochlorite solutions (NaOCl).

(2) ***Safe water storage*** in containers specially designed to prevent recontamination

(3) **B*ehavioral modification*** techniques designed to influence water handling and storage behaviors and increase basic awareness of the benefits of safe water.

This chapter is intended to provide a brief introduction to the SWS approach and provide some examples of its successful implementation throughout the developing world. It is not intended to be a comprehensive look at the program, nor is it designed to guide potential SWS program developers. The CDC produces a manual designed to guide users through the planning process for a SWS program. "Safe Water Systems for the Developing World: A Handbook for Implementing Household-Based Water Treatment and Safe Storage Projects" is available online at the CDC Safe Water Systems website, www.cdc.gov/safewater, or in hard copy through the CDC's Atlanta office.

3.1 Components of the Safe Water System Approach

3.1.1 Point-of-Use Treatment

Traditional methods for water treatment in developing countries include filtration and boiling. Filtration can effectively remove turbidity and larger biological contaminants such as *cryptosporidum*, *giardia,* and amoebae. It can also reduce bacterial and viral contamination but it cannot usually produce complete removal of these contaminants (Gadgil, 1998). Boiling can remove bacterial contamination and produce potable water but is both economically and environmentally unsustainable in most developing countries. Boiling water to produce the minimal requirement of 2 liters of drinking water per person per day would require 10 kilograms of fire-wood each day for a household of five (Mintz et al, 1995). Boiling on this magnitude would significantly increase deforestation pressures already facing many developing nations and alternative fuel sources available in these countries, such as kerosene and other fossil fuels, are often prohibitively expensive (Mintz et al, 1995). Furthermore, boiling and filtration do not provide disinfectant residual that can prevent the recontamination of stored household water.

The CDC and PAHO have identified several key characteristics for appropriate disinfectants for household use in developing countries. According to these guidelines, a suitable water disinfectant should fulfill the following criteria (Reiff, 1996):

- Complete inactivation of drinking water pathogens under conditions likely to encountered during the disinfection process
- Reasonably safe for household storage and use
- Adequate shelf-life to ensure effective disinfection potency is maintained
- Affordable for regular household use
- Provision of an adequate disinfection residual to prevent recontamination and ensure maintenance of a microbially safe water supply throughout expected storage periods

- Availability of an accurate, rapid, low-cost test for disinfectant residual, which can be performed by local users or household members
- Avoidance of the introduction or production of toxic substances, or the alteration of water characteristics so as to produce disinfected water that is unsuitable for human consumption or unacceptable to local populations.

Several disinfectants were considered for the SWS program including chlorine, mixed oxidant solutions, ozone, iodine, UV light, and commercial disinfectant tablets. Ultimately chlorine disinfectants, specifically locally generated sodium hypochlorite solutions, were identified as the most appropriate choice for household disinfection in the developing world. This disinfectant is safe, effective, and affordable. Under the normal disinfection conditions with a free chlorine residual of 0.5 mg/L or more and a contact time of at least 30 minutes, consistent with the chlorine dosage and contact time recommended by the SWS program, chlorine can provide reductions of over 99 percent in E.Coli contamination, and significant reduction in most other pathogens (WHO,1993). Chlorine can provide an effective disinfectant residual to prevent recontamination and this residual can be easily measured using simple detection tests.

Two options exist for obtaining sodium hypochlorite solutions for household water treatment. These solutions can be produced on-site using electrolysis cells that can produce disinfectant solutions from salt and water or they can be purchased from commercial manufacturers (Mintz, 2001). Commercially produced sodium hypochlorite disinfectants are less desirable because they may contain impurities or additives intended to improve laundering effectiveness that may be harmful if introduced to drinking water supplies. Dosing with commercial disinfectants can be challenging as concentrations vary from product to product as well as within product lines (Mintz, 1995). Local users may also be reluctant to use commercially manufactured disinfectant solutions for drinking water treatment because commercial bleach bottles often contain instructions for laundering clothes or cleaning sanitary facilities, purposes that are not associated with safe drinking water (CDC, 2001). For these reasons the CDC recommends on-site production of sodium hypochlorite solution. This can be accomplished through the use of a sodium hypochlorite generator, which uses grid electricity or solar power to electrolyze salt and water solutions to sodium hypochlorite. Several different models of sodium hypochlorite generators are available. Typical sizes can produce between 10 liters and 400 liters of disinfectant each day. One larger unit can meet the chlorination needs of up to 8000 households (CDC, 2001). These units generally cost between $2000 and $2500 each (Van Zyle, 2001).

Figure 3.1: Sodium Hypochlorite Generator in Kathmandu, Nepal (Morganti, 2002)

No one disinfectant can be universally suitable for household water treatment and sodium hypochlorite disinfectants do have some disadvantages. Chlorine disinfectants are not completely effective against all pathogens, particularly *cryptosporidium* cysts and helmith eggs (*Section 2.3*), and especially when used in low concentrations with short contact times, as is typical for household disinfection. Chlorine taste or odor, though minimal in properly treated water, can be unacceptable for some consumers. Finally, the use of chlorine disinfectants can result in the production of trihalomethanes (THMs) and other disinfection by-products (DPBs) that have recently been implicated in increased incidence of bladder cancer in the United States and other developed countries that have been practicing drinking water chlorination since the 19^{th} century (Melosi, 2000). As previously mentioned, the Safe Water System program founders recognize the risk of trihalomethane formation in chlorinated drinking water, but maintain that the small potential cancer risks from THMs and other disinfection byproducts are of little concern to populations in developing countries who suffer immediate and severe health risks from bacterially contaminated water supplies (*See Section 2.4*).

3.1.2 Safe Water Storage

Studies carried out through the CDC and other international agencies involved in waterborne disease research have revealed that bacterial contamination of household water supplies often occurs after water is collected because of unsafe water storage practices (Mintz, 1995). This contamination frequently occurs when human hands or household utensils are used to withdraw water from storage vessels or when vessels are left uncovered for long periods of time. These practices are common with many traditionally used water storage vessels, such as 55-gallon oil drums, clay pots, or open buckets. Household contamination of stored drinking water can be prevented through the use of appropriate water storage vessels. Safe water storage vessels are essential for household chlorination in order to prevent recontamination of disinfected water supplies. The CDC has identified several key characteristics of appropriate water storage vessels. According to these guidelines, a water storage vessel should meet the following criteria in order to be able to facilitate household water disinfection and prevent the contamination or recontamination of stored water (CDC, 2001):

- Suitable size, so as to provide adequate water volumes without being too heavy to lift and carry (~10 to 30 liters)
- Presence of handle to facilitate lifting and carrying and sturdy base to prevent overturning
- Durable material, resistant to impact and oxidation, easy to clean, lightweight
- Opening large enough to facilitate filling and cleaning but small enough to prevent the insertion of hands, cups, or household utensils to withdraw water
- Durable screw-on lid, preferably fastened to container with a cord or chain
- Durable spigot or spout for withdrawing water that can provide one liter of water in about 15 seconds
- Instructions for use and cleaning of the container, as well as instructions for water disinfection, permanently affixed to the container on material that does not deteriorate when wet

The CDC and PAHO have created a specially designed water storage vessel for SWS programs. The 20-liter plastic vessel has a narrow mouth, lid, and spigot. It is durable and lightweight, has an opening large enough to allow for cleaning, and its standard volume allows for simple uniform dosing. As of August 2000, the CDC vessel, or similar vessels designed by Oxfam or the Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS) were available in only 5 locations: South Africa, Bolivia, Ecuador, Peru, and the UK. Programs can import SWS vessels from one of these production facilities or can manufacture their own specially designed vessel. The major disadvantage of this second approach is the high cost of establishing a production facility. The three molds required to produce a vessel, lid, and spigot cost approximately $100,000 (CDC, 2001).

Figure 3.2: Specially Designed CDC Safe Water Systems Vessel (CDC, 2001)

An alternative approach to using a specially designed vessel is to promote the use of a locally available vessel that meets as many of the desired characteristics as possible. Locally available jerry cans or buckets can be used as storage vessels, but often lack certain desired characteristics such as tight fitting lids or spigots (Mintz, 1995). These issues may need to be addressed through education programs designed to insure that the vessels are used properly. If locally available vessels are chosen for a Safe Water System program, developers may also want to encourage households to use vessels of a specified volume to avoid confusion over chlorine dosage because of varying vessels sizes.

Only one storage vessel is needed for each household participating in a Safe Water System intervention, but the use of two suitable containers for each household may be preferable for several reasons. If two containers are available one container can be used for household water while disinfection is occurring in the other system. This will both increase the temperature of water in the vessels and increase the amount time that pathogens are exposed to disinfectant. Both of these factors can improve the efficiency of household disinfection. This procedure may also permit lower doses of chlorine, which will reduce chlorine taste and potentially lead to greater user acceptance (Reiff, 1996).

3.1.3 Behavior Modification

The introduction of household disinfection with sodium hypochlorite solution and the use of safe water storage vessels is a simple, low-cost means for safe water provision in the developing world. But the benefits of these "hardware" components of the Safe Water System approach will not be realized if households do not recognize that contaminated water and unsafe water storage practices can lead to poor health, or if they do not use the disinfectant or storage vessels properly. The final component of the Safe Water System approach is therefore designed to address these concerns through the use of behavior modification techniques to educate people about the causes of water contamination and the links between water contamination and disease, to encourage people to adopt household chlorination and safe water storage, and to ensure that disinfection and storage practices are followed properly.

Behavior modification programs can be conducted through several channels including interpersonal channels including door-to-door visits or teacher-student interactions, local media outlets including traditional musicians or public announcement by religious leaders or local leaders at community gathering, mass media outlets including radio, television, and films, or printed material including posters, brochures, or newsletters.

Figure 3.3: Potential Communication Channels for Behavior Modification Programs (CDC, 2001)

Interpersonal Channels	**Local Media**	**Mass Media**	**Printed Materials**
- Community Meeting	- Drama	- Radio	- Posters
- Door-to-Door Visits	- Traditional Musicians	- Television	- Brochures
- Health Workers/Client Interactions	- Public Announcements by Local Leaders	- Video Films	- Labels on Vessels or Disinfectant
- Shopkeeper/Customer Interactions	- Storytelling	- Cassettes	- Leaflets
- Teacher/Student Interactions	- Puppet Shows		- Newspapers
			- Newsletters

Messages included in behavior modification programs can pertain to waterborne disease prevention, to the use of the Safe Water System specifically, or to other behavioral changes outside of the Safe Water System components that can reduce waterborne disease. Some examples of messages that might be included in a behavior modification campaign:

Pathogens that cause waterborne disease are present in feces. These pathogens are ingested when a person drinks contaminated water.

Pathogens are too small to see, so water that appears very clear may still be contaminated.

You can prevent diarrhea and other waterborne diseases by using the Safe Water System.

Always treat water before drinking it, or using it to wash or prepare food.

Clean your storage vessel once a week, and never allow anyone to put his or her hands or utensils into the vessel.

Store disinfectant indoors in a cool dark place, safely away from children.

It is important to consider the intended target audience when developing messages for behavior modification programs, and tailor both messages and communication channels to properly reach these audiences. Important groups to target include individuals who perform household water collection and storage, individuals who make decisions about household purchases, mothers of young children, and community leaders who may be able to influence the behaviors of others in their communities (CDC, 2001).

Figure 3.4: Educational Materials from a Safe Water System program (CDC, 2001)

3.2 Safe Water System Programs

Between January 1996 and November 2000, Safe Water System programs were developed and implemented in 14 countries in Latin American, Africa, Asia, and Eastern Europe: Guatemala, Nicaragua, Bolivia, Ecuador, Peru, Cote d'Ivoire, Guinea-Bissau, Kenya, Madagascar, Malawi, Uganda, Zambia, Pakistan, and Uzbekistan.

3.2.1 Case Studies

Guatemala

Beginning in June 1996, the Safe Water System approach was used in Guatemala City to improve the microbial quality of street-vended beverages. Street-vended food and beverages have been implicated in the transmission of cholera in Latin America, yet they remain a vital part of urban economics in the developing world and are often the only affordable source of food and beverage for urban workers (Sobel, 1998). Street venders in Guatemala City routinely store water for long periods of time because they do not have access to a continuous supply while conducting business during the day. Street venders also lack access to adequate facilities for sanitation or handwashing, further exacerbating problems of bacterial contamination in vended food and beverages. A baseline survey conducted in Guatemala City found that over 30 percent of stored water and 60 percent of vended beverages tested positive for fecal coliform bacteria. After the Safe Water System intervention, which consisted of three 5-gallon narrow mouthed plastic vessels with spigots, dilute bleach disinfectant solution, and handwashing soap, significant reductions in both total coliform and fecal coliform bacteria were observed in both stored water and sold beverages of the 41 intervention venders when compared to control venders (Sobel, 1998).

Figure 3.5: Three-Vessel System Used in Guatemalan Street Vender Intervention (CDC, 2001)

Cote d'Ivoire

Beginning in April 1999, the Safe Water System approach was introduced in Abidjan, Cote d'Ivoire to provide microbially safe water for the preparation of infant formula by HIV-positive mothers. Municipal water supplies in Abidjan are treated and adequate free chlorine residuals are present in piped water supplies but because public taps are often unreliable or located far from homes, households typically store water for use throughout the day (Dune, 2001). An evaluation of free chlorine residuals in stored water revealed levels significantly below those present in municipal water, less the 0.05 mg/L versus 0.2 mg/L. Eighty-four percent of households surveyed reported dipping a cup in the storage vessel opening in order to withdraw water (Dune, 2001). These practices lead to bacterial contamination of stored water supplies. This is of considerable concern when stored water is used in the preparation of infant formula. Although infant formula represents an effective means of reducing mother-to-child HIV transmission, it has been associated with higher rates of child mortality due to waterborne disease. Infant formula is often prepared with contaminated water and the low acid and high nutrient content of the formula itself provides a growth medium for pathogenic bacteria, especially when kept un-refrigerated in tropical climates (Dune, 2001). The Safe Water System program in Abidjan began with the distribution of storage vessels through the health clinic treating HIV-positive mothers. It was initially believed that safe water storage, without the use of sodium hypochlorite disinfectants, could restore proper free chlorine residuals and prevent recontamination in stored water, but this approach has not been effective in eliminating contamination and program developers are now investigating the feasibility of the addition of disinfectant to maintain proper free chlorine residuals (CDC, 2001).

Ecuador

Beginning in January 1998, the Safe Water System program was used to provide safe water for households in several provinces of Ecuador that had been affected by El Nino. Approximately 200,000 individuals in Guayas, El Oro, Los Rios, Manabi, and Galapagos Provinces benefited from the program. The project was developed in collaboration between the government of Ecuador and several independent organization including the Pan American Health Organization. It incorporated the use of twenty-four existing but under-utilized sodium hypochlorite generators and established over 200 sodium hypochlorite distribution centers in both Ministry of Health Facilities and in private homes of health educators and volunteers. Disinfection and storage was completed in locally produced 20-liter plastic containers with spigots for dispensing. The project appears to have been successful, with no detectable fecal coliform colonies found in over 50% of sampled household water. The government of Ecuador has welcomed the program with the creation of a "National Program of Water Disinfection at the Household Level," administered by the Ministry of Health (CDC, 2002).

3.2.2 Comparison of Key Components of SWS Implementation Programs

This comparison examines a few selected components of Safe Water System programs to gain an understanding of how successful implementation programs can vary their approach. The components highlighted here include target populations, funding, disinfectant manufacturing process, and brand-name marketing. Other components of Safe Water System programs that typically vary from program to program include local government or NGO involvement, behavior modification techniques, incorporation of schools or children, involvement of women, established monitoring programs, and levels of cost-recovery. These components can be explored further through the CDC's website (www.cdc.gov/safewater), or through the Safe Water Systems Manual.

Target Populations

The CDC identifies several groups that the Safe Water System approach was designed to target. These include (CDC, 2001):

- Populations that depend on surface water sources such as lakes, rivers, or streams.
- Populations that rely on shallow groundwater wells, particularly open wells.
- Populations served by piped systems with inadequate water treatment or intermittent flow.
- Population that store water in households for long periods of time due to distant sources or intermittent availability.
- Populations that depend on water vendors who lack safe water sources or use contaminated storage tanks.
- Populations that practice unhygienic water collection and storage behaviors, specifically water storage in wide-mouth containers.

The groups targeted by actual SWS programs have included both urban and rural populations, populations with access to piped municipal water, populations dependent on surface water sources, populations affected by floods, cyclones, or El Nino weather patterns, households with children under 5, street venders that serve both food and beverage in urban areas, hospitals that use bulk oral rehydration solutions, HIV-positive mothers preparing formula for infants, and populations living in low-income squatter settlements or refugee camps.

Target audiences for education and promotion may differ slightly from the intervention target population because these messages may be designed to reach a specific subset of the target population, such as young mothers or schoolchildren. It may also be valuable to identify and target influential individuals, such as community leaders and educators, who can in turn help educational and promotional messages reach the target audience. The CDC suggests that the following subgroups be targeted when designing educational and promotional materials for a SWS intervention:

- Individuals that make decisions about household purchases, water treatment, and water storage.
- Households with young children.
- Community leaders, formal or informal, who can influence community-wide behavior change.
- Groups that are typically not targeted, such as men, but who can divert household resources to other uses.

Funding

Funding for Safe Water System Programs can vary widely depending on the level of implementation planned. Small programs that make use of commercially available disinfectant and storage vessels and incorporate grassroots education and promotion schemes can be constructed with minimal funding. Larger programs that involve sodium hypochlorite generation, specialized vessel production, complex social marketing programs and education campaigns can require hundreds of thousands of dollars in financial support. The majority of SWS programs supported by the CDC take this second route. For example, the social marketing portion alone of a project conducted in Madagascar in April 2000 cost almost $200,000 (CDC, 2001). A commercial sodium hypochlorite generator can cost between $2000 and $3000 (Van Zyle, 2001). Molds for specialized vessels can also be expensive. The cost of molds to produce a vessel, spigot, and lid for a SWS program are estimated at $100,000. Molds to make a small bottle of disinfection solution in Bolivia cost $8000 (CDC, 2001).

This level of expenditures requires substantial funding, usually from donor agencies. Donors that have provided financial or material support for Safe Water System programs include United Nations agencies, such as the Pan American Health Organization (PAHO), government agencies such as the CDC itself or USAID, non-governmental organizations such Population Services International, Rotary International, and Cooperation for Assistance and Relief Everywhere (CARE), and private sector companies such as Coca-cola, Exceltech International, and Millipore.

Many of the SWS projects to date have relied on funding donations from a combination of sources. The CDC’s SWS manual suggests soliciting donations from organizations with potential interests in specific aspects of a SWS program. In Bolivia for example, Proctor and Gamble and Rotary International purchased a mold for the vessel, Exceltech International donated a sodium hypochlorite generator, USAID provided money for project implementation, and local NGOs and Bolivian municipalities subsidized distribution costs and provided some health and education workers for the program (CDC, 2001).

Another option for funding involves the use of sponsorship and advertisement. Some companies may being willing to fund vessels or disinfectant solution in exchange for the placement of their logo on storage vessels or disinfectant bottles.

Disinfectant

Although the CDC recommends the use of locally generated sodium hypochlorite solution for the disinfectant component of Safe Water System programs, not all programs have used sodium hypochlorite solutions. Alternative solutions are typically used when the installation of a sodium hypochlorite generator is too costly or not technically feasible in the project area. Alternative disinfectants used in Safe Water System programs include commercially produced sodium hypochlorite solutions and commercially or locally produced calcium hypochlorite solutions. Some programs, such as the Cote d'Ivoire program highlighted in the previous section, have chosen to supply only storage vessels, not disinfectant, with the hope of maintaining free chlorine residual levels already present in the municipal water supply (Dune, 2001).

Of the fourteen studies evaluated for this research, seven (50 percent) used a locally generated sodium hypochlorite solution for disinfectant, five (36 percent) used a commercially generated sodium hypochlorite solution, and two (14 percent) did not use a disinfectant solution. None of the programs evaluated used a calcium hypochlorite disinfectant, locally or commercially produced.

Figure 3.6: Locally Manufactured Sodium Hypochlorite Solutions (CDC, 2001)

Most projects that have used locally manufactured sodium hypochlorite solutions have relied on donations to obtain the sodium hypochlorite generator, and have sold disinfectant at a price that recovers only the operation and maintenance costs of running the generator, typically $0.10 to $0.20 for a one month supply for a household of six (CDC, 2001). The project in Ecuador, highlighted in the previous section, made use of under-utilized sodium hypochlorite generators already present in the country.

Disinfectant Brand Name, Logo, and Marketing

Figure 3.7: Sur 'Eau and Clorin Disinfectant Logos (CDC, 2001)

Many Safe Water System programs have placed a considerable emphasis on product promotion programs. The programs have included the use of catchy brand names, or logos for disinfection solutions, mascots, and promotional materials such as T-shirts or drinking glasses. Brand names have been used in Bolivia, Kenya, Madagascar, and Zambia, and include names such as Claro, Clorin, Klorin, or Sur 'Eau. These brand names and their associated logos are useful for improving product identification, and increasing perceptions of quality among target groups. If brand names are used, they should be both simple and representative of health or purified water in target populations. Similarly logos that accompany these brand names should be simple, easy to understand, and should symbolize the key benefits of a Safe Water System program.

CHAPTER 4 SAFE WATER SYSTEMS IN NEPAL: THE LUMBINI PILOT STUDY OF HOUSEHOLD CHLORINATION

The MIT-Nepal Water Project has been investigating water quality and evaluating options for household water treatment in Nepal since 1999. Over this time, twenty MIT Master's of Engineering Students have traveled to Nepal to study topics ranging from nitrate contamination in Kathmandu, to arsenic removal processes in Nawalparasi. By January of 2002, MIT students had investigated almost a dozen options for household water treatment, including various methods of household filtration, solar disinfection (SODIS), and coagulation. But large-scale field tests to determine how these technologies would perform in specific local settings and how they would be accepted by local villagers in Nepal had not been conducted.

Social acceptability of water treatment technologies, though always a key component of the MIT-Nepal Water Project's mission, was brought to the forefront of the project's vision with Nathaniel Paynters 2001 thesis, "Household Water Use and Treatment Practices in Rural Nepal." Paynter and Tse Luen Lee, another MIT Master of Engineering student, traveled to 42 households in Nepal that were practicing household water treatment using Biosand Water Filters (BSF), a simple household filter designed in 1988 by Dr. David Manz of the University of Calgary, Canada (Manz, 1998). The purpose of Paynter's work was to assess the appropriateness of the BSF in Nepal. This work represented the first attempt by the MIT-Nepal Water Project to evaluate the effectiveness of an emerging household water treatment program.

As fieldwork was reaching a close in Nepal during January of 2001, the MIT-Nepal Water Project made the decision to establish its own household water treatment program. Lumbini, a rural community in the Terai region of Nepal, was chosen as the location for this program. The MIT-Nepal water project had previously conducted field tests of several household water treatment technologies in Lumbini and the time had come to attempt to implement some of the household water treatment technologies that have been identified by the MIT Nepal Water Project over these two years of field and laboratory research. Project leaders felt that there was a need not only to test the social acceptability and household practicability of some of these technologies, but also to begin to provide safe water and give something back to the people of Nepal that had hosted the project for two years, waiting patiently for solutions.

The CDC's Safe Water System Program was chosen as a model for this pilot treatment program, because it represented a proven technology for household water treatment and had been successfully implemented in other regions of the developing world. Prior to the Lumbini Pilot Study, household water chlorination had not been explored in Nepal due to the lack of availability of an appropriate chlorine solution, and due to concerns about the social acceptability of household water chlorination. This changed in 2000 when a local NGO based in Kathmandu, Environmental Public Health Organization (ENPHO), began to manufacture a dilute calcium hypochlorite solution (0.5%) for household water disinfection using bleaching powder imported from India. With the creation of this disinfection solution, now marketed under the brand-name Piyush, household chlorination became a viable option for water treatment in Nepal, but questions remained about the social acceptability of household chlorination and the willingness to consume chlorinated water. At the time that the pilot study was established, Piyush was marketed only in urban Kathmandu and would not be available to rural villagers in Lumbini without the introduction of a distribution system specifically designed to reach them. Ultimately, the Lumbini Pilot Study of Household Chlorination was designed to bring Piyush to Lumbini and provide safe drinking water to a portion of the population, and to test the acceptability of household drinking water chlorination in Nepal.

4.1 Study Area

The CDC suggests that the location of a Safe Water Systems pilot study be selected based on the following criteria (CDC, 2001):

- A need for safe water in homes evidenced by waterborne disease or observed unsafe water handling and storage practices.
- Presence of community leaders that recognize drinking water safety as a major concern.
- Existence of government or NGO structures to build on, in order to make programs more sustainable in the long-term
- Interest in pilot study participation from the local population and presence of motivated individuals willing to assist with preparatory work.
- Presence of a functioning neighborhood organization with active and effective health promoters.
- Feasibility of a pilot project, including funding, qualified staff and an appropriate number of households that can be reached with disinfectant solution and storage vessels.
- Cooperation of local authorities that can give permission to implement the pilot project.

Based on these criteria, Lumbini was an ideal location for the MIT-Nepal Project's initial pilot study attempt. Previous field studies in Lumbini have identified problems of bacterial contamination in village water sources and health surveys in the region have revealed significant incidences of waterborne disease among the local population (Moulton, 1999; Smith 2001; IBS 2002). Villagers in Lumbini are concerned about water quality and have shown interest in water treatment programs. A demonstration of solar disinfection (SODIS) technology conducted in 1999 by Peter Moulton of the Global Resource Institute (GRI) drew over 100 participants (Moulton, 1999). The International Buddhist Society (IBS), an organization in Lumbini that focuses on rural development, has hosted MIT-Nepal Water Project students during January fieldwork since 2000, and has been committed to safe water provision in Lumbini since 1996. IBS partnered with the MIT-Nepal Project to design and implement the pilot study and this ensured that the program could continue throughout the year in MIT's absence.

4.1.1 Lumbini, Nepal

Figure 4.1: Map of Nepal Showing Location of Lumbini

Lumbini, Nepal is located less than 10km from the Indian border in the Terai region of Nepal. Lumbini is widely recognized as the birthplace of the Buddha and is therefore a religiously significant area for many of the world's people. In recent years this religious significance has lead to substantial development in Lumbini. A development plan created in 1978 divides the three square miles of land surrounding the birthplace into several development zones, including a Sacred Garden comprising the birthplace itself and a monastic zone that sets aside space for monasteries from participating countries (Kathmandu Post, 2001). Several of these structures are already complete, including monasteries, pagodas, stupas, and other Buddhist architectural structures from Tibet, China, Thailand, Sri Lanka, Burma, Japan and Germany.

In spite of the religious development that has occurred in the Lumbini region over the last decade, the local villagers of Lumbini remain impoverished. Over 90 percent of villagers in the region are entirely dependant upon agriculture (Panday, 2001) and the availability of basic services is limited. The electrical grid has been extended to the area, but power supply is intermittent and very few villagers are connected. Piped water supplies are nonexistent and sanitation facilities are extremely limited. Water sources available to villagers include open water sources, dug wells, and tubewells. The majority of villagers draw their drinking water from tubewells which range from shallow private tubewells usually under 45 feet in depth, to public tubewells installed by local NGOs and government programs that typically reach depths of over 150 feet. Well testing conducted in 1999 and 2001 revealed that between 30 and 75 percent of these wells show signs of bacterial contamination (Moulton, 1999; Smith, 2001).

The International Buddhist Society conducts a quarterly health survey in the region during March, June, September, and December of each year. These studies have revealed that waterborne disease affects a large percentage of the Lumbini population. At any given time during the dry season, 5-10 percent of the population suffer from various diarrheal diseases, and 15-20 percent of the population suffer from amoebiosis (IBS, 2002). These numbers increase significantly during the monsoon season (Mallick, 2002).

4.1.2 The International Buddhist Society (IBS)

Figure 4.2: The International Buddhist Society, Lumbini

The International Buddhist Society (IBS) was established in August of 1993 by Bhikkhu Maitri, a Buddhist monk who was born in Nepal and educated in Sri Lanka. Its accompanying medical clinic, headed by Dr. Narendra Kumar Mallik, was opened in September 1993 with a mission of providing free medical treatment to villagers in the Lumbini area (IBS, 1998). Since its opening, the health clinic has served almost 200,000 patients, offering health screenings, vaccinations, acupuncture and health education services (IBS, 2001). IBS has been involved in safe drinking water provision since 1996, when visiting foreign physicians at the health clinic expressed concern about the prevalence of waterborne disease in Lumbini. Generous donations by Dr. Daniel Moncondiut of Tahiti, France, now an IBS honorary committee member, lead to the installation of handpumps in 6 villages in Lumbini (Maitri, 2002). The program has since been expanded to include 17 villages in the Lumbini area. Over the last 5 years, 44 wells have been installed at depths of 170 to 350 feet and 14 additional wells are currently under construction (IBS, 2002). A new sanitation initiative began in 2002 with the installation of 472 meters of drainage channels in Sonbarshi village. An additional 1450 meters of drainage channels in 12 different villages were under construction in January 2002 (IBS, 2002), and materials for the construction of 7 latrines have been provided to selected IBS villages (IBS, 2001)

Since 1999 IBS has worked with Cross Flow Nepal Trust, a local NGO dedicated to health education and safe drinking water provision in the Lumbini area (IBS, 2002). With the assistance of Cross Flow Nepal Trust, IBS has hired 7 women motivators to conduct health education in the 17 villages that IBS serves and to assist in the IBS Health Clinic. Applicants for these positions were solicited through advertisements in local and national newspapers and the selection process for each position was highly selective. The motivators currently employed by IBS were selected based on an extensive interview process that involved both a written examination and a verbal interview with IBS staff. Motivators were ultimately selected based on their knowledge of health and sanitation practices and their motivational and educational skills (Maitri, 2002).

Figure 4.3: The IBS Women Motivators

The current IBS motivators are primarily in their early to mid twenties. They possess secondary school educations and therefore represent a highly educated segment of the female population in Nepal. Only 60 percent of girls in Nepal currently attend primary school, and significantly fewer move on to secondary educations (UNDP, 2002). All of the motivators are fluent in Nepali, and several command at least a rudimentary knowledge of English, as well as familiarity with several of the local dialects spoken in Lumbini. Most of them commute by bus to Lumbini from the nearby city of Bhairawa, a ride that typically lasts one hour or more. These women are each assigned to 2 or 3 villages and spend 3 or 4 days a week traveling to their assigned villages to work with village leaders and conduct health and sanitation education programs. They spend the remainder of their time assisting the doctor and lab technicians in the IBS health clinic. Here they perform administrative duties for the CrossFlow Nepal Trust Coordinators, assist the doctor with patient visits and run health education programs for local villagers in the clinics meeting room. The IBS motivators were an essential component of the Lumbini Chlorination Pilot Study. They assisted with the distribution of storage vessels and disinfectant, educated villagers about the proper use of the chlorination systems, collected household water samples for bacterial analysis, and conducted surveys to determine the incidence of waterborne disease among study participants.

4.2 The Lumbini Pilot Study of Household Chlorination

The pilot study in Lumbini was designed by Susan Murcott, a Lecturer in the Master of Engineering Program at Massachusetts Institute of Technology who founded the MIT Nepal Water Project in 1999 and Lee Hersh, a retired chemist from the Corning Corporation who has been involved in the program since its inception. Murcott and Hersh worked closely with Bhikkhu Maitri and Dr. Mallick of the International Buddhist Society to establish a program that could be run by IBS after their departure.

4.2.1 Participants

All of the participants selected for the pilot study were drawn from the 17 villages currently served by IBS. The pilot study design called for the inclusion of an intervention group consisting of 50 families and 10 schools that would receive the chlorine solution and a modified bucket system for household water storage practices and a control group consisting of 50 families and 10 schools that would continue with their traditional water collection and storage practices. All of the households selected for the study were to have been drawing water from tubewells that were known to be contaminated.

4.2.2 Storage Vessel

Households participating in the intervention group were provided with one of two water storage vessel systems created using 10 and 20-liter plastic buckets that are widely available throughout Nepal. The original chlorination system design used in Lumbini incorporated both filtration and disinfection to provide more complete pathogen removal. The two-level system included a filtration unit constructed from a 20-liter plastic bucket and two locally manufactured ceramic candle filters that drained into a 10-liter plastic bucket. Chlorination would occur in the top bucket and water would pass through the candle filter to the bottom bucket where it could be withdrawn via a plastic spigot (*Figure 4.4*).

Figure 4.4: Modified-Bucket Chlorination System, with Candle Filter

This initial design was modified within a few weeks of the pilot project installation because of concerns about the social acceptability of the slow flow rate of the candle filter*. If these initial systems were rejected by villagers in the pilot study, it would be difficult to determine if this was due to the taste of chlorinated water, one of the major concerns about household chlorination in Nepal, or due to the slow flow rate of the candle filters. In order to address this concern, the design of the chlorination system was simplified, removing the candle filter from the 20-liter bucket and replacing the filtration step with a settling procedure to remove turbidity and larger contaminants. Study participants were instructed to use the 20-liter bucket as a water collection device, allow the collected water to settle for several hours and pour it into the 10-liter bucket leaving a small layer of turbid water at the bottom of the 20-liter bucket. Chlorine was then added directly to the 10-liter bucket, which is equipped with a spigot for safe dispensing of water and a secure lid to prevent recontamination. The majority of study group households received this simplified bucket system.

4.2.3 Disinfectant

At the time of the establishment of the Lumbini Pilot Study, sodium hypochlorite solutions were not commercially available in Nepal. Bleaching powder imported from India was the only accessible form of chlorine disinfectant for people in Nepal but was not generally available in local marketplaces. Fortunately a local NGO based in Kathmandu, Environmental Public Health Organization (ENPHO) had begun to manufacture a dilute calcium hypochlorite disinfection solution (0.5%) using this bleaching powder. This solution, which ENPHO has marketed under the name Piyush since September 1998, is sold through a distributor in Kathmandu and is available in Kathmandu pharmaceutical stores in 60ml bottles for NRs12 to NRs 17 (US$0.16 to US$0.23)**. The retail cost set at NRs 17 but many retailers are willing to offer substantial discounts as the distributor sells the solution to retailers for NRs10 per bottle (Morganti, 2002).

Figure 4.5: Piyush Disinfectant Solution

* The flow rate of these ceramic filters is only 0.3 L/hr (Smith, 2001).
** January 2002 Exchange Rate US$1.00 = NRs 75

A year's supply of Piyush was purchased from ENPHO and brought to the IBS health clinic in two lots. The first delivery occurred in January 2001 and the second occurred midway though the pilot study. Households in the pilot study sample group received an initial supply of Piyush from the IBS health clinic. When they needed additional disinfectant they could pick it up from the health clinic or obtain it from the women motivators during village visits. The Piyush solution was provided to these households free of charge and Dr. Mallick and the motivators kept detailed records of the number of bottles of Piyush each participating household received.

4.2.4 Instructions

Households where instructed on the proper use of the chlorine disinfectant at the onset of the program. Households were told to use 3 drops of Piyush solution for each liter of water to be treated. They were instructed to put 30 drops of Piyush in the 10-liter bucket or 60 drops of Piyush in the 20-liter bucket, depending on the vessel system they were using, and wait at least 30 minutes before consuming the chlorinated water. They were told to keep the lid of the bucket secure and draw water only via the attached spigot. They were also instructed to clean each of their plastic buckets regularly with soap and water. The women motivators reinforced these instructions regularly and checked on all program participants during their village visits to ensure that Piyush solution and storage vessels continued to be used properly.

4.3 Ongoing Pilot Study Monitoring

In an effort to ensure continuous monitoring of the Lumbini Pilot Study, a plan for periodic program evaluation and reporting was developed. The major components of this monitoring plan were biweekly water testing, and bimonthly program reports. Because the MIT-Nepal water project visits Lumbini only once yearly during MIT's January term, this monitoring program was the responsibility of IBS staff members. The IBS women motivators were an essential component of the monitoring program. The motivators participated in the collection of water samples for biweekly testing, and surveyed study participants during village visits in order to collect health data that would assist the IBS health clinic doctor with the preparation of the bimonthly program reports.

4.3.1 Water Quality Testing

Biweekly water testing was conducted by IBS staff using IDRC H_2S bacterial tests. These tests detect the presence of hydrogen sulfide producing bacteria including *Salmonella, Citrobacter, Proteus, Edwardsiella and Klebsiella* (HACH, 1997). These organisms are indicator organisms whose presence has been shown to be associated with the fecal contamination of water supplies (Manya, 1982; Kromoredjo, 1991; Grant, 1996). US and international water quality standards typically require the use of enumeration tests for E.Coli and Total Coliform contamination (WHO, 1993) but these tests would not be feasible for IBS staff to conduct because of the absence of lab facilities and appropriate equipment. The H_2S test was selected as an alternative monitoring test because it is simple to perform and interpret and does not require complex facilities for sterilization or incubation. This test is discussed in more detail in Chapter 5.

4.3.2 Health Surveying

The major component of the bi-monthly reports prepared by Dr. Mallick and the motivators was a numerical assessment of the prevalence of waterborne disease among households participating in this study. The health-monitoring program was designed with the assistance of Dr. Mallick and its ultimate objective was to quantify the health effects of household chlorination in Lumbini. Based on his clinical experience, Dr. Mallick selected several common waterborne diseases that affect rural villagers in Lumbini to monitor among pilot study participants. These included abdominal pain, diarrhea and amoebiosis. Pilot study participants were surveyed monthly during home visits by the women motivators. During these visits, motivators recorded the self-reported incidence of each of these common waterborne diseases and reported these numbers to Dr. Mallick, who then compiled them into the bimonthly reports.

4.4 Identified Criteria for Success

At the onset of the Lumbini Pilot Study, several key criteria for program success were identified. The pilot study developers felt that a successful program of household chlorination in Lumbini would result in significant reductions in the incidence of waterborne disease among sample group participants, elimination or reduction of microbial contamination in stored water at sample group households, and high rates of user acceptance of household chlorination.

An effort was made to introduce simple numerical indicators that would allow program evaluators to determine if the pilot study was successful in meeting its stated objectives. Ultimately three measurable indicators of success were identified for this purpose:

(1) Greater than 30 percent reduction in waterborne disease among sample group participants

(2) Less than 10 percent of chlorinated stored water in sample group households testing positive for bacterial contamination

(3) Less than 10 percent of sample group participants reporting complaints about chlorine taste, resulting in non-treatment of drinking water.

4.5 January 2002 Household Chlorination Pilot Study Evaluation

The Lumbini Pilot Study was designed to test the acceptability of household water chlorination in one community in Nepal, prior to proceeding with large-scale implementation of household chlorination. The primary purpose of this pilot study was to determine if household chlorination based on the CDC's Safe Water System Program is an appropriate approach for household water treatment and safe water provision in Nepal.

Pilot studies allow researchers to develop and test new approaches to water provision, through small-scale implementation projects that simultaneously benefit participating communities (World Bank, 1999). Pilot studies are not designed as long-term programs; they are intended to be exploratory in nature. They should be structured to assist developers in designing successful large-scale program programs. For its water and sanitation programs, the World Bank [1999] requires that "the credible prospect of large-scale replication" be present, before a pilot project is undertaken. Now that the Lumbini Pilot Study has been in place for the intended year-long period it is essential that a thorough evaluation of the program occurs in order to fulfill the objectives of a sound pilot study and make decisions on how to proceed with household chlorination in Nepal. The decision that needs to be made in this case is whether to expand the pilot study to reach additional villagers in the Lumbini area and throughout Nepal or to discontinue the program of household chlorination.

The Lumbini Pilot Study was revisited in January 2002 by members of the MIT-Nepal Water Project team in order to complete a thorough field investigation and make recommendations for the expansion or discontinuation of household chlorination in Lumbini. This field evaluation took place in five stages:

(1) A complete well survey was conducted in Lumbini to evaluate the prevalence of microbial contamination in this region of Nepal as well as to observe the water handling and storage practices of Lumbini villagers.

(2) IBS records of the on-going pilot study monitoring, including health survey data and microbial testing results, were compiled and reviewed to evaluate the effects of households chlorination in Lumbini.

(3) Water samples were collected from households participating in the Lumbini Pilot Study. Samples were analyzed for free chlorine residuals and bacterial contamination, to determine if chlorination was being properly conducted in these households.

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(4) Dosage testing was conducted at IBS to determine if the recommended dose of chlorine disinfectant is sufficient to treat Lumbini tubewell water.

(5) A household survey was conducted to observe household water storage and chlorination practices, to evaluate the social acceptability of household chlorination in Lumbini, to determine if villages perceived any changes in their health due to the chlorination project and to assess the willingness of Lumbini residents to pay for chlorine disinfectant and storage vessels.

The results of the well survey, as well as a discussion of microbial testing in the field, are discussed in Chapter 5. The review of ongoing monitoring, household water sampling, dosage testing, and household survey results are all presented in Chapter 6. Other key components of the Lumbini Pilot study including the inclusion of women and schools are examined more thoroughly in Chapter 7.

If the pilot study is deemed successful, based on the community acceptance, bacterial contamination reduction and health improvement criteria outlined in Section 4.4, the logical response is program expansion. But this expansion can only occur with substantial forethought and planning. The chlorination pilot study in Lumbini required an input of financial support from outside donors and was run largely as a charitable program through IBS. An expanded project will require additional planning, participation and cost-recovery components in order to ensure its sustainability. This expansion process is discussed in detail in Chapter 9.

CHAPTER 5 MICROBIAL WATER QUALITY ASSESSMENT IN LUMBINI, JANUARY 2002

Between January 8, 2002 and January 20, 2002 a complete well survey was conducted in Lumbini to evaluate the prevalence of microbial contamination in this region of Nepal as well as to observe the water handling and storage practices of Lumbini villagers.

The January 2002 well survey represents the most rigorous survey of tubewell water quality conducted in Lumbini to date. During the two weeks of the well survey, all 17 villages currently served by IBS were visited and all IBS installed wells, as well as several privately installed and operated wells, were tested for bacterial contamination using both H_2S presence/absence tests and fecal coliform enumeration tests. This water quality analysis was accompanied by a preliminary sanitary survey designed to identify potential sources of tubewell contamination and waterborne disease in Lumbini.

5.1 Indicator Organisms and Microbial Testing

5.1.1 Indicator Organisms

Direct testing for bacterial pathogens can be extremely difficult and often involves lengthy and potentially hazardous testing procedures. Because of this, indicator organisms are often used to detect the possible presence of bacterial contamination in water supplies. Indicator organisms are not necessarily pathogenic, rather they are bacterial organisms that are generally present when pathogens are present, and generally absent when pathogens are absent (HACH, 1997). Key characteristic of indicator organisms identified by the World Health Organization include (WHO, 1993):

- Universal presence in high numbers in the faeces of humans and warm-blooded animals
- Readily detected by simple methods
- Unable to multiply in natural waters
- Persistence in natural waters and extent of removal in treated waters similar to those of waterborne pathogens.

Several different options are available for use as indicators of pathogenic organisms. The MIT-Nepal Water Project team has selected total coliforms, fecal coliforms, Escherichia coli (E. coli), and hydrogen sulfide (H_2S) bacteria for use as indicator organisms during field-testing in Nepal.

5.1.2 Microbial Testing in Lumbini

Between January 8 and January 18, 2002, 109 water samples were collected from various sources in Lumbini and analyzed for microbial contamination at IBS. The majority of these samples were collected from IBS installed tubewells, but samples were also collected from public open wells, private tubewells, Biosand Filtration units and chlorinated household water supplies. Samples were collected each morning, during visits to the 17 IBS villages, packed in sodium thiosulfate whirl-pack bags, and kept in coolers until they were analyzed. Sample analysis took place in a room behind IBS, that has be set aside for water quality analysis and clinical testing. All of the equipment used for bacterial analysis was brought to the field by the MIT-Nepal Water Project team.

Several tests were used to detect the presence of microbial contamination in the water samples collected in Lumbini. Two presence/absence tests for hydrogen sulfide producing bacteria were used including a 20-ml HACH PathoScreen™ medium test and a 10-ml International Development Research Centre (IDRC) H_2S test. Membrane Filtration enumeration testing were performed for both fecal coliforms and E. coli. More information on the HACH PathoScreen™ test and the membrane filtration tests are available at the HACH website (www.hach.com). The IDRC test is similar to the HACH H_2S test but is designed as a low-cost alternative for testing in developing countries and is prepared in the lab from basic reagents. The procedure for preparing the lab-made IDRC H_2S test is given in Appendix A.

Not all samples were analyzed using all 4 tests. Of the 109 samples collected from 88 wells, 7 chlorination systems and 9 Biosand filters over the 10 days, 107 were analyzed using the IDRC H_2S presence/absence test, 60 were analyzed using the HACH H_2S presence/absence test, 23 were analyzed using the E. coli Membrane Filtration test, and 67 were analyzed using the Fecal Coliform Membrane Filtration test.

Total Number of Samples	109
Analyzed w/ IDRC H_2S P/A Test	107 (98%)
Analyzed w/ HACH H_2S P/A Test	60 (55%)
Analyzed w/ E coli MF Test	23 (21%)
Analyzed w/ Fecal Coliform MF Test	67 (61%)

Table 5.1: Microbial Test Conducted in Lumbini, January 2002

5.1.3 H_2S Bacterial Tests and Incubation Requirements

The IDRC and other international organizations have promoted the use of H_2S tests in tropical countries. Studies carried out through the IDRC have shown that the H_2S test is one of the simplest, most reliable, and least expensive methods for bacterial testing in these regions (Jangi, 1997). One of the major advantages of these tests is that they do not require incubation in tropical climates. Previous work in Nepal has made use of simple, inexpensive field incubators created by Amy Smith from the Mechanical Engineering department at MIT. These incubators contain a chemical substance that undergoes a phase-change reaction, from a solid wax to liquid wax at 35 degrees Celsius, allowing for incubation of microbial tests. They are heated in boiling water until the phase-change occurs and will remain at the proper incubation temperature for over twenty-four hours if well insulated. The Amy Smith incubators were used because it was assumed that winter temperatures in Nepal would be too cold for proper tests results without incubation, but heating these incubators can be time consuming, and incubator space constraints limit the number of samples that can be collected and tested each day, especially when 72 hours of incubation is desired. In Lumbini, five Amy Smith incubators were used and they often required up to four hours of boiling time to prepare. This was not only time-consuming, but also wasteful in a region of the world already strapped for energy resources.

During the January 2002 well survey, tests were conducted in Lumbini to determine if incubation of the IDRC H_2S tests was necessary. To complete this evaluation 49 duplicates were prepared using the IDRC tests. One sample was incubated for 72 hours using the Amy Smith incubator, another was left on a laboratory bench for 72 hours under ambient temperatures ranging from 5 to 25 degrees Celsius. The correlation between these sets of tests was 84 percent and non-incubated samples were only slightly less likely to yield negative results than incubated samples, 45 percent positive among non-incubated samples versus 48 percent positive among incubated samples. These tests were conducted during the coldest part of the year in Lumbini and correlations should be even higher during the summer months in Lumbini when ambient temperatures are closer to the recommended incubation temperature of 35 degrees Celsius. These results indicate that incubation is not necessary in Lumbini. In fact non-incubated samples may have some advantages over incubated samples. Incubated samples usually read positive results in less than 24 hours. Positive results in non-incubated samples take longer to develop, generally turning black after 24 to 72 hours. The time it takes for a non-incubated sample to read a positive results may be indicative of the level of bacterial contamination present in a water sample. Further work needs to be completed to confirm this result.

Comparison of Incubated and Non-Incubated IDRC H_2S Tests (49 Tests)	
	Percent Positive
Incubated	48
Non-Incubated	45
Test Correlation 84%	

Table 5.2: Correlation between Incubated and Non-Incubated IDRC H_2S P/A Tests

5.1.4 A Comparison of Microbial Indicators and Testing Methods

One of the goals of this work was to determine the correlation between each of the 4 tests for microbial contamination, and identify the most appropriate test for microbial field-testing of water samples in Nepal. The correlation between each set of tests, and the number of paired tests conducted is shown in Figure 5.1.

Correlation (# Tests)	**HACH H_2S**	**IDRC H_2S**	**MF E. coli**	**MF Fecal Coliform**
HACH H_2S	-	0.86 (60)	0.55 (18)	0.33 (32)
IDRC H_2S		-	0.48 (23)	0.57 (67)
MF E. coli			-	0.50 (24)
MF Fecal Coliform				-

Figure 5.1: Correlation between HACH H_2S P/A Tests, IDRC H_2S P/A Tests and Fecal Coliform MF Tests, and E. coli MF Tests

The tests that show the highest correlations are the IDRC H_2S Test and the HACH H_2S test. This is to be expected because these tests detect the same indicator organisms. The correlation is not as high as might be predicted because the two tests used different sample sizes and therefore have different detection limits. The IDRC test used in Lumbini analyzed a 10 ml sample, giving a presence/absence detection limit of 10 CFU hydrogen sulfide producing bacteria per 100 ml. The HACH test used in Lumbini analyzed a 20 ml sample, giving a presence/absence detection limit of 5 CFU hydrogen sulfide producing bacteria per 100 ml (IDRC, 1998). This variation in detection limits makes direct comparison difficult.

The correlation between the two H_2S detecting tests and the two coliform detecting tests was generally much lower, ranging from 0.33 for the HACH H_2S test and the fecal coliform test, to 0.57 for the IDRC H_2S test and the fecal coliform test. Some variation is expected because these tests test for different indicator organisms, but low correlation such as these pose a significant challenge to field engineers attempting to find suitable indicator organisms for their work.

One possible reason for the low correlation between the H_2S tests and the coliform tests is the low level of bacterial contamination found in Lumbini tubewell water as measured by membrane filtration counts of fecal coliform organisms and E. coli. Eighty percent of the samples tested had fecal coliform levels of less than 10 CFU per 100ml. The 57 percent correlation between the IDRC H_2S test shown in the table above may be misleading. When fecal coliform bacteria are measured as present in quantities greater than 5 CFU per 100 ml, this correlation jumps to over 88 percent. Correlation between the two tests reaches 100 percent when only samples with fecal coliform bacteria levels over 15 CFU per 100 ml are considered. When fecal coliform bacteria levels are measured at 0 CFU per 100 ml, correlation with the IDRC H_2S test also rises to over 82 percent. The region of lowest test correlation is the 1 CFU per 100ml to 4 CFU per 100ml range, representing low-level well contamination. The H_2S tests detects only a portion of these positives because of its small sample size. Thus negative results for H_2S presence/absence tests in Lumbini suggest either the absence of fecal coliform contamination or the presence of low-level contamination. This result is encouraging because it suggests that H_2S presence/absence testing with small sample sizes can be useful for field researchers attempting to identify areas of high-level contamination for priority treatment.

Level of Fecal Coliforms	Correlation
All Levels	0.57
0 CFU per 100 ml	0.82
1–4 CFU per 100ml	0.54
> 5 CFU per 100 ml	0.88
> 15 CFU per 100 ml	1.0

Table 5.3: Correlation between IDRC H_2S P/A Tests and Fecal Coliform MF Tests

5.1.5 Discussion

The 2002 Lumbini well survey represents the first attempt by the MIT Nepal Water Project to perform enumeration tests for coliform indicators under field conditions in Nepal. Previous work made use of HACH presence/absence tests for total coliform bacteria and E. coli. These presence/absence tests are less complex than membrane filtration techniques and simpler to perform under field condition in that they require less involved sterilization techniques and less precise incubation procedures. However, they are not useful for determining bacteria counts in a water sample. Membrane filtration can be more appropriate when enumeration is desired, but this procedure proved difficult in Lumbini for several reasons, including a shortage of sterile water to use for apparatus rinses between filtration runs, and the lack of a reliable power supply to run incubators at the precise temperatures needed for indicator selection. These complications were avoided by running frequent blanks between filtration runs and by operating the incubator off battery power whenever possible. More difficult to address was the long wait time that often occurred between sample collection and membrane filtration. Because only one apparatus for membrane filtration was available, samples often sat without refrigeration for long periods of time before they were analyzed. Future well surveys could avoid this potential source of error by collecting samples twice daily or by collecting fewer samples each day, but this will lengthen the time required to complete a full well survey in Lumbini. In light of the work conducted in Lumbini in January 2002, the MIT-Nepal Water Project has identified several ways to improve the efficiency and accuracy of membrane filtration techniques, making these tests appropriate for use in the field. For a detailed description of these recommendations, refer to Heather Lukacs'

2002 Master of Engineering Thesis, entitled, “From Design to Implementation: Innovative Slow Sand Filtration for Use in Developing Countries.”

H_2S presence/absence testing has some advantages over membrane filtration in the field. The IDRC tests used in Lumbini are inexpensive to prepare, costing between \$0.05 and \$0.23 per tests, compared with \$0.60 per test for the HACH H_2S and \$1.50 per test for the fecal coliform membrane filtration (Low, 2002). The sterilization and incubation techniques for these tests are simple to perform. Glass vials for H_2S testing are usually prepared in advance, making in-field sterilization unnecessary. Over 250 tests vials were prepared and brought to Lumbini for the January 2002 well survey. As explained in section 4.1.3, the H_2S tests do not require incubation under most temperature conditions, including those experienced during January in Lumbini, Nepal.

H_2S presence/absence tests can also be used for Most Probable Number (MPN) testing. H_2S MPN tests using five 20-ml vials without dilutions can enumerate contamination ranging from <1.1 indicator organisms per 100-ml to >8.0 indicator organisms per 100-ml. This range should be adequate for the low level contamination observed in Lumbini, and dilutions can be used to increase the range in which the MPN tests can enumerate contamination. Unfortunately the precision of H_2S MPN tests, based on 95 percent confidence intervals given by Standard Methods, is not as high as Membrane Filtration techniques (Lukacs, 2002). Furthermore, the need to use additional test vials and perform dilutions may negate the time and cost-savings of H_2S testing.

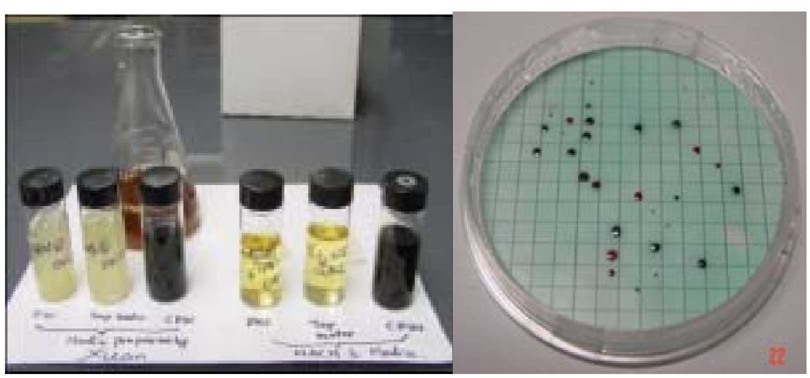

Figure 5.2: H_2S Presence/Absence tests (left) and MF Coliform Tests (right).

For a further discussion of microbial indicators and testing procedures for the detection of their presence in both laboratory and field settings, see Chian Siong Low’s 2002 Master of Engineering Thesis, “Appropriate Microbial Indicator Tests for Drinking Water in Developing Countries and Assessment of Ceramic Water Filters.”

5.2 Microbial Water Quality Survey

The January 2002 well survey sampled 88 wells in the 17 Lumbini villages served by IBS. These wells included 33 privately installed tubewells and 55 public tubewells installed by IBS or other aid organizations serving the Lumbini area. The results of this well testing and its implications for bacterial contamination levels in Lumbini are discussed below.

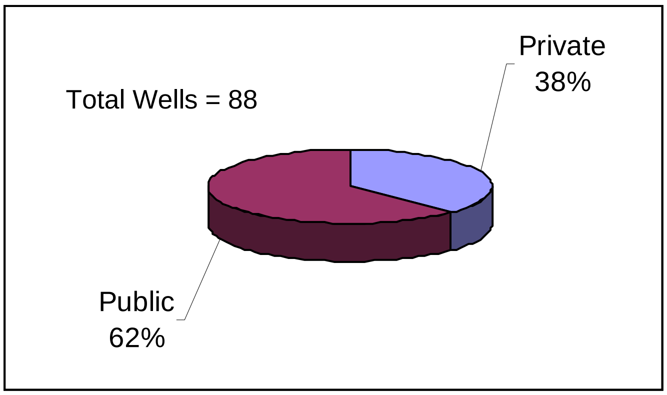

Figure 5.3: Distribution of Public and Private Wells Tested

5.2.1 Private Wells

Water samples were collected from 33 private tubewells used by schools and households in Lumbini. The average depth of these private wells was 62 feet, though over 60 percent were less than 40 feet, and the average age of these wells was 10 years, although several had been in place for over 25 years. Thirty-two of these samples were analyzed for H_2S producing bacteria using the IDRC presence/absence test and the HACH presence/absence test. Forty percent tested positive for H_2S producing bacteria in at least one of the two tests. Eighteen samples were analyzed for fecal coliforms. Thirty-nine percent tested positive for fecal coliform bacteria with concentrations ranging from 1 CFU/100ml to greater than 500 cfu/100ml. Only eight samples were analyzed for E. coli, and half of these samples tested positive with concentrations ranging from 12 CFU/100ml to greater than 500 CFU/100ml.

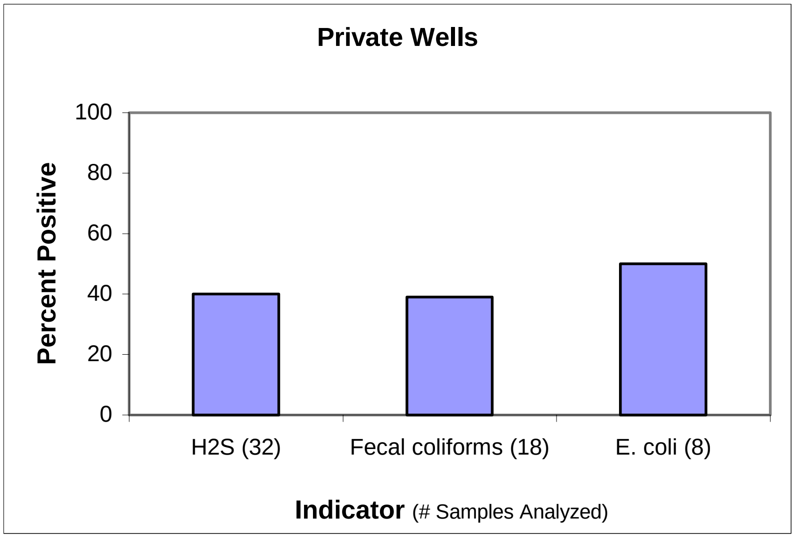

Figure 5.4: Bacterial Contamination in the 17 IBS villages (Private Wells)

5.2.2 Public Wells

Water samples were collected from 55 public tubewells in the Lumbini area. The average depth of these wells was 184 feet and the average age of these wells was just less than two years. All of these wells were installed between 1997 and 2002 by IBS, with the exception of one 180 foot well installed in Lankapur in 1990 by the Nepal Red Cross Society. All 55 of these samples were analyzed for H_2S producing bacteria using the IDRC presence/absence test and the HACH presence/absence test. Thirty-six percent tested positive for H_2S producing bacteria in at least one of the two tests. 40 samples were analyzed for fecal coliform bacteria; 32 percent tested positive. Only 12 samples were analyzed for E. coli; 33 percent tested positive. The fecal coliform enumeration results, and their implications under WHO guidelines are discussed in more detail below.

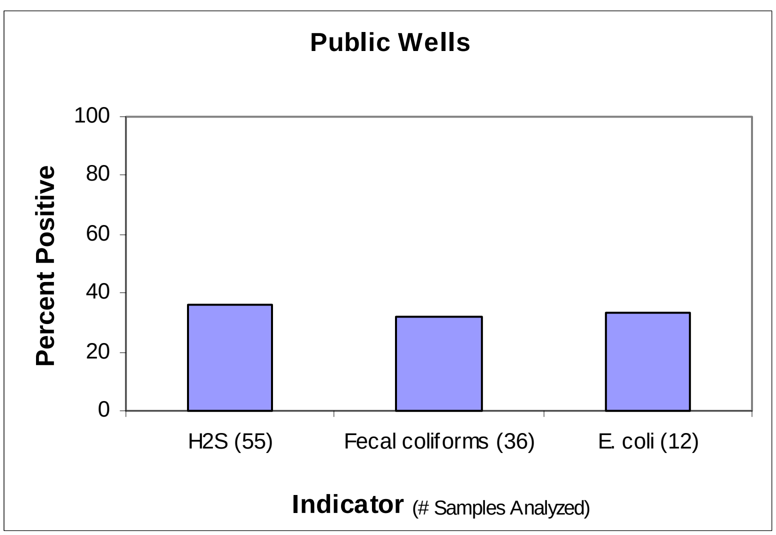

Figure 5.5: Bacterial Contamination in the 17 IBS villages (Public Wells)

5.2.3 Comparison with World Health Organization Guidelines

World Health Organization Guidelines for Drinking Water Quality specifies the use of E. coli and fecal coliforms for the detection of microbial contamination in drinking water supplies. The WHO recommends the use of E coli as an indicator because it is routinely present in the greatest numbers in feces but fecal coliform bacteria are an acceptable alternative. According to WHO organization guidelines these indicator organisms must not be detected in 100 ml samples from any water source that is used for drinking (WHO, 1993). The majority of membrane filtration tests conducted in Lumbini used fecal coliforms as indicators of fecal contamination. E. coli enumeration tests were only performed on a small number of samples, and results were generally similar to those obtained with fecal coliforms. This section considers only the membrane filtration fecal coliform tests conducted in Lumbini because they are one of the standard indicator organisms used by the World Health Organization to set microbial water quality standards.

Overall 40 public tubewells were tested for fecal coliform bacteria in Lumbini[*]. These included wells installed by IBS and other aid organizations and were between 74 and 350 feet in depth. The majority of these wells were installed between 1997 and 2002, and villagers have been instructed to obtain their drinking water from these sources. Fecal coliform bacteria were detected in 12 wells, or 33 percent of the public wells sampled. Wells that were installed just prior to sampling showed extremely elevated levels of fecal contamination sometimes on the order of 10,000 CFU per 100ml. These elevated levels of contamination are due to the use of cow dung slurry in well construction and are not indicative of long-term contamination. The highest level of contamination found in wells older than one month was 14 CFU/100 ml, indicating that contamination from the use of cow dung slurry does not persist in tubewell water longer that one month after well construction is completed. Eliminating the 4 wells that were constructed in the month immediately prior to sampling, fecal coliform bacteria were found in only 22 percent of public tubewells in Lumbini. Furthermore, the concentrations of fecal coliform bacteria detected ranged from 2 to 14 CFU per 100 ml (detection limit of 2 CFU/100ml), with an average concentration of less than 1.2 CFU/100 ml among all public wells.

Age of Well	Number of Wells	Percent Contaminated	Average Contamination
< 1 month	4	100%	> 500 CFU per 100 ml
> 1 month	36	22%	< 5 CFU per 100 ml

Table 5.4: Fecal Coliform Contamination in Public Tubewells

[*] One public open well was also tested in Lumbini and was found to have E. coli and fecal coliform levels of over 300 CFU/100 ml. This well was not included in the public well statistics because the open wells in Lumbini are widely understood to be contaminated and villagers have been instructed to use the IBS tubewell near this open well for their drinking water.

Bacterial contamination in rural water supplies at the levels detected during this well survey in Lumbini are not necessary a cause of concern. As one researcher with significant experience in developing countries states, “Untreated water sources almost always contains some fecal coliform bacteria; the question is, does a particular source contain more than the alternative sources available? To apply the [WHO] standard for disinfected water would be to condemn the water supplies used by most rural people in developing countries (Cairncross, 1993).” In fact in recent years, there have been suggestions to adapt the WHO guidelines for use in developing countries. The WHO is now acknowledging the relevance of “medium-term” targets aimed at progressive improvements in water quality, recognizing that “in the great majority of rural water supplies in developing countries, fecal contamination is widespread and achieving the guideline values for E. coli or fecal coliforms is often not possible (WHO, 1993).”

Based on the well survey results obtained in January 2002 and the considerations discussed above, there does not appear to be a significant bacterial contamination problem in the IBS tubewells in Lumbini[*]. These results should not be viewed as conclusive for two reasons. One, potentially significant complications were encountered with the use of membrane filtration techniques in the field, as discussed above. And two, this well survey was conducted during the dry season in Lumbini and an additional well survey must be completed during the monsoon season, between June and September, to confirm these results and determine if bacterial contamination levels increase significantly in Lumbini during this period. Follow-up surveys should be completed in Lumbini to confirm the finding presented here, fine-tune the use of membrane filtration in the field, and develop microbial data for the rainy season in Lumbini.

If these follow-up studies reveal similar low levels of microbial contamination in public tubewells during the monsoon season it will be important to investigate other potential causes of the waterborne disease so prevalent in Lumbini. Several possible causes for the prevalence of waterborne disease in Lumbini should be examined, including:

- The use of private tubewells, open wells, and open water sources for drinking water
- Improper household water storage leading to bacterial contamination
- Lack of sanitation facilities, including latrines and washing platforms
- Limited awareness about basic hygiene practices such as handwashing

[*] This considers only the membrane filtration tests for fecal coliform bacteria because these are the standard indicator organisms used by the World Health Organization to set microbial water quality standards.

5.3 Previous Lumbini Area Well Surveys

The January 2002 well survey was not the first attempt to evaluate microbial water quality in Lumbini. Between April 1999 and January 2001, three previous well surveys were conducted by different teams of researchers to evaluate the presence of microbial contamination in Lumbini.

In April 1999 Peter Moulton of the Global Resources Institute (GRI) in Eugene Oregon, tested 42 wells including 22 shallow wells (less than 60 feet), 9 deep wells (greater than 150 feet), and 9 open wells, using both 10ml IDRC H_2S presence/absence tests and coliform enumeration tests. He found that 72 percent of shallow wells, 78 percent of deep wells, and 100 percent of open wells showed signs of bacterial contamination (Moulton, 1999).

In January 2000, a team from the MIT-Nepal Water Project, led by Susan Murcott, tested 27 wells, including14 shallow wells (less than 45 feet), and 13 deep wells (greater than 200 ft) using 20ml HACH H_2S presence/absence tests. This study found that 64 percent of shallow wells and 62 percent of deep wells showed signs of bacterial contamination (Murcott, 2002).

In January 2001, Meghan Smith and Tim Harrison, also from the MIT-Nepal project tested 32 wells, including 13 shallow wells with an average depth of 47 feet, 16 deep wells with an average depth of 190 feet, and 3 open wells, using 10ml IDRC H_2S presence/absence tests. They found that 46 percent of shallow wells, 25 percent of deep wells, and 100 percent of open wells showed signs of bacterial contamination (Smith, 2002).

Date	Test Method	# of Wells Tested	Percent Contaminated		
			Shallow	Deep	Open
April 1999	H_2S P/A & MF	42	72	78	100
January 2000	H_2S P/A (20ml)	27	64	62	-
January 2001	H_2S P/A (10ml)	32	46	33	100
January 2002	H_2S P/A (10ml) & MF	88	40	36	-

Table 5.5: Results of Lumbini Well Surveys, 199-2002

Although the results of the January 2001 survey conducted by Smith and Harrison are similar to those found in Lumbini during the January 2002 well survey, the well data collected in April 1999 and January 2000 show significantly higher levels of microbial contamination in both public and private water sources. This discrepancy should be addressed before the low-level contamination conclusions derived from the January 2002 evaluation are accepted. There are several possible explanations for these discrepancies,

- Studies, previous to the January 2002 work sampled only a small subset of public or deep wells in Lumbini
- Previous studies do not differentiate between public and private wells, only between “shallow” and “deep” wells, and definition of “shallow” and “deep” vary from researcher to researcher.

- Previous studies do not differentiate between deep wells installed by IBS and deep wells installed by other aid organizations. Wells in this second category are often older and were generally found to be contaminated during the January 2002 survey.

- The age of tested wells was not recorded during previous well surveys. It is therefore not possible to determine if any of these wells represent newly installed wells, which were also found to be contaminated during the January 2002 well survey. It is possible that previous surveys differentially selected these newer wells because IBS was eager to present their newest wells for bacterial testing. This pride in newly constructed wells was observed frequently during the January 2002 survey.

- Finally, although no evidence for this was observed during sanitary surveying conducted in January 2002, conditions may have changed in Lumbini since the 1999 and 2000 well survey to improve the microbial water quality in the Lumbini wells.

In sum, the cause of discrepancies in results from well surveys conducted in Lumbini between 1999 and 2002 is not immediately apparent. Only continued monitoring of microbial water quality in Lumbini will reveal accurate measurements of the level of microbial contamination in the region. For further information on the well testing data presented in this chapter, as well as a more rigorous discussion of the previous well testing conducted in Lumbini, refer to Heather Lukacs' 2002 Master of Engineering Thesis, entitled, "From Design to Implementation: Innovative Slow Sand Filtration for Use in Developing Countries."

5.4 Sanitary Survey

Sanitary surveys are designed to record visual observations of risk factors that could lead to the contamination of potable water sources. In Lumbini, the risk factors assessed pertained specifically to the microbial contamination of potable water supplies, i.e. tubewells, but these surveys can be used to assess potential sources of microbial, chemical or physical contamination of water supplies. Comprehensive sanitary surveys can be useful under several circumstances. Including (Shaw, 1999):

- To compare water sources for potential development
- To identify potential causes of contamination
- To identify potential causes of water-borne disease epidemics
- To monitor sanitary conditions

Sanitary survey's can be particularly beneficial when conducted in conjunction with water quality analysis. Water quality analysis will determine if a well or water source is contaminated, but without an accompanying sanitary survey it can do little to assess the potential sources of contamination. Comprehensive water quality analyses are often challenging to complete under rural field conditions. They can require expensive laboratory equipment and trained personnel, and are therefore difficult to perform on a routine basis. In contrast, sanitary surveys are inexpensive to complete and can be performed regularly without the assistance of highly trained technicians (Shaw, 1999). For this reason, if risk factors are properly identified, sanitary surveying can be used as a surrogate for comprehensive water quality surveying when the equipment, funding and technical know-how to perform water quality analysis is not routinely available.

Sanitary risk factors that can lead to microbial contamination of rural tubewells and should be included in a comprehensive sanitary survey include:

- Close proximity of well to latrine or rural sanitation facility (Shaw, 1999)
- Nearest latrine situated on higher ground than well (Shaw, 1999)
- Open defecation in close proximity to well
- Well platform used for bathing, clothes washing, dish washing
- Close proximity to animal excreta or lodging (Shaw, 1999)
- Close proximity to rubbish disposal (Shaw, 1999)
- Missing, cracked or inadequate concrete platform
- Inadequate drainage, leading to stagnant standing water in close proximity to well

In Lumbini, visual observations of sanitary risk factors were recorded at each well where samples were taken for microbial analysis. Sanitary risk factors that were examined in Lumbini included:

- Size and condition of concrete platform
- Level of drainage and/or presence of standing water
- Proximity to animal lodging and/or prevalence of cow dung in surrounding area
- Observations of bathing, clothes washing, and/or dishwashing on well platform
- Presence of algae growth on well handle, spout, or concrete platform

The presence of latrines and their siting relative to the tubewells was not considered in this survey because pit latrines or sanitation facilities have not been installed in these villages. There is currently only one latrine in the 17 IBS villages. It is privately owned and used only by a very small number of individuals. Plans are underway for drainage and latrine installation in several of these villages and IBS has received funding and materials support for the construction of 7 latrines. The siting of these latrines will need to be carefully considered so as to avoid the creation of additional risk factors for microbial contamination. After the installation of latrines in Lumbini becomes more widespread, future sanitary surveys will need to include observations about the siting of latrines relative to common water sources.

Sanitary surveys may represent a simple solution to the problems presented by routine water quality analyses in Lumbini. These surveys could be conducted by IBS staff without outside help, and they could be completed without sophisticated testing, sterilization, and incubation equipment. It would also be possible to complete a full sanitary survey of the 17 Lumbini area villages served by IBS in significantly less time than the two weeks that was required to complete the full well survey.

5.5 Potential Sources of Microbial Contamination

Based on the water quality analysis and the sanitary surveying conducted in Lumbini, several potential sources of microbial contamination were identified. These include:

- Well construction with cow dung slurry
- Lack of drainage infrastructure
- Open defecation in close proximity to tubewells
- Close proximity to animal lodging
- Use of cow dung for building material and other household purposes
- Bathing, clothes washing, and dishwashing on community well platforms
- Unsafe water storage practices and well "priming" with contaminated stored water

Some of these sources are more significant than others. For example several wells had been installed within the two weeks prior to the sampling and microbial testing that occurred in January 2002. The level of E. coli and fecal coliform contamination in these samples was unusually high, significantly beyond the counting limits of the testing procedures because of the limited amount of sterile dilution water available at the field site. This confirms that the installation of wells using cow dung slurry may contribute the initial contamination of a rural tubewell, but this source still cannot account for long-term well contamination because of the inability of these enteric bacteria to live outside a host for long periods of time (Smith, 2001).

The list above refers to potential sources of bacterial contamination of tubewell water in the Terai region of Nepal. Bacterial contamination of drinking water can also occur after water is collected from these tubewells, because of improper water storage and handling practices in the home. A water quality assessment conducted in Eastern Nepal in 1990 determined that 55 percent of household water samples showed elevated contamination levels when compared with source water samples (Shrestha, 2001). This points to the central role of in-home water contamination, which occurs after water is collected from local sources. Whenever possible, a separate sanitary survey should be conducted to assess risk factors for in-home water contamination. These factors might include:

- Use of visibly dirty water storage vessels
- Water storage in open containers without lids
- Dipping of hands or household utensils to draw water from storage vessels
- Improper handling and disposal of child/infant excreta
- Absence of hand-washing facilities, or soap

Risk factors for well contamination can be eliminated through the setablishment of comprehensive well maintenance programs, including platform and pump repair, drainage monitoring, periodic cleaning of the wells and surrounding areas, as well as through careful considerations about the placing of water supply facilities in relation to latrines and animal lodging. For additional information on tubewell maintenance programs, see Xuan Gao's 2002 Master of Engineering thesis entitled, "Community-Based Water Supply: Tubewell Program in Lumbini Zone, Nepal." Risk factors for in-home water contamination can be identified and addressed by hygiene education and the installation of safe water storage practices as prescribed by the Lumbini Household Chlorination Pilot Study and other CDC Safe Water System programs.

5.6 Recommendations for Future Well Surveys

If well surveying is to be continued in Lumbini, a standardized sampling, testing, and inventory method must be established to ensure that results can be used to assess annual, seasonal, or geographic trends contamination trends. Long-term well surveys may be able to give insights into the sources of microbial groundwater contamination in Lumbini. The ability to detect contamination sources will be enhanced if sanitary surveys are conducted in conjunction with microbial water quality surveys.

Based on the experience of the January 2002 Lumbini Well Survey, well surveying in Lumbini should be continued and expanded with the following recommendations:

Establishment of a Well Inventory: All wells in Lumbini should be assigned an identification number that incorporates the village in which the well is located, the date of installation, and the well depth. A well inventory should be established that incorporates this data, as well as additional information such as a well's classification as public or private and a well's owner or installer. The well inventory should be tied to a mapping system that allows each well to be easily located and identified by future well surveyors. This mapping system could make use of GPS coordinates, as used during the January 2001 well survey, to catalogue well locations. It may be beneficial to tie the inventory system to IBS village maps to insure that wells can be properly located and identified by IBS staff and other surveyors who may not have access to handheld GPS systems. Hand drawn maps of all 17 IBS villages have been created by IBS and could be used for this purpose (Appendix C). These maps show the locations of open wells and tubewells in several villages and are in the process of being updated by IBS staff to be more comprehensive.

Establishment of a Uniform Testing Procedure: Well testing in Lumbini is difficult because of a lack of both sterilization and incubation equipment. Previous studies have made use of several different indicator organisms including H_2S producing bacteria, total coliforms, fecal coliforms, and e. Coli, and have used both presence/absence techniques and membrane filtration enumeration techniques. Efforts must be made to ensure that proper bacterial testing methods are followed and results can be compared from survey to survey. This will require the selection of a uniform indicator organism and testing method. At this time it appears that the most appropriate technique for well surveying in

Lumbini should incorporate membrane filtration tests using apparatus specially designed for field sterilization and m-Coli Blue24™ broth, which tests for both total coliform and e.Coli indicators. This method will allow for the enumeration of bacterial contamination while increasing the simplicity of both sterilization and incubation procedures. For additional information on the selection of bacterial testing methods and indicators for use in Lumbini refer to Heather Lukacs' 2002 Master of Engineering Thesis, entitled, "From Design to Implementation: Innovative Slow Sand Filtration for Use in Developing Countries."

Establishment of a Sanitary Surveying Program: Sanitary surveys should accompany bacterial well surveying in Lumbini. Complete sanitary surveys may be able to provide insights into the sources of microbial groundwater contamination in Lumbini. When bacterial well testing procedures cannot conform to the uniform standards outlined above, due to financial or technical constraints, it may be desirable to focus solely on sanitary surveying. Investigators should attempt to address risk factors identified through sanitary surveys to minimize future bacterial contamination.

Establishment of Uniform Classification and Data Analysis Methods: Uniform data classification and analysis is essential if well survey results are to be compared from survey to survey. Previous investigators have used similar categories to describe sampled wells, including deep, shallow, public, private, IBS, non-IBS, open, dug, tubewell, and handpump. However, the characteristics of wells that fall into each of these categories have varied widely. Shallow wells are in some instances defined as less than 40 feet, in other instances as less than 100 feet. Some investigators have made distinctions between public wells installed by IBS and public wells installed by other organizations; some have chosen to place them under one classification. Furthermore, well classifications can be misleading if they are inconsistent with standard industry terms. For example, "deep" wells in Lumbini have in some instances been defined as wells with depth greater than 150 feet, but a "deep" well classification in other regions of the world may refer to a well depth of greater than 300 feet, or even 500 feet. Uniform well classifications should be defined for Lumbini, and data analysis should occur in such a way that survey to survey comparisons are feasible. It may be possible to facilitate these comparisons through the use of a standardized spreadsheet program developed to perform data analysis and compare survey results in Lumbini.

Establishment of a Seasonal Surveying Program: The MIT-Nepal Water Project team conducts the majority of its fieldwork in Nepal during MIT's January term. Thus, rainy season well data for the Lumbini region is limited. It may be beneficial to establish a seasonal surveying program that will allow for data collection outside of the January fieldwork period. This will allow for an evaluation of seasonal trends in microbial contamination in Lumbini and may provide valuable insights into the levels of microbial groundwater contamination experienced in Lumbini during the rainy season.

CHAPTER 6 JANUARY 2002 HOUSEHOLD CHLORINATION PILOT STUDY EVALUATION

The Lumbini Household Chlorination Pilot Study was revisited in January 2002 by members of the MIT-Nepal Water Project term in order to complete a thorough field investigation and make recommendations for the expansion or discontinuation of household chlorination in Lumbini. The January evaluation took place in four stages: (1) review of ongoing monitoring conducted by IBS, including an analysis of microbial testing data and health survey data, (2) water quality and chlorine residual testing of stored household water among pilot study participants, (3) dosage testing designed to determine the proper dose of Piyush for Lumbini tubewell water, and (4) completion of a household survey designed to evaluate the appropriateness of household chlorination in Lumbini.

Although the original Chlorination Pilot Study design called for an intervention group of 50 families and a control group of 50 families, the actual Pilot Study included only 36 families and no control group was formed for health comparison. At the time of the January 2002 Lumbini Pilot Study evaluation only 16 of the original 36 households in the pilot study were still practicing household chlorination. Ten of these households were visited during the evaluation, between January 8 and January 18, 2002 to conduct the household survey and collect samples of stored household water for free chlorine residual testing and bacterial analysis.

6.1 Evaluation of IBS Pilot Study Monitoring

6.1.1 Bacterial Testing

Throughout the Lumbini Chlorination Pilot Study, periodic bacterial testing of stored water supplies in the intervention households was conducted by IBS. These tests were performed on a bimonthly basis using IDRC H_2S bacterial tests. The tests used in Lumbini were prepared for IBS by ENPHO in their Kathmandu laboratory. The IDRC tests detect hydrogen sulfide producing bacteria with a simple color change reaction from yellow to black and were selected for this study because they could be performed by IBS staff without specialized equipment or incubators. See Chapter 5 for a further discussion of bacterial testing using the IDRC tests. The report submitted by Dr. Mallick in January 2002 included H_2S test results for January 2001 through October 2001. The H_2S testing was discontinued in October 2001 because of a shortage of testing supplies.

The January 2002 report listed a total of 63 H_2S presence/absence tests conducted on the household water supplies of chlorine users. All of these test results were recorded as negative for bacterial contamination. Because these tests were conducted on chlorinated water samples, de-chlorination steps must be performed before microbial analysis can be completed. Prior to this time, the H_2S testing that had occurred through IBS had been performed only on non-chlorinated water sources so the IBS clinic staff was unaware of the need to de-chlorinate and the sodium thiosulfate reagents necessary to do so were not provided to IBS. Because of this oversight, the negative H_2S testing results reported by IBS cannot be used as evidence of contamination removal. Similar bacterial testing was conducted on stored water supplied in intervention households that were visited in January 2002 during the pilot study evaluation. Sodium thiosulfate was used to neutralize the chlorine in these samples and insure the accuracy of bacterial testing. These results are presented in section 6.2.

6.1.2 Health Survey

The original design of the Lumbini Household Chlorination Pilot Study called for an experimental health survey that would compare the incidence of waterborne disease in a intervention group of 50 households and 10 schools who would receive the chlorine disinfectant and bucket system with the incidence of waterborne disease in a control group that would continue with their traditional water collection and storage practices. The purpose of this type of health study is to determine, through direct application, whether a particular treatment, or preventative technology, in this case, produces an expected outcome (Aday, 1996). In Lumbini, the experimental health study was designed to determine if a program of household water chlorination could lead to reductions in the prevalence of waterborne disease. In an experimental study such as this, households should be randomly assigned to the intervention group or the control group. It is thus assumed that households in the experimental group and the control group are equivalent and any observed differences can be attributed to the intervention, in this case the practice of household chlorination (Aday, 1996).

A control group was never formed in Lumbini. The experimental study therefore had to be adapted so the health benefits of household chlorination could be assessed. This new health study can be described as a longitudinal health survey. In a longitudinal health study, a particular population is surveyed at various points in time to determine how certain characteristics of that population change (Aday, 1996). In Lumbini, beginning in January 20001, monthly health information was collected from the 36 households practicing household chlorination. This data collection continued until January 2002, or until a household abandoned the practice of household chlorination.

All of the data collection occurred through the IBS women motivators during their weekly village visits. The motivators collected information on the incidence of several common waterborne diseases, including abdominal pain, diarrhea, and amoebiosis. Diagnosis of amoebiosis was determined by a symptomatic analysis, similar to the method that Dr. Mallick, the IBS health clinic doctor, uses when patients visit IBS. The health clinic currently does not have laboratory equipment that allows them to make these diagnoses through stool tests or other commonly used diagnostic methods[*]. Instead, Dr. Mallick and the women motivators diagnose amoebiotic infections using common symptoms including “stomach pain below the navel, white threadlike discharge in stool, back pain, vertigo and headache, and weakness (Mallick, 2002).”

[*] The IBS Health Clinic is in the process of obtaining diagnostic laboratory through Cross Flow Nepal Trust. During MIT’s visit in January 2002, a laboratory room had been built for this equipment and a laboratory technician had been hired but the equipment’s arrival had been delayed for many months.

In January 2002 after the health study had been completed, Dr. Mallick compiled the collected data into a report that was submitted to the MIT-Nepal Water Project. Only the 16 families still practicing household chlorination were included in this report. No information was given on the other twenty households, either about their health status over the time they participated in the study or about the date or cause of their discontinuation of household chlorination. The use of the term "intervention group" in this analysis will therefore refer to the 16 families that continued with household chlorination until January 2002. There are several possible reasons for the abandonment of household chlorination by the remaining 20 families. It is important to note that some of these households may have discontinued the use of household chlorination because they did not perceive an improvement in their health, thus the intervention group data presented here represents only those individuals that continued chlorination for the entire study period, presumably those that perceived health benefits from household chlorination.

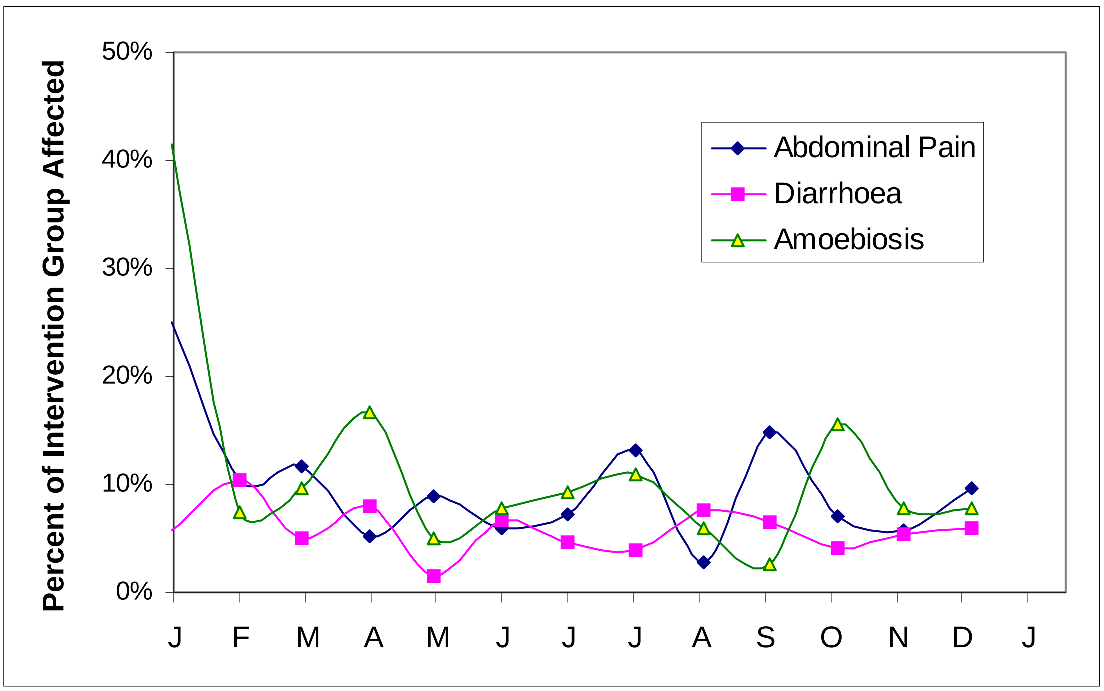

Figure 6.1: Health Trends in the 16 Family Intervention Group Between January 2001 and January 2002

Figure 6.1 shows incidence of water borne disease among the intervention group households between January 2001 and January 2002. In January 2001, before the intervention group was provided with disinfectant and storage vessels the incidence of abdominal pain among household members was 237 cases per 1000 individuals, the incidence of diarrhea was 35 cases per 1000 individuals and the incidence of amoebiosis was 430 cases per 1000 individuals. After the introduction of household chlorination in February 2001 , the incidence of both abdominal pain and amoebiosis appear to decline substantially, the incidence of diarrhea, already quite low for the Lumbini area, appears to remain more stable.

Analyzing this longitudinal data for trends is difficult because the incidence of waterborne disease in this region of Nepal is not constant over the year. Lumbini is located in the southern Terai, a semi-tropical area with a significant rainy season lasting from June to September. As in many developing countries, this monsoon season is accompanied by substantial flooding and high temperatures, increasing vectors for waterborne disease and typically leading to large spikes in the incidence of abdominal pain, diarrhea and amoebiosis. Thus, it is not valid to compare health data from the dry season in January with health data from the rainy season in September. Without the benefit of a control group, the inclusion of both January 2001 and January 2002 data becomes invaluable for assessing the health effects of the household chlorination program in Lumbini. The inclusion of two data sets for January eliminates seasonal variation and allows for a before-and-after comparison of the health effects of household chlorination in Lumbini (Figure 6.2).

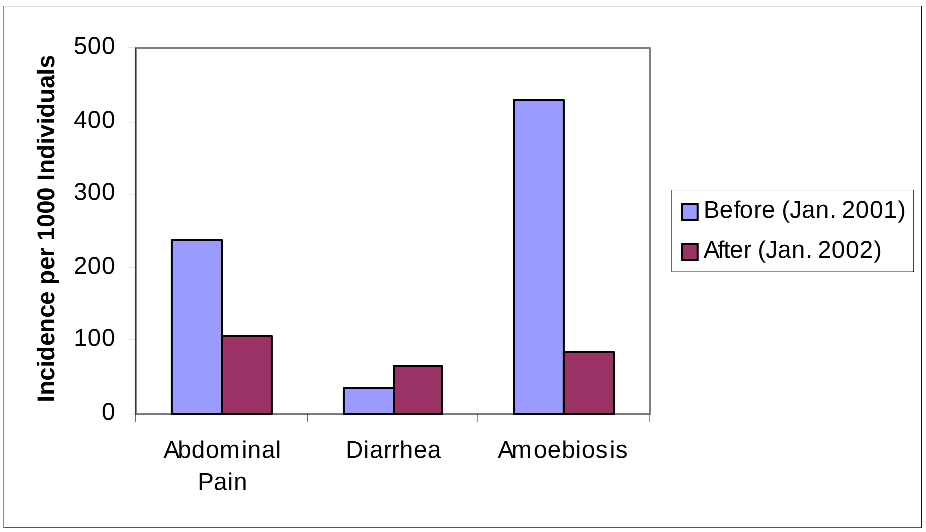

Figure 6.2:Waterborne Disease Incidence in 16 Family Intervention Group Before and After Chlorination.

In January 2002 the incidence of abdominal pain among intervention households was 107 cases per 1000 individuals, the incidence of diarrhea was 65 cases per 1000 individuals and the incidence of amoebiosis was 86 cases per 1000 individuals. This represents a 55 percent reduction of incidence of abdominal pain and an 80 percent reduction in incidence of amoebiosis after 12 months of household chlorination. The data for diarrheal disease is less promising, actually showing an 85 percent increase in reported cases of diarrhea after the 12 months. This analysis may be misleading as the initial diarrhea incidence of 35 cases per 1000 individuals collected in the January 2001 baseline survey was extremely low for this region of Nepal. The incidence of diarrhea cases among the general population of Lumbini in January 2001 was 65 cases per 1000 individuals (Smith, 2001) almost double that in the intervention group at the time of the January 2001 baseline survey and identical to the January 2002 findings. This may explain the apparent discrepancy between very favorable health improvements in the categories of abdominal pain and amoebiosis and the increase in diarrhea incidence.

Table 6.1: Reduction in Waterborne Disease Incidence, 16 Family Intervention Group .

Abdominal Pain	55 Percent Decrease
Diarrhea	85 Percent Increase
Amoebiosis	80 Percent Decrease

6.1.3 Comparison of 16 family Intervention Group with General Population

As part of the new partnership between IBS and Cross Flow Nepal Trust, quarterly health surveys of the 17 villages are now being conducted to assess the effects of health and sanitation education programs and to gain a better understanding of the health problems faced by Lumbini villagers. The results of the September 2001 survey are shown below:

Table 6.2: Waterborne Disease Incidence Among General Population of Lumbini

Village	Population	Diarrhea	Amoebiosis
Lankapur	157	8	22
Mahuwari	644	30	71
Khambe	445	70	41
Laxmipur	382	20	39
Mahilwari	730	108	101
Dhodawa	544	3	126
Sujandihawa	896	18	114
Ramuwapur	595	25	99
Sonbarshi	251	12	40
Ramuwapur	373	14	80
Sonbarsha	804	46	67
Bhagatpura	310	20	45
Shivagadiya	426	7	56
Sekhuwadand	213	15	42
Mujhana	689	80	94
Bhagwanpur	975	0	104
Lamtihawa	893	7	67
Total	**9327**	**483**	**1208**
Incidence per 1000 Individuals		**51.8**	**129.5**

The information from this quarterly survey presents an additional opportunity to evaluate the health effects of the household chlorination. Using the data collected in the September 2001 survey and the data collected from the intervention group during the same time period, it becomes possible to compare the incidence of waterborne disease among chlorine users with the incidence of waterborne disease among the general population of Lumbini.

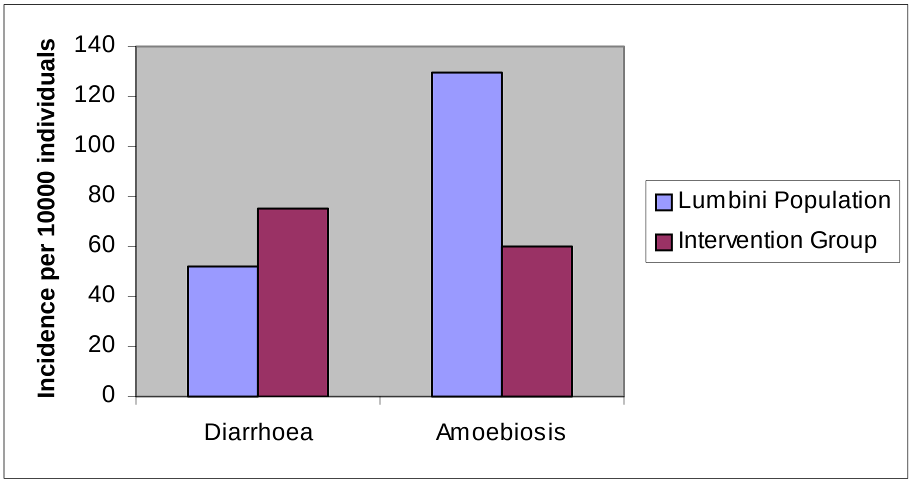

Figure 6.3: Waterborne Disease Incidence: Intervention Group vs. General Population, September 2001

This comparison reveals a substantial reduction amoebiotic disease among chlorine users. Households in the intervention group had 60 cases of amoebiosis per 1000 individuals in September 2001 versus an incidence of 130 cases per 1000 in the general population. The incidence of diarrheal disease was slightly higher among chlorine users. Households in the intervention group had 75 cases of diarrhea per 1000 individuals in September 2001 versus an incidence of 52 cases per 1000 in the general population.

Initially it appears that the chlorine users have lower incidences of amoebiotic diseases than the general population but greater incidences of diarrheal disease than the general population. It is difficult to draw conclusions from this analysis because a comparison with the general population is more complex than a simple control group comparison. As discussed above, in an experimental study the experimental group and the control group are assumed to be equivalent and observed differences can be attributed to the intervention or treatment that the experimental group received. In this analysis the intervention group and the general population are not necessarily equivalent. In fact, the intervention group was selected for inclusion in the household chlorination project by IBS because of their high rates of waterborne disease. IBS selected households to receive the chlorine disinfectant and storage vessels based on their frequent visits to the health clinic with complaints about waterborne disease. This was done in an effort to provide the chlorine systems to households with the greatest need but in doing this IBS complicated the possibility of a direct comparison between the health of the intervention group and the health of the general population because the baseline health levels of these two groups cannot be considered equivalent.

6.1.4 Summary of Health Survey Results

Drawing conclusions from the health survey that accompanied the Lumbini Pilot Study was complicated by the absence of a control group and the non-reporting of health data from users who discontinued household chlorination before January 2002. A comparison of the incidence of waterborne disease among the intervention households between January 2001 and January 2002 shows a 55 percent reduction in complaints of abdominal pain and an 80 percent reduction in the incidence of amoebiosis after continued use of household chlorination. A similar reduction in diarrheal disease was not observed, in fact, the incidence of diarrheal disease increased by 85 percent over this time period. It should be noted that the incidence of diarrheal disease among the intervention group was significantly lower than that of the general Lumbini population and the rates of diarrheal disease among intervention group households in January 2002, though representing an 85 percent increase when compared to January 2001 before the intervention, are consistent with those measured among the general population of Lumbini in January and September 2001.

6.2 Household Water Testing

During January 2002, 10 of the 16 households participating in the pilot survey were visited to conduct bacterial water quality testing and free chlorine residual analysis to determine if household chlorination was being conducted properly. Water samples were obtained from the 7 households that had prepared chlorinated water available at the time of the visit. Unfortunately many of the program participants are using their systems for large numbers of people, sometimes up to 40 individuals using one bucket system, and often all chlorinated water at these households had been consumed at the time of the visit. Stored water was analyzed on-site for free chlorine residual using the DPD titration method. Additional water samples were collected in sodium thiosulfate whirlpack bags to neutralize any chlorine that might be present, and were taken back to IBS for bacterial analysis using H_2S presence/absence tests.

6.2.1 Free Chlorine Residuals

Measured free chlorine residuals in stored household water ranged from 0 mg/L to 0.95 mg/L. Only 2 of the 7 households (29%) maintained proper free chlorine residuals between 0.2 mg/L and 1.0 mg/L.

Table 6.3: Total Chorine (TC) and Free Chlorine Residuals (FCR) in Stored Water

Household	Village	TC (mg/L)	FCR (mg/L)
1	Mujahana	-	-
2	Kambe	1.1	0.9
3	Bhagawanpur	0.3	0.0
4	Bhagawanpur	0.0	0.0
5	Sekhuwadan	0.8	0.2
6	Mahilwari	0.4	0.0
7	Muhuwari	0.0	0.0
8	Muhuwari	-	-
9	Bhagatpuruwa	0.0	0.0
10	Ramwapur (K)	-	-

6.2.2 Bacterial Analysis

Complete bacterial removal, indicated by the absence of H_2S producing bacteria was observed in only 3 of the 7 households (43%). These results are likely due to the inadequate free chlorine residuals measured in most households. Complete bacterial removal was observed in all households that maintained a free chlorine residual between 0.2 mg/L and 1.0 mg/L.

Table 6.4: Measured Bacterial Contamination at Intervention Households Visited in January 2002

Household	Village	Source Water	Stored Water
1	Mujahana	-	-
2	Kambe	P	A
3	Bhagawanpur	A	P
4	Bhagawanpur	P	P
5	Sekhuwadan	P	A
6	Mahilwari	P	A
7	Muhuwari	A	P
8	Muhuwari	-	-
9	Bhagatpuruwa	P	P
10	Ramwapur (K)	-	-

(P=Presence, A = Absence)

Bacterial contamination after source water collection was observed in 2 of the 7 households. Bacterial contamination after collection was assumed when source water tested negative for H_2S producing bacteria but stored household water tested positive for H_2S producing bacteria. This indicates a higher level of bacterial contamination in stored water supplies that in source water. This result is troublesome because the chlorination program can encourage additional water storage and if chlorination is not completed properly or vessels are used incorrectly this could lead to increased bacterial contamination after water collection.

6.3 Dosage Testing

Measured free chlorine residuals in household water varied widely from 0 mg/L to 0.95 mg/L. Only 29 percent of households were able to maintain proper free chlorine residuals of 0.2 to 1.0 mg/L but all households understood the dosing procedure and stated that they had added 3 drops of Piyush to each liter of water, the correct dosage.

Households may be having difficulties maintaining proper free chlorine residuals because they do not follow this dosing procedure properly. Households may add too little chlorine because the object to the taste of the chlorinated water when the proper dosage procedures are followed. This is unlikely because only one of the 10 households interviewed reported complaints about the taste of chlorinated water and this complaint was only from one individual.

Households may also add too little or too much chlorine because the dosing procedure itself is hard to follow. When the pilot study was designed, Lee Hersh pointed to the need to find a suitable measuring devise that could be used to measure disinfectant, removing the need for households to count out 30 drops or 60 drops of Piyush each time they chlorinate their water supply. He suggested using widely available mineral water bottle caps for this purpose. This would require identifying a cap that holds approximately 2-ml of Piyush for the 10-liter bucket and 4-ml of Piyush for the 20-liter bucket. Unfortunately this recommendation was not followed when the pilot study design was implemented and users were not provided with measuring caps to simplify dosing.

One concern, expressed by Roshan Shrestha, director of ENPHO, was that the "three drops per liter" dosage scheme for Piyush disinfectant developed using Kathmandu distribution system water might not be appropriate for tubewell water in the Terai. In an effort to determine if improper dosing instructions were responsible for the low measured free chlorine residuals in household water, dosage testing was conducted at IBS during January 2002, after the field visits were completed. Chlorination was performed on 10 one-liter water samples from 5 sources; the IBS tap which is pumped from a shallow tubewell located behind the property, a shallow tubewell near the entrance to Lumbini gardens, a private tubewell in Buddanagar, a tubewells from Ramawapur(T) village, and a private tubewell from Sonbarshi village. Small samples were used because of collection constraints and because of the limited availability of the 10-liter bucket systems. All of the dosage tests were preformed on private tubewells because the majority of chlorine users in Lumbini drew their drinking water from these wells. During these dosage tests, each liter of water was chlorinated with 3 drops of Piyush and free chlorine residuals were measured immediately after dosing, 30 minutes after dosing, and 1, 2 and 4 hours after dosing. Figure 6.4 shows the average measured free chlorine residual in each of the five source waters.

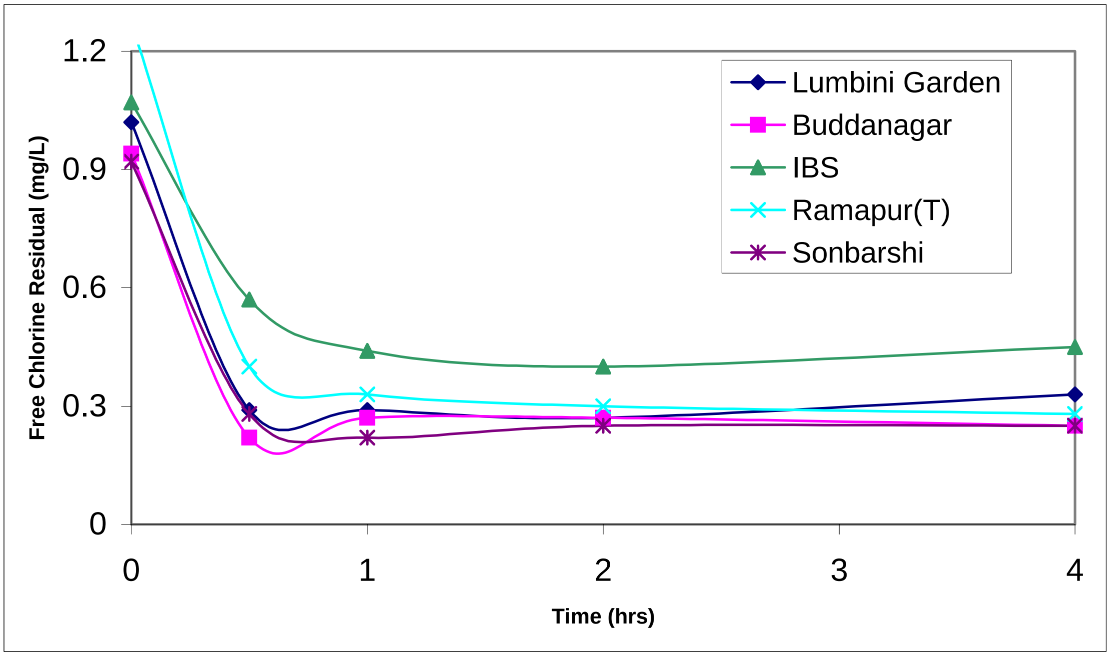

Figure 6.4: Free Chlorine Residuals After Piyush Addition (3 drops/Liter) to Various Source Waters

Free chlorine residuals 30 minutes after the addition of Piyush were between 0.2 mg/L and 0.6 mg/L for all source waters. This indicated that the 3 drops per liter dosage developed in Kathmandu seems to be appropriate for Lumbini tubewell water. The low measured chlorine residuals in stored household water do not appear to be the result of improper dosage instructions. The free chlorine residuals obtained during dosing testing do indicate that it may be possible to increase the dosage recommendation to 4 drops per liter without exceeding proper free chlorine residual levels. Further testing should be conducted to see if 4 drops per liter might be a more suitable dosage for Lumbini tubewell water. Further tests should also be conducted to see if chlorine demand increases in tubewell water during the monsoon season, requiring the application of higher chlorine doses.

Measured free chlorine residuals will differ in water samples collected from different sources, as shown by the variation in free chlorine residual measured during dosage testing. Sources that are relatively free of organic matter will have lower chlorine demand, resulting in higher free chlorine residuals. The addition of too large a dose of disinfectant to water from these sources may result in a disagreeable chlorine taste, causing user rejection of chlorinated water. Sources that have high levels of organic matter will have higher chlorine demand resulting in lower free chlorine residuals. The addition of insufficient doses of chlorine to water from these sources may result in incomplete bacterial removal. Thus one dosing scheme may not be appropriate for all water sources. This issue can be addressed by adjusting chlorine doses on a case-by-case basis after measuring free chlorine residuals. This may be possible in Lumbini if the IBS motivators are instructed on how to complete these chlorine residual tests and how to alter chlorine dosage based on the results they obtain. ENPHO currently produces a free chlorine residual detection kit that is capable of measuring free chlorine residual in 3 ranges, 0-0.2 mg/L, 0.2-0.5mg/L, and 0.5 – 1.0 mg/L, using an orthotolidine test method. This test could be used by the motivators for dosage adjustment. Compliance with proper dosing instructions may also increase when villagers are aware that the IBS motivators will be using chlorine residual tests to determine if they are chlorinating properly.

6.4 Household Survey

A household survey was conducted during the January 2002 evaluation period to observe household water storage and chlorination practices, to evaluate the social acceptability of household chlorination in the Lumbini area, to determine if villages perceived any changes in their health due to the chlorination project and to assess the willingness of Lumbini residents to pay for chlorine disinfectant and storage vessels. The survey that was developed for this purpose was designed in six sections:

1) *Household Information*: This section included questions that gathered household information including the number of individuals in the household and the number of children in the household. This section was designed to determine what portion of the Lumbini population was affected by the Pilot Study and whether children were targeted.

2) *Source Water and Pre-Treatment Practices*: This section relates to source water quality and was designed to assess the need for and practice of pre-filtration or settling.

3) *Water Chlorination, Water Handing, and Consumption*: This section included several questions about chlorine dosage, wait time, use of chlorinated water, hygiene practices and availability of sanitation facilities. This section was designed to assess whether the chlorination systems were being used properly and determine what levels of sanitation or hygiene practices are in place.

4) *Project Acceptance – Social Acceptability of Chlorination*: This section included questions about the taste and smell of chlorinated water and the additional time that disinfection takes. These questions were designed to assess the social acceptability of household chlorination. This section also included some questions about willingness to pay to determine if market demand would exist for chlorination products in Lumbini.

5) *Health Impact*: This section was designed to assess the health impact of household chlorination and asked villagers about the incidence of diarrhea in their households over the last month, and whether they perceived any effects on their health since they began using the chlorination systems.

6) *Alternative Treatment Options*: This section asked several questions about the use of alternative treatment technologies including solar disinfection (SODIS), boiling, filtration with ceramic candle filters, and Biosand Filtration.

The complete list of survey questions is presented in appendix B.

This survey was altered significantly in the field due to several complications. No control group was formed in the Lumbini Pilot Study, so questions designed to gather information for an intervention versus control group comparison had to be altered. Translation in the field was also difficult because the original survey instrument was written in English and the field survey was conducted by English speakers. Household visits were conducted with the help of the IBS motivators the majority of whom possess only a limited knowledge of the English language. Furthermore, simple translation of survey questions into Nepali was not adequate for household interviews because there are many local languages spoken in the Lumbini region. The language spoken by each village visited was often unique to that particular village making translation difficult because villagers would have to speak in Nepali, which was not their first language, or the motivators would have to speak the local language, with which they often had only limited familiarity. Because of these limitations, the survey questions were asked when possible, though typically in an abbreviated format and a non-participatory, observation-based approach was used to generate answers to other questions. For example, a participatory survey would ask households about the sanitation facilities that they have access to, and a non-participatory approach would rely on direct observation of sanitation facilities. The results of the household survey and their implications are presented for each of the six survey sections.

6.4.1 Household Information

The majority of households participating in the chlorination study were large. The average number of individuals per household was 24.2 compared with an average household size of 7.7 throughout the 17 IBS villages (IBS, 2002). This large household size may have been due to the fact that many of the chlorination buckets were actually being used by more than one household because there was a tendency to share the chlorinated water among extended families and neighbors. Thus a household with an actual size of 10 may report that 20 or 30 individuals are in their household because 20 to 30 people are in fact using the chlorinated water.

Few of the households participating in the study included children of any age. This may have been due to the selection process for program participation. The households participating in the pilot study were selected by IBS because they had been frequent visitors in the health clinic with complaints of waterborne illness. Many of the program participants happened to be village leaders, heads of the village leadership committees or the women empowerment committees that have been established in the villages. Presumably these households were chosen for participation not only because of their waterborne disease complaints but also because of their close ties to IBS. This type of elite capture can be undesirable because it can prevent programs from reaching those in the greatest need, but it also has some benefits when it occurs in a pilot project. If village leaders participate in pilot projects, such as the chlorination project that occurred in Lumbini, they may be able to promote water treatment technologies to the rest of the community. If villagers see their village committee leaders are using household chlorination to treat water for their families, they may be more inclined to treat their own water with chlorine disinfectant.

6.4.2 Source water and pre-treatment practices

Water was drawn from the well of each household that was interviewed for bacterial testing. No turbidity measurement where taken, but these water samples ranged from very clear to very cloudy, sometimes containing visible amounts of organic matter. Even in homes with visibly turbid water no pre-filtration or settling procedures were followed before chlorination.

A limited number of households did have the two-bucket candle filter systems but the Piyush solution was added to these systems before the water passed through the ceramic filters, thus this can not be considered pre-filtration because organic matter was not removed prior to the addition of the chlorine. It was suggested to these households that they instead add the disinfectant to the lower bucket after filtration but the women using these systems were understandably reluctant to follow this procedure because it would require them to wait several hours for the water to pass through candle filter* before they could add the chlorine solution. They would then have to wait an additional 30 minutes before they could consume the water.

The majority of households used the two-bucket systems without candle filters but none of these households reported using the 16-hour pre-settling procedure. In fact, none of the women using these systems received instructions about this procedure, and the women motivators who have been responsible for the education supporting the chlorination study were not aware of such a procedure. This misunderstanding most likely occurred because the suggested settling procedure was a late addition to the program, added after concerns arose about the acceptability of the candle filters in the original chlorination system design, and was therefore never communicated to the IBS motivators or to the villagers using the modified systems. When this procedure was suggested to households they again appeared reluctant to implement it, suggesting that it would not be possible for them to wait for such a long period of time before chlorinating.

Villagers gave several reasons for not wanting to wait for candle filtration or settling before chlorinating. Some villagers said this procedure was too difficult or too much work. Some villagers said that if they waited that long they would not be able to chlorinate enough water for their households. This may be related to the large number of users in each of the pilot study households. Although the average household size in Lumbini is 7.7 individuals, the average number of users reported by the 16 households in the Pilot Study was 24.2. These large numbers of users for each chlorination system are a result of the communal nature of Lumbini villages and the tendency for chlorine users to share their treated water with extended family and neighbors. With as many as 40 individuals reportedly sharing one 10L vessel of chlorinated water it becomes necessary to refill and re-chlorinate the vessel several times each day. A solution to this unwillingness to pre-treat may be to simplify pretreatment procedures. Although a 16-hour settling procedure may represent the ideal, it may be possible to obtain most of the benefits of pre-settling with a shorter settling time that would be more acceptable to participants, perhaps on the order of 1 hour. It may also be possible to incorporate a filtration step using locally available cloth. These types of pre-filtration procedures have been used in several CDC Safe Water Systems Programs (CDC, 2001).

It should also be emphasized to villagers that they should always use the best available water source, regardless of the treatment options that have been made available to them. Prior to the Lumbini Pilot Study, villagers were encouraged by the IBS women motivators to use only the deeper newly installed IBS tubewells for drinking water collection and to use private wells only for bathing, washing clothes, and other non-consumptive practices. Many villagers were reluctant to follow these instructions choosing to continue using private wells for drinking water because these wells are located closer to their homes and are therefore more convenient for users. This practice seems to increase when villagers are provided with household water treatment options. Although large numbers of villagers can be observed using the IBS wells for drinking

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* The flow rate of these ceramic filters are only 0.3 L/hr (Smith, 2001). Therefore, it would take almost 17 hours for 10L of water to pass through the 2 candle filter units contained in the top bucket.

water collection, none of the villagers that had been provided with chlorination systems were using these wells, choosing instead to use the Piyush solution to disinfect water from their private wells. This practice was also observed in the newly established Biosand filter program. Many villagers requesting Biosand filters stated explicitly that they wanted a filter for their household so they could not have to walk to the village well. This practice can result in less effective filtration or disinfection when filters become clogged with organic matter from poor water sources or when bacterial kills are reduced because of the elevated chlorine demand caused by high levels of organic matter. For these reasons, the best available water source should always be used regardless of the household treatment options that are in place. It is, of course, important to recognize that this recommendation places an added burden on those who are required to collect and carry water, typically village women.

6.4.3 Water chlorination, handling, and consumption

Most households collect well water in the morning and chlorinate it for use throughout the day. All households knew the correct dose of chlorine to apply to their systems, although measured chlorine residuals may have indicated that these dosing procedures are not always followed (section 5.2.1). All participants reported cleaning their vessel daily, usually with soap and water, as instructed by the motivators, though a few of the vessels appeared visibly dirty inside. All households reported using the chlorinated water only for drinking and using untreated water for handwashing and dishwashing. None of the households carried chlorinated water with them to consume outside of the home.

Few questions were asked about the availability of sanitation facilities because latrines, public or private, have not been installed in any of the villages visited with the exception of one private latrine used by an individual household not participating in the chlorination study. Residents of the villages visited practice open defecation usually in the fields surrounding the central village area.

6.4.4 Project Acceptance – Social Acceptability of Chlorination

Household chlorination seems to have been well received by participants in the pilot study. During the household visits only one complaint about the taste of chlorinated water was recorded, and only one member of this household had refused to drink the chlorinated water. The women using the chlorination systems did not feel like the procedures were difficult or time consuming, although they did not perform pre-filtration or settling procedures. All of the households were asked to explain what the chlorine solution does to the water and each household correctly stated that the Piyush solution removes “contamination” which improves their health, indicating a high level of understanding regarding the purpose of household chlorination. Many of the program participants also reported that their neighbors were interested in using Piyush solution and asked if the program could be expanded to include more households.

This portion of the survey also included a question designed to assess participants’ willingness-to-pay for household chlorination. This survey question asked villagers if they would continue to use the Piyush solution if they were required to pay a small amount for each bottle. No specific price was specified and the question was designed only to gauge initial responses to the removal of subsidies. The women motivators who assisted with the translation of the survey were reluctant to ask this question to study participants, stating repeatedly that the villagers were too poor to contribute to the cost of the chlorination solution or storage vessels. Because of the reluctance of the women motivators and the negative responses received during the first few days of field visits, this question was dropped from the January survey in favor of planning and conducting a more thorough willingness-to-pay survey at a future date. The requirements for this survey are discussed in more detail in Chapter 9.

6.4.5 Perceived health effects

This portion of the survey was originally designed to generate data for a comparison of diarrheal disease between the intervention group and the control group of the pilot study. This method was chosen because it has been widely used by other SWS programs to evaluate the health effects of household chlorination (CDC, 2001). The majority of these questions were abandoned because of the lack of a control group to allow for comparison. Instead, the analysis of health effects focused on the monthly health data complied by Dr. Mallick (*See section 6.1.2*). After this modification villagers taking part in the Pilot Study were simply asked if they had noticed effects on their health or their family's health since they had begun chlorinating their water. Overall, the responses to this line of questioning were positive, all households interviewed reported improvements in their health, including reductions in abdominal pain, diarrhea and gastro-intestinal disease in general. Although these questions were only designed to gather information about perceived health effects, villagers were not asked for specific numerical incidences of each disease nor where they requested to provide evidence of health improvement. The responses that were generated   provide valuable insights into future demand for chlorination in Lumbini. Participants in the pilot study felt that the chlorination systems had improved their health and they openly shared these health improvements with other villagers, thereby generating significant demand for an expanded household chlorination program in Lumbini.

6.4.6 Alternative Treatment Options

This series of questions was designed to determine if villagers in Lumbini were using other water treatment methods including solar disinfection (SODIS), boiling, or candle filters. These questions were eliminated from the survey because of translation difficulties. However, through village visits and discussion with the IBS motivators, a general sense of water treatment practices was obtained and it became possible to assess the use of alternative treatment technologies without this portion of the survey. In general most villagers in Lumbini do not practice any form of water treatment. Some of the wealthier village residents may boil water, but on a limited basis and usually only for use by those who are very old or very sick. Candle filters are not used in the villages, with the exception of those distributed during the chlorination pilot project. The motivators and some of the villagers did attend the SODIS training session put on by

Peter Moulton in 1999 at IBS, but none of the villagers are currently practicing SODIS. The motivators report that it was too much work and never caught on with villagers.

This section also included questions about the Biosand Filter to determine how many villagers are aware of the Biosand program and how many would like to participate. Twelve Biosand filters were installed in several Lumbini villagers at the time of the January evaluation. All villagers living in these villages seemed to be aware of the program and several individuals requested Biosand filters for their households. The program has not been in place long enough to determine how the community will ultimately respond to these filters, but the initial reaction seemed positive.

CHAPTER 7 KEY COMPONENTS OF THE LUMBINI PILOT STUDY OF HOUSEHOLD CHLORINATION

The Lumbini Pilot Study of Household Chlorination represents the first attempt by the MIT-Nepal Project to implement a water treatment program for rural villagers in Nepal using technologies identified as appropriate and effective based on previous project work. As the MIT-Nepal Project moves forward with its work in Nepal and identifies additional suitable technologies, it is likely that further implementation program will be developed. For example, in January 2002 three MIT Master's of Engineering students, Barika Poole, Jeff Hwang, and Tommy Ngai, visited Nepal to field-test several household level arsenic removal technologies. A number of these technologies, including an iron-coated sand arsenic removal system and the BP/I3 & A/M arsenic removal system appear to be both effective and appropriate for treating arsenic contaminated tubewell water in Nepal. Based on the 2002 findings, it may be appropriate to move forward with implementation programs to install these technologies at the household level in regions of Nepal affected by arsenic contamination.

As the Lumbini Household Chlorination Pilot Study draws to a close, it is important to identify key components that contributed to the success of the study, in order to incorporate them into a larger scale implementation of household chlorination and replicate them in other implementation programs developed by the MIT-Nepal Water Project. The following discussion highlights three key components of the Lumbini Household Chlorination Pilot Study that, because of their success in this study, should be incorporated both in an extended chlorination program and in any new implementation programs conducted during future MIT work in Nepal. These components include: the building of partnerships with existing organizations, the inclusion of user groups, particularly women, and the inclusion of schools.

7.1 Building Partnerships

Building partnerships with existing organizations when establishing an implementation program or pilot study is desirable for several reasons. Local organizations that are already well-established in the project area will be more familiar with the needs of local people and may be able to suggest the most appropriate treatment technologies and educational channels. Local participants may be more responsive to a water treatment program when it is promoted through a local organization with which they are familiar. And finally, programs are more likely to be sustainable if they are established through organizations that exist independently of the pilot study or implementation program (CDC, 2001).

Two national and local organizations in Nepal were used in the establishment of the Lumbini Pilot Study, the Kathmandu-based NGO Environmental Public Health Organization (ENPHO), and the Internal Buddhist Society (IBS), a Lumbini-based social development organization.

Figure 7.1: The International Buddhist Society (left) and ENPHO (right).

7.1.1 ENPHO

ENPHO played an essential role in the project because of the calcium hypochlorite disinfectant solution, Piyush, that they currently produce for distribution in urban Kathmandu. The use of this solution allowed the Lumbini Pilot Study to be implemented without the creation of a production facility for disinfectant. Because sodium hypochlorite generation was not required for the pilot study, the funded needed to successfully establish a pilot program for household chlorination in Nepal was significantly reduced. ENPHO's lab facilities in Kathmandu also proved valuable to pilot study evaluators visiting Lumbini in January 2002. These lab facilities allowed members of the MIT-Nepal water project team to create additional H_2S presence/absence bacterial tests for use by IBS in Lumbini. In addition, ENPHO provide technical support for IBS throughout the pilot study through their scientific knowledge base.

A sodium hypochlorite generator has now been installed at ENPHO and the disinfection solution produced by this instrument will soon replace the calcium hypochlorite Piyush product (Morganti, 2002). With this new sodium hypochlorite generator, ENPHO will play a central role in any expansion of the Lumbini Pilot Study, as they will be the primary producer of disinfectant solution for an expanded project.

7.1.2 IBS

IBS also played a central role in the Lumbini Pilot Study, as they were ultimately responsible for many components of program implementation in the absence of the MIT-Nepal Project Team. The participation of IBS allowed the pilot study to continue between its establishment in January 2001 and the return of the MIT-Nepal Project team to Lumbini in January 2002. As described in Chapter 4, IBS was responsible for selecting program participants, distributing vessels and disinfectant solution, explaining dosing procedures to participants, collecting monthly health data from participants and collecting bi-monthly samples of stored household water for bacterial analysis.

7.1.3 Village-Level Organizations

In addition to national level organizations such as ENPHO and local organizations such as IBS, the Lumbini Pilot Study also made use of village level organizations in Lumbini. These village level organizations included the Village Development Committees and Women Empowerment Committees established through IBS to improve village government and leadership in Lumbini. Many of the pilot study participants were members or leaders of these organizations and worked to actively promote Piyush and household chlorination in the Lumbini villages. If villagers see members of these leadership organizations practicing household water treatment, they may be more likely to consider practicing household water treatment in their own homes. Village level organizations can therefore play a substantial promotional role in implementation projects. Village level organizations may also have a better sense than local level organizations of what technologies and educational channels are most appropriate for their villages. Thus, village level organizations should be included in the development of implementation program as well.

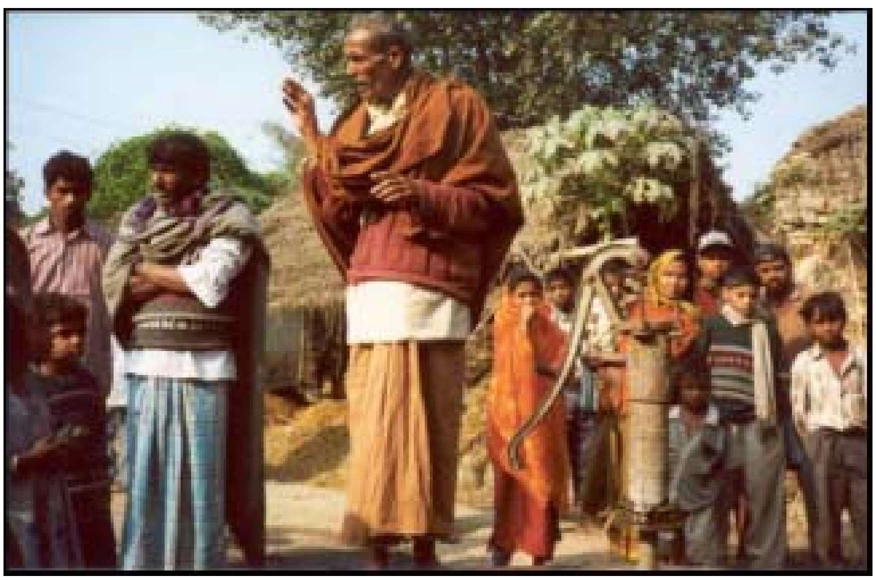

Figure 7.2: Member of a Village Leadership Committee, Lumbini.

Because the MIT-Nepal Project teams visit Nepal only once yearly during MIT's January term, partnerships with existing organization in Nepal become essential when implementation projects are attempted. It can take several weeks to establish a pilot study or implementation program and any program of this sort will require frequent monitoring to ensure its success. Program participants will need to be visited periodically to ensure that they are using their treatment technologies properly and to evaluate the success of the program. This type of monitoring cannot occur without the participation of local organizations.

7.2 Inclusion of Women

7.2.1 The Importance of Inclusion

Women are often responsible for water provision in developing countries. In many places around the world the majority of a women's day is spent walking to distant water sources, waiting in line for water collection, or caring for individuals affected by waterborne disease. Because of their central role in water provision, childcare, and other domestic tasks, women can reap significant benefits from water provision or water quality improvement projects. When women in developing countries no longer have to devote such a large portion of their day to water provision, they will have more time to pursue education and engage in employment or entrepreneurial ventures.

The Dutch Buba-Tombali well project that began in 1974 in the West African Republic of Guinea-Bissau illustrates the importance of recognizing the differential benefits of water supply projects among gender groups. The Buba-Tombali project required that recipient communities play a substantial role in both project planning and implementation. One component of this participation was the provision of local laborers for well construction. Villages that were to receive water supply wells from the project were required to build an access road that would allow trucks carrying construction material to reach the well sites. In many project areas, these access roads never materialized because the road building was the responsibility of village men, whereas the major beneficiaries of the water supply project, in terms of timesavings and living standard improvements, were village women (Chauhan, 1983).

Other programs have attempted to use young men as well care-takers responsible for the upkeep and repair of village wells, only to find that these men commanded very little respect from villagers and failed to interact with well-users because the majority of these users were women. A water supply and well maintenance program in South India found that many village women did not even know the name of their male well caretaker and other women where reluctant to notify well caretakers when they experienced problems with their handpumps, because they were unaccustomed to dealing with young village men and preferred to contact village elders about pump repair (Chauhan, 1983).

7.2.2 Women in the Lumbini Pilot Study

In the region of the Terai where the Lumbini Pilot Study was conducted, women are largely responsible for water provision. They decide which water sources to use and for what purpose. They collect water daily for household use and use the village wells for washing clothes or bathing children. They are often responsible for any water treatment that occurs within the home. Thus the inclusion of women in a water treatment project is essential for project success. This inclusion can often be difficult, especially in regions where women are not always allotted the same privileges as their male counterparts. Women in Nepal generally have fewer opportunities from birth. Nepal is one of the only countries in the world where female life expectancy is lower than male life expectancy. The most recent census revealed that boys outnumber girls significantly in the 0-14 age group. These trends are likely due to an unequal access to resources throughout life (Sattaur, 1996). In the 17 villages with which IBS currently works, only 10 percent of women over the age of 15 are literate, yet 64 percent of men over age 15 are literate. This may improve slightly in the future because almost 40 percent of girls between the ages of 5 and 15 are now attending area schools, but educational discrepancies still continue. Seventy-three percent of boys between these ages attend schools.

Table 7.1: Educational Characteristics of the Lumbini Population, by Gender

	Male	Female
Children (5-15) in School	74 percent	40 percent
Literate Population (15+)	65 percent	10 percent

Previous attempts to include women in water supply projects in Nepal have not necessarily been successful. The Nepal Human Development Report 2001 reported substantial gender disparities in participation in water and sanitation supply projects. Only 30 percent of women surveyed participated in the planning of their communities' water and sanitation supply projects, compared with 54 percent of men (UNDP, 2002).

The Lumbini Pilot Study seems to have been more successful than previous programs in achieving high participation levels from female villagers. In the 10 households in the Lumbini Pilot Study that were interviewed in January 2002, 8 of the primary survey respondents were women. All of the women interviewed regarding the chlorination systems exhibited thorough knowledge of the use of the Piyush solution and chlorination vessels. They were able to recite the proper dose of chlorine to use in their systems, they were able to explain how the systems should be cleaned and how often and they demonstrated an understanding of why water chlorination could improve the heath of their families.

Figure 7.3: The IBS Women Motivators

The inclusion of women in the Lumbini Pilot Study was simplified by the presence of the IBS women motivators who played a large role in the pilot study. The women motivators were largely responsible both for the distribution of Piyush and storage vessels and for conducting follow-up visits to collect health data and ensure that the chlorination systems were being used properly. The women motivators tend to interact primarily with village women during these visits. This allowed the women in Lumbini to assume primary responsibility for the chlorination system and play a central role in the pilot study, because they received instructions on household chlorination directly from the women motivators and they were usually the primary respondents to the monthly health surveys. This type of inclusion could be replicated by future implementation projects in Nepal by stressing the importance of using female staff members and educators so village women can receive training directly from other women.

7.3 Inclusion of Schools

7.3.1 Inclusion of Schools in the Lumbini Pilot Project

In addition to the 34 households that participated in the Lumbini Household Chlorination Pilot Study, 374 students in 4 villages benefited from the chlorination program while at school. Four Lumbini area primary and secondary schools received Piyush solution and bucket systems as part of the pilot study. The original pilot study design called for the inclusion of 20 area schools, 10 that would receive the chlorination materials and 10 that would participate as a control group in order to assess the effect that chlorine would have on the health of school children. This large-scale schools project proved difficult for IBS to implement and only four schools were included. Full health surveys were difficult to conduct in the intervention schools and would be difficult to analyze without the benefit of a control group. In spite of these challenges, the inclusion of four Lumbini area schools gave valuable insight into possible methods for promotion of household chlorination or for education about the proper usage of chlorine disinfectant.

During January 2002, three of the four schools included in the Lumbini Household Chlorination Pilot Study were visited in order to conduct bacterial and chlorine residual tests and to interview teachers and students at the schools to find out how they felt about the chlorination program. Unfortunately these visits usually occurred before students arrived, as the school day does not start until mid-morning to allow students to travel from home, so no student interviews were conducted.

Since all of the visits took place before school was in session, only one school had water available for testing. The free chlorine residuals measured in the school chlorination systems were slightly lower than desired, between 0.0 mg/L and 0.1 mg/L, though the principal reported adding the correct amount of Piyush, 60 drops per 20-liter bucket. These low chlorine residuals may have been due to high levels of organic matter in the school well. No turbidity measurements were taken but the sample was visibly cloudy and appeared to contain large amounts of organic matter. Bacterial analysis revealed complete bacterial removal in spite of these low chlorine residuals.

Principals of all three schools were eager to have their water tested, and welcomed any suggestions to improve their chlorination practices. The teachers in these schools expressed substantial concerns about waterborne disease and indicated that many of their students suffer in school because of these ailments. Many of the teachers reported requests from parents who wanted chlorination systems in their homes. As one principal explained, "they [the students] see us using Piyush at school. They learn about water diseases and water disinfection at school and go home and tell their parents about it. Then their parents want Piyush too . . . "

All of the teachers interviewed felt that the chlorination program had improved the health of their students, usually stating that they now have less complaints of stomach trouble. None of the teachers reported complaints about the taste of chlorinated water, saying that students were happy to drink the chlorinated water because they learned in school that it could improve their health. Many teachers requested additional buckets or chlorination systems saying that they were not able to produce enough water for their students. At one school, teachers reported chlorinating 25 buckets of water per day. This raised some concerns with program evaluators because it would not be possible to chlorinate such a large volume of water each day if teachers were waiting the required 30 minutes to consume the water after adding disinfectant. The principal of this school asked about the possibility of installing a Biosand filter at his school to solve this problem, expressing an interest in another pilot study now being established in Lumbini.

Figure 7.4: Primary School in an IBS village

The experience gathered by the inclusion of schools in the Lumbini Chlorination Pilot Study demonstrates the substantial role that schools can play in water and sanitation programs. Every effort should be made to include schools in future chlorination or household water treatment projects conducted in Nepal. These schools can play valuable roles not only in educating students and parents about waterborne diseases and treatment options, but also in promoting particular treatment technologies or behaviors related to water and sanitation. Only about 60 percent of children in the Lumbini between the ages of 5 and 15 attend these schools regularly (IBS, 2002), but a large portion of the Lumbini population can still be reached through the school system. If Piyush is introduced as a commercial product in Lumbini, the schools could play a valuable role in product promotion and demand generation. Similarly any sanitation or hygiene education program planned for the Lumbini area should include components that make use of the Lumbini school system.

7.3.2 Incorporation of Schools in Other Programs

The incorporation of schools in the Lumbini Pilot Study is not unique to this chlorination program. Other Safe Water System programs have used schools either as a component of chlorination programs directly or as a forum for behavioral modification and for hygiene and sanitation education programs. The CDC's Safe Water System Manual suggests that schools be used as educational and promotional channels in the following manner:

> "Seminars are held to teach teachers about diarrheal diseases and home water treatment to encourage them to include this information in their curriculum. Presentations are then held in schools to educate students and their parents. Teachers keep Safe Water Systems vessels in their classrooms. Day to day children take turns adding disinfectant and they all enjoy a supply of safe drinking water at school. When children learn how to disinfect water and keep it safe, they can help their families do the same at home (CDC, 2001)."

Even in Lumbini, the idea of incorporating schools into water supply and treatment programs is not new. In 1999, Peter Moulton of the Global Resources Institute (GRI) in Eugene, Oregon visited the International Buddhist Society to test the viability of solar disinfection (SODIS) in this region of Nepal. He suggested that SODIS education be incorporated into school health programs with the dual purpose of providing safe water during school hours and training students to take SODIS technology back to their homes and villages (Moulton, 1999).

The integration of schools and schoolteachers in the Lumbini Household Chlorination Pilot Study and Safe Water System programs can be expanded beyond the educational roles these programs have traditionally established for them. Schoolteachers are generally well-respected community members. They are privileged enough to hold steady, paying positions, perhaps freeing some of their time to contribute to community water supply and sanitation projects. Schoolteachers can hold motivational roles in community projects; encouraging villagers to use newly installed sanitation facilities or obtain drinking water from sources that have been found to be microbially safe. They can also pay a role in well maintenance and repair both for wells on school grounds and more generally for wells in villages surrounding school grounds. Using teachers as well technicians has several advantages. Well repair equipment can be kept on schools grounds, if proper facilities exist. Routine well maintenance can be incorporated into the routine of village schoolteachers and maintenance skills can be passed down to new teachers insuring the sustainability of village well maintenance programs. This approach was highly effective in a water supply and well maintenance program established in South India in the 1970s. Schoolteachers in this program have been trained as caretakers for pumps located near their schools and have not only been able to ensure that pumps remain in working order and well areas are kept clean, but have also been able to assist in health education and motivation because they are already well-respected as educators in the villages where they live and work (Chauhan, 1983).

7.4 Applications for Future Household Water Treatment Programs

Lessons learned in Lumbini, from partnership building, to the inclusion of women, to the use of schools as educational and promotional forums for household water treatment, should be applied to future projects conducted in Lumbini and in Nepal more generally. The Biosand Pilot Study established in Lumbini in December 2001 can make immediate use of these lessons. The Biosand program is in the early stages of development. Partnerships with both IBS and Durga Ale, a local Biosand builder, have been formed, efforts to train the IBS women motivators on the use of these filters are underway, and filters have already been installed at several local schools. All of these components will likely play a role in the success of the Biosand Pilot Study.

CHAPTER 8 LUMBINI PILOT STUDY OF HOUSEHOLD CHLORINATION – FINAL ASSESSMENT AND RECOMMENDATIONS FOR FUTURE IMPROVEMENT AND EXPANSION

Now that the Lumbini Pilot Study has been in place for the intended year-long period, it is essential to revisit the goals of the program and determine if household chlorination was a success in Lumbini. This chapter includes both a final assessment of the Lumbini Household Chlorination Pilot Study, and a series of recommendations to improve and expand the pilot study's impact in Lumbini and throughout Nepal.

8.1 Final Assessment of the Lumbini Household Chlorination Pilot Study

The first step in assessing the success or failure of the Household Chlorination Pilot study is to revisit the criteria for success outlined in Chapter 4. These criteria for success included significant reductions in the incidence of waterborne disease among sample group participants, elimination or reduction of microbial contamination in stored water at sample group households, and high rates of user acceptance of household chlorine disinfection. In order to assess these criteria for success, the three numerical indicators below were selected:

(4) Greater than 30 percent reduction in waterborne disease among sample group participants
(5) Less than 10 percent of chlorinated stored water in sample group households testing positive for bacterial contamination
(6) Less than 10 percent of sample group participants reporting complaints about chlorine taste, resulting in non-treatment of drinking water.

The first indicator, a greater than 30 percent reduction in waterborne disease, is difficult to evaluate without the benefit of a control group in Lumbini, but the review of health data collected by IBS from pilot study participants indicates significant reductions in waterborne disease (*Section 6.1*). The first indicator therefore points to program success.

The second indicator, less than 10 percent of chlorinated water testing positive for bacterial contamination, was clearly not met by the Lumbini Pilot Study. Of the seven water samples collected from stored water in January 2002, four water samples (57 percent) tested positive for bacterial contamination using H_2S presence/absence tests (*Section 6.2*). Thus, the second indicator points to program failure.

The third indicator, less than 10 percent of sample group participants reporting complaints about chlorine taste, is perhaps the most challenging to evaluate because records were not kept on households that discontinued the use of chlorine prior to January 2002. One only complaint about chlorine taste was recorded during the January 2002 Pilot Study evaluation. This complaint was from an individual who no longer drank the chlorinated water, the rest of his family was continuing with chlorination with no taste complaints (*Section 6.4*). Clearly this demonstrates that less than 10 percent of the households visited in January reported complaints about chlorine taste but no information is known about the households that have discontinued chlorination. Presumably some of these households dropped out of the program due to a dissatisfaction with the taste of chlorinated water. Based on the interviews conducted in January 2002, this indicator points to program success, but high dropout rates may indicate program failure. In sum, it is not possible to draw clear conclusions regarding this third indicator.

Criteria	Outcome
(1) Waterborne Disease Reduction	SUCCESS
(2) Bacterial Contamination Elimination	FAILURE
(3) Acceptance of Chlorinated Drinking Water	SUCCESS/FAILURE

Table 8.1: Evaluation of Pilot Study Criteria for Success

Positive Results for all three indicators would point unambiguously to project success, but the varied results from the Lumbini Pilot Study do not necessarily point to project failure. The central question that must be answered is, "Is household chlorination an appropriate approach to safe water provision in Nepal?" An affirmative answer to this question requires that two conditions be met. First, villagers in Nepal must accept household chlorination. That is, villagers must be willing to use their chlorine disinfectant and vessel to treat their household water supplies and they must be willing to consume the chlorinated water that results from these treatment processes. Second, chlorination must be able to effectively provide safe water to villagers in Nepal. That is, household chlorination must be able to remove bacterial contamination and maintain proper free chlorine residuals that can prevent recontamination of stored water supplies.

The results of the Lumbini Pilot Study indicate that first condition of user acceptance of household chlorination is being met in Lumbini. Although over half of the original pilot study participants have discontinued the use of household chlorination, less than one percent of current users report complaints about the taste of chlorinated water and all households surveyed in January 2002 indicated that they had perceived health effects, including reductions in diarrhea and abdominal pain, since they had begun the chlorination program in January 2001. Furthermore, the generation of demand for household chlorination was clearly demonstrated during the January 2002 evaluation. Many villagers requested chlorination systems for their households and several school principals reported requests from parents for home chlorination systems. Brand recognition of the "Piyush" name in Lumbini was widespread. Almost all villagers in the areas visited during the evaluation period knew of the Household Chlorination Pilot Study and understood the purpose of household chlorination and the Piyush disinfectant.

The second condition was not so easily meet in Lumbini. Only 43 percent of the households visited in January 2002 demonstrated complete bacterial removal in their chlorinated water supplies, and only 29 percent maintained proper free chlorine residuals between 0.2 and 1.0 mg/L. These results are troubling because they indicate that household chlorination is not effectively providing safe water in Lumbini. At this stage in the program it is essential to investigate the cause of this failure to provide safe water through household chlorination and determine if improvements can be made to the program to reverse this trend. Although household chlorination has gained acceptance among Lumbini villagers and a significant demand for chlorination products has been generated, many villagers are not practicing household chlorination properly. The inadequate bacterial removal and free chlorine residuals measured in Lumbini are caused by improper pretreatment practices, improper chlorine dosing, and poor chlorine water handling practices.

Key Finding of the Lumbini Chlorination Pilot Study
Positive Indicators
▪ Acceptance of Household Chlorination
▪ Brand Recognition and Demand Generation
▪ Measured Reduction in Waterborne Disease
▪ Inclusion of User Groups: Schools, Women
▪ Positive Response and Commitment from IBS
Negative Indicators
Large Drop-out Rate
Non-Removal of Bacterial Contamination
Inadequate Chlorine Residuals
Difficult Dosing Regime and Non-Ideal Storage Vessel

Table 8.2: Key Findings of the Lumbini Chlorination Pilot Study

The CDC differentiates between two categories of Safe Water System Program components, hardware and software. *Hardware* refers to the actual products used in a household chlorination project, including disinfectant solutions and safe water storage vessels. *Software* refers to product promotion, education, community mobilization and other components of the program designed to generate behavior change, encourage people to use the hardware products, and educate people to use them properly (CDC, 2001).

The Lumbini Household Chlorination Pilot Study is an example of what can happen when the hardware components of a program are installed without full consideration of the software components. Although demand generation and acceptance of household chlorination was a success in Lumbini, the hardware products themselves did not function as expected because insufficient instruction was given by program leaders due the rapid installation of the pilot study in January 2001 and villagers had trouble using the hardware products properly. Fortunately for the villagers in Lumbini, IBS has reacted positively to the chlorination pilot study and is committed to improving the effectiveness of household chlorination. This can be accomplished through a series of education programs, run by IBS and the women motivators, designed to introduce the missing "software" components in Lumbini, and improve household chlorination and water storage practices.

Although the first attempt at household chlorination in Lumbini, as demonstrated by the pilot study, was not immediately effective at safe water provision, this can be improved in the future with minor adjustments designed to ensure that household chlorination is conducted properly and user demand in Lumbini is meet.

8.2 Final Recommendations for Improvement and Expansion

Based on the January 2002 evaluation, the Pilot Study of Household Chlorination established in Lumbini in January 2001 has shown that household chlorination is an appropriate approach to point-of-use water treatment in this region of Nepal. As the pilot study has reached the end of its intended year-long period, it should be discontinued and replaced with a Household Chlorination Program designed to reach a larger number of villagers. This program should incorporate the following recommendations for expansion or improvement:

Expand Program Reach: The Lumbini Household Chlorination Pilot Study is currently providing safe water storage vessels and disinfectant solution to 16 households in Lumbini. Thus, only 386 villagers or 4 percent of the Lumbini population have been reached directly by the program, yet almost all residents of the 17 villages served by IBS have now been exposed to the Safe Water System approach either through direct use, through observation of use by their neighbors, or through the school chlorination component of the program. This exposure has generated a considerable amount of demand for vessels and Piyush solution in the Lumbini area. A household chlorination program should be created to build on the success of the pilot study, include more users, and meet this demand.

Plan for Community Participation: An expanded household chlorination program will be successful in Lumbini only if users are given the opportunity to participate in the planning process. A series of public meetings should be held to allow local villagers the opportunity to voice their ideas and opinions on program expansion. These meetings could be run through IBS with the help of the IBS women motivators and should help program developers to understand the cultural context within which they are working. Enhanced community participation will ensure that the needs of Lumbini villagers are meet through the expanded chlorination program.

Introduce User Contributions and Cost Recovery: Any expansion of household chlorination in Lumbini should introduce user contributions for both Piyush solution and storage vessels. Increased user contribution may lead to full or partial cost recovery and will increase funding available to the program. It may also lead to greater user investment in the project, thereby increasing long-term program sustainability. Users contributions could be in the form of monetary payments for disinfectant solution and storage vessels or through payment in kind, such as a "Vessel for Work" program (CDC, 2001).

Develop a Sodium Hypochlorite Disinfectant Solution: The Lumbini Pilot Study used a calcium hypochlorite disinfectant solution. This type of chlorine disinfectant is not recommended by the CDC because of the caustic, hazardous nature of powdered calcium hypochlorite and because the dissolution of this powder to create dilute disinfection solutions can produce large volumes of hazardous waste (CDC, 2001). An effort should be made to switch to a locally generated sodium hypochlorite solution. Fortunately the

MIT-Nepal Water Project received the donation of a SANILEC-6 sodium hypochlorite generator from Severn Trent de Nora Inc. in December 2001. This generator was installed at ENPHO's Kathmandu Laboratory in January 2002 and ENPHO is now using it to manufacture a sodium hypochlorite disinfection solution that will replace the calcium hypochlorite product. The new product will retain the Piyush brand name and packaging (Morganti, 2002). This development will allow the Lumbini project to switch to a sodium hypochlorite disinfectant without losing the Piyush brand recognition established by the pilot study.

Develop Simplified Dosing Regimes: The dosing schemes used during the Lumbini Pilot Study required users to add 30 to 60 drops of Piyush solution to their storage vessel, depending on its volume. This dosing scheme is unnecessarily complicated and should be simplified so users are more likely to dose accurately and "drop-counting" is not necessary. Because a 30 drop dose corresponds to approximately 2-ml of Piyush and a 60 drop dose corresponds to approximately 4-ml of Piyush, the dosing scheme could be easily simplified by providing users with a measuring cap with a volume of 2-ml or 4-ml and simple instructions to fill the cap halfway, full, or twice, depending on the size of the dosing cap and the size of the vessel. This cap could be incorporated into the design of the Piyush bottle or a separate cap, such as a mineral water bottle cap of appropriate volume, could be located and distributed with each bottle of Piyush solution.

Investigate Proper Chlorine Dose and Introduce Periodic Free Chlorine Residual Testing: Adequate free chlorine residuals were rarely maintained in pilot study homes yet preliminary dosage testing conducted in Lumbini in January 2002 indicated that the 3 drops per liter dose recommended by ENPHO should be adequate for tubewell water in the region. These dosage tests should be continued to confirm this result and periodic free chlorine residual testing should be introduced in Lumbini to monitor chlorine levels in stored water supplies. The IBS women motivators should be trained in the use of the simple free chlorine residual test kits currently produced by ENPHO and they should begin using these tests to monitor free chlorine residual levels in household water supplies, adjusting chlorine dosage when appropriate.

Introduce Simplified Pretreatment Procedure: If further dosage tests reveal high levels of chlorine demand in Lumbini tubewell water, this demand can be reduced through simple pretreatment measures, potentially eliminating the need to increase chlorine dosage in the region. Pretreatment may be more desirable than increased chlorine doses because higher levels of chlorination may result in a disagreeable chlorine taste. Pretreatment practices used in the Lumbini Pilot Study included candle filtration and a lengthy 16-hour settling procedure. Simplified procedures should be introduced to make pretreatment more socially acceptable to chlorine users. Potential pretreatment procedures that should be investigated include simple filtration through locally available cloth or a modified settling procedure that requires only one to two hours of wait time.

Improve Household Storage Vessels: The modified bucket storage vessel used in the Lumbini Pilot Study is not recommended by the CDC for Safe Water System programs because of its wide mouth and unsecured lid. Alternative storage vessels that could be explored for use in Lumbini include commercially available jerry cans, locally produced earthenware jugs, or specially molded SWS storage vessels. The plastic buckets used in the pilot study are widely available and generally inexpensive compared with alternative vessel options. It may be desirable to continue with the use of these modified buckets systems and implement education program designed to insure they are used properly. Messages that should be incorporated in such education programs include, keeping lids tightly secured, cleaning and drying buckets regularly, using only the attached spigot to withdraw water from the vessel, and never dipping hands or household utensils into the bucket to withdraw water.

Greater Focus of Proper Storage: The well survey conducted in Lumbini in January 2002 revealed low-level microbial contamination in only a fraction of the IBS installed tubewells. Based on these results, a significant portion of the Lumbini population has access to microbially safe water sources and the high incidence of waterborne disease in the region may be due, at least in part, to unsafe water storage practices. If funding for the expansion of chlorine disinfectant distribution in Lumbini is not available, the development or expansion of education programs encouraging the use of microbially safe wells along with safe water storage, with or without chlorination, may still result in significant reductions in waterborne disease incidence.

Improve User Education: Many of the negative observations recorded during the January 2002 Pilot Study evaluation related to the improper use of disinfectant or storage vessels. Low free chlorine residuals, contamination of stored water, and improperly maintained systems could be prevented through a comprehensive education program designed to insure that users are fully aware of the proper way to use and maintain their chlorination systems. These education programs should include components that explain the purpose of household chlorination as a preventative measure against waterborne disease, explain the importance of using appropriate source water and performing pretreatment, and encourage proper dosing, wait time, and use of vessels.

Expansion of Sanitation and Hygiene Education Programs: In addition to programs encouraging the proper use disinfectants and storage vessels, education programs can be used to disseminate knowledge of the mechanisms of waterborne disease transmission and encourage household hygiene and sanitation practices that can lead to reductions in waterborne disease. This type of education program is already in place in Lumbini through the IBS women motivators. Ideally proper sanitation facilities should be constructed to accompany these education programs. Currently, sanitation facilities available for rural villagers in Lumbini are limited and although some funding has been provided through IBS for the construction of public latrines and installation of drainage infrastructure, it will not be sufficient to provide for the sanitation need of the 10,000 villagers living within IBS villages. An expansion of the sanitation and hygiene education programs already in place in Lumbini may be able to reach a large portion of the Lumbini population with significantly reduced financial investments. The expansion of these programs should be explored while funding for additional infrastructure improvements is obtained.

Geographic Program Expansion: Based on the success of the Lumbini Pilot Study, the household water chlorination and safe water storage approach prescribed by Safe Water Systems is a viable method for providing safe water to Nepal's rural villagers in the Terai region. The Safe Water System approach may also be appropriate for other subgroups of the Nepali population, particularly residents of the hills districts whose water treatment options are limited due to their remote locations, and residents of urban Kathmandu who must rely on the city's distribution system, which is rarely chlorinated to proper levels (Shresha, 2001). It may be valuable to establish additional pilot studies in these areas to evaluate the appropriateness of the Safe Water System approach.

Many of these recommendations are intertwined. For example, without programs to develop at least partial cost recovery in Lumbini it is unlikely that the program will be able to expand to reach more users. The ideas of improved disinfection solution, alternative storage vessels, and modified dosing regimes have been explored through the discussion of the Lumbini Pilot Study presented in Chapter 6 and 7. New ideas introduced in these recommendations include cost recovery, program expansion and the introduction of advanced education programs

Cost recovery and program expansion are discussed in Chapter 9. The introduction of an improved household chlorination user education program and the development of behavior modification, hygiene and sanitation education programs for Lumbini are explored in Chapter 10.

CHAPTER 9 PLANNING FOR SUSTAINABILITY – COST RECOVERY AND WILLINGNESS-TO-PAY IN LUMBINI

There are multiple advantages to establishing a cost-recovery plan for the household water chlorination project in Lumbini. Higher levels of cost recovery will lead to programs with a greater potential for long-term sustainability and may generate revenue allowing for wider program expansion without substantial subsidies (Churchill, 1987). Fully subsidized programs may also be less sustainable because villagers who receive vessels and disinfect at little or no cost are less invested in the program. If IBS villagers have not made monetary or labor contributions to the program they may not use the vessels and disinfectant they have been provided and sustained participation in the household chlorination program may be difficult to achieve (CDC, 2001).

9.1 Potential for User Contributions in Lumbini

One of the critical questions to address in providing a sustainable means of safe water provision to the people of Lumbini is how much should these rural villagers be expected to pay or contribute for their water supply. Traditionally, the World Bank and other organizations involved in rural water provision have used a "5 percent rule-of-thumb" affordability criterion, implying that rural residents should be expected to contribute no more than 5 percent of their total income to water supply (Churchill, 1987). The residents of the 17 villages served by IBS currently make no monetary contributions to the installation or operation and maintenance of village wells. Thus the full cost of water supply in these villages is covered by IBS and its donors. In theory this subsidy could free the residents of IBS villages to use their 5 percent income contributions for household treatment systems that provide microbially safe water. Income levels in Lumbini are not widely known, and much of the population is dependant on agriculture, so it is not clear what a 5 percent contribution would mean in terms of monetary funding for an expanded Safe Water Systems project. Furthermore, the use of the 5 percent rule-of-thumb has been questioned extensively in recent years and many water and sanitation projects have moved toward individual assessment of willingness to pay on a community-by-community basis using techniques such as revealed preferences and contingent valuation surveying (McPhail, 1993).

Initial assessment of willingness to pay conducted in Lumbini in January 2002 may have underestimated the income and ability of Lumbini villagers to pay for household water disinfection systems. A survey of pilot study participants found that *all* participants gave negative responses when asked if they would continue to use Piyush if they were required to pay for the disinfectant. The IBS women motivators were also reluctant to speculate on willingness to pay. The motivators emphasized that 90 percent of villagers in Lumbini are entirely dependant on agriculture for subsistence and income and maintained that monetary contributions from villagers would not be possible in Lumbini (Panday, 2002). Willingness and ability to pay for water services are often underestimated in rural communities and Lumbini may be no exception. Although the IBS motivators maintain that villagers cannot pay for water services, both villager actions and previous willingness-to-pay studies in Lumbini may indicate otherwise (CEDA, 2001; Tiwari, 1997).

Many households in the IBS villages have installed private wells near their homes. Thirty-three of these private tubewells were tested for bacterial contamination during the January 2002 well survey (*Section 5.2.1*). This represents only a small sampling of the private wells in the region, as bacterial testing supplies available for this survey were limited, and in general private wells were tested only upon special requests by homeowners. Installing a private well in Nepal is not inexpensive. These wells are hand dug by local laborers, and typically cost between NRs 1215 for an 18 foot well to NRs. 2400 for a 50 foot well in Nepal (CEDA, 2001). The average depth of the private wells sampled in Lumbini was 62 feet, indicating that many households in the region have made considerable investments for private water supply provision and may be able to contribution to a water treatment project such as the household chlorination program. Willingness-to-pay studies conducted in the region by the Finnish International Development Agency (FINNADA) in 1997 confirm these findings. FINNADA found that the majority of users in the Terai region of Nepal are willing to pay, at least for system and operation costs, for new water supply projects (Tiwari, 1997).

One concern in Lumbini is that villagers will not be willing to pay for household disinfection because they have already received subsidized services from IBS during the pilot study period. The World Bank has classified rural communities into four categories of water demand ranging from communities willing to make substantial financial contributions for private connections to communities where willingness to pay for any type of improved service is low. Communities may fall into this latter “Type IV” classification for two reasons. Some of these communities are unwilling to pay for improved services because traditional water supplies are considered adequate (World Bank, 1992). The IBS villages in Lumbini are unlikely to fall into this category because there is a general awareness of the link between waterborne disease and traditional open water sources in Lumbini and villagers have supported the installation of IBS tubewells because of this understanding. In other communities low willingness-to-pay exists because water supply is considered to be the financial responsibility of government and donor organizations (World Bank, 1992). This is a concern in Lumbini because IBS has provided handpumps to villages for many years without requiring monetary contributions from villagers. The household chlorination pilot project has provided both Piyush and water storage vessels free of charge to participants in Lumbini for over a year. The change to a system that requires monetary contributions from villagers may be met with considerable opposition if villages feel that it is the responsibility of IBS to provide these products.

9.2 Assessing Willingness-to-pay for Piyush Disinfectant

The first step in the development of a cost-recovery scheme for the expansion of the Lumbini Household Chlorination Pilot Study is an accurate assessment of the willingness and ability of Lumbini’s residents to pay for disinfectant and storage vessels. This information will allow for the development of a sustainable and affordable pricing and distribution scheme for Piyush and will help to assess the viability of expanding the program without further subsidies. Contingent valuation and revealed preference are two methods for assessing willingness to pay that are commonly used in water and sanitation supply projects and may be appropriate for use in Lumbini. *Contingent valuation* surveys attempt to determine what households are willing to pay for improved water services by explaining the options that exist for future services. They describe the benefits that could result from various water and sanitation supply option and asking households how much they would be willing to pay for these services. *Revealed preferences* surveys attempt to evaluate what people are currently paying for similar services, either through user tariffs or through privately funded water supply and sanitation improvements, such as privately constructed latrines or wells (World Bank, 1999).

9.2.1 Contingent Valuation Surveys

A contingent valuation survey to determine how much households in Lumbini are willing to pay for Piyush disinfectant could be designed with minimal complexity because only one option for safe water provision is being offered, the purchase of Piyush disinfectant. A simple one-question survey could be designed as follows,

> Suppose the Piyush disinfectant, that households in your village have been using to treat drinking water during the Lumbini Household Chlorination Pilot Study, was no longer available free of charge from IBS, but could be purchased in the market for NRs ___. Would you purchase the Piyush disinfectant to treat drinking water for your household?

Each household would respond to the question once and would be quoted only one price, but the question could be asked to a larger number of households in Lumbini, with several different pricing options. The information gathered with the survey could be used to create a "Willingness-to-pay Curve" like the example shown in Figure 9.1. This would allow program developers to determine if cost recovery for Piyush solution is possible in Lumbini and would assist them in setting an appropriate price for Piyush that could result in a large number of Lumbini households choosing to purchase the disinfectant to treat their water.

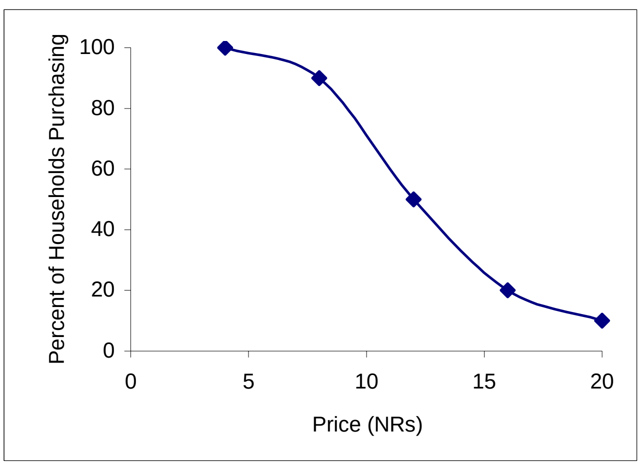

Figure 9.1: Example WTP Curve for Piyush Disinfectant Solution

It may be beneficial to determine the amount of Piyush the average household in Lumbini will consume on a weekly or monthly basis and phrase survey questions to determine how much households would be willing to pay each week or month for Piyush. This may allow for more accurate survey responses because households may not be aware of the length of time they can treat their drinking water with the purchase of one bottle of disinfectant.

Households that participate in the survey should be chosen in such a way as to ensure that the survey group forms a representative sub-segment of the Lumbini population. The traditional approach to ensuring representation is to compare characteristics of households in the sample group, such as income and education levels to census data for the region as a whole, and verify that no major discrepancies exist. This will not be possible in Lumbini because detailed census information of this kind is not available. Selection techniques for survey participation should therefore be designed to address representation and ensure that the results of a contingent valuation study represent the willingness-to-pay of the Lumbini community as a whole, not just the willingness to pay of village leaders or leadership committee members. Studies by the World Bank have shown that village leaders often misperceive the needs of their communities or fail to consider certain sub-segments of the population. Sustainability can therefore be improved through a more inclusive approach to decision-making that ensures that all members of the community are given the opportunity to participate (Katz, 1997).

If a contingent valuation survey to assess willingness-to-pay for Piyush is planned in Lumbini, it will be essential to use a carefully chosen set of enumerators or translators to ensure that accurate survey results are obtained. In some instances villagers may feel pressured into positive responses to willingness-to-pay questions because of "social desirability" concerns. Davis (2002) describes the social desirability phenomenon as follows; "Individuals prefer to present a positive image of themselves to others, particularly during face-to-face interaction. In a research setting, social desirability can be manifested as over-reporting of "good" behavior such as voting or helping others, or as providing positive responses to attitudinal questions. Clearly "yea-saying" has important implications for contingent-valuation research used in a development planning context, if respondents overstate their demand for development initiatives as a result of social desirability pressures."

This "yea-saying" phenomenon may have been observed previously in Lumbini through the use of the IBS women motivators as translators during the January 2002 pilot study evaluation (Section 6.4). The IBS motivators are well-respected among women in the villages where they conduct their sanitation and hygiene education programs. The women in these villages may feel pressured to answer willingness-to-pay questions in the affirmative in order to receive approval from the women motivators who played a substantial role in the chlorination pilot study. Furthermore, the motivators may feel pressured to encourage affirmative answers during translation, because of their desire to present positive survey results to visiting program developers. Because of these constraints it may be valuable to use enumerators or translators who are not associated with IBS or ENPHO for willingness-to-pay surveys conducted in Lumbini. If this is not possible, it will be essential to stress to the IBS motivators, and to the survey respondents themselves, the importance of obtaining accurate, honest survey responses, even if these responses reveal low willingness-to-pay.

9.2.2 Revealed Preferences

Revealed willingness-to-pay methods cannot be used directly in Lumbini because Piyush and other water disinfection products are not available in the region. Thus, Lumbini villagers cannot reveal their willingness-to-pay preferences for these products. An alternative method for assessing the ability or willingness of IBS villagers to pay for household chlorination would be to assess the amount that villagers are currently paying for other household products such as soap, laundry detergent or cooking fuel. If the price of Piyush is in line with other commonly used products, villagers should be able to afford the disinfectant (CDC, 2001). Determining what household products are used and what villagers are paying for them will also require additional surveying in Lumbini.

9.3 Piyush Pricing and Sales in Lumbini

Once an acceptable price for Piyush disinfectant in Lumbini has been established, the pilot study can be expanded to include a greater portion of the Lumbini population through the direct sale of Piyush disinfectant and storage vessels. The support structure of the pilot study, including the IBS heath clinic participation and the follow-up visits and educational work of the motivators, should remain in place but handouts of disinfectant should be discontinued, signaling the end of the pilot study. With the newly obtained "willingness-to-pay" knowledge, a distribution system with potential for cost-recovery and long-term sustainability can be put in place. Piyush must become available to all Lumbini villagers who are willing to pay the established price. This can be accomplished by making Piyush available both at the IBS health clinic, at area retailers and village markets, and perhaps through the women motivators as they make their weekly visits to the villages.

If cost recovery appears possible and the price of Piyush established by willingness-to-pay surveys in Lumbini is in line with the production costs of Piyush incurred by ENPHO and the cost of transportation and distribution to and within Lumbini, the expanded chlorination project will be able to maintain itself without external funding. If the price determined through "willingness-to-pay" surveying proves to be less that the cost of Piyush production and distribution, IBS may wish to continue to subsidize the program if the health improvements resulting from the chlorination project reduce pressures on the IBS health clinic and the benefits of this disease reduction warrant the cost of the subsidy.

9.4 Willingness-to-pay for Storage Vessels

The cost-recovery and pricing discussion presented here has focused on the appropriate pricing level for Piyush disinfectant. Determining a pricing level and providing for cost-recovery may be more difficult when the costs of water storage vessels enter the discussion. Storage vessels are typically much more expensive than disinfectant solutions and require substantial upfront investments that may be difficult for many rural villagers. Because of this many Safe Water System programs have sold vessels at a highly subsidized price and relied on disinfectant sales to establish cost recovery (CDC, 2001). This is again problematic because it can lead to lower user investment in the program and may jeopardize sustained use of the disinfection system.

9.4.1 Vessel Financing

An alternative option is to establish a vessel-financing program that could spread the cost of the vessel over a longer period of time, making it more affordable to individual households. Although this method is recommended by the CDC's Safe Water Systems manual, it has not been attempted in a Safe Water Systems Program to date. This type of system can be particularly difficult if the infrastructure necessary to support it is not already in place. In Lumbini credit and payment collection could be conducted through IBS, but the administration of the program may prove to be more costly than any funds recovered from user contributions.

9.4.2 "Water Vessels for Work" Program

A final option that may be able to create a greater sense of investment among users without requiring household to pay cash for their vessels would be a "Water Vessel for Work Program." These programs have been successful in other Safe Water System Programs. As described in the Safe Water Systems manual, this type of program would require villagers to participate in some form of community improvement project to earn their vessel. Although households participating in such a program would not be required to pay for their vessel, they would value the vessel and may be more inclined to use it because they have earned it through labor contributions. This may allow for subsidies while eliminating concerns about the sustained use of fully subsidized vessels. Possible "Water Vessel of Work" community improvement projects in the Lumbini area could include,

- Digging of improved drainage ditches
- Building or improving health centers or schools
- Community garden work
- Community clean-up

Several of these projects, such as drainage installation, may have the advantage of added health and sanitation benefits that would further contribute to meeting the health-related goals of a Household Chlorination program in Lumbini.

CHAPTER 10 CLOSING THE GAPS: DEVELOPING A SANITATION AND HYGIENE PROMOTION PROGRAM FOR LUMBINI

At the time of the January 2002 evaluation, sanitation facilities in the 17 villages served by IBS were extremely limited. Only one latrine was in place, in Khambe village. This latrine is privately owned and used by a single five-member household in the village. IBS has received monetary donations and materials that will allow for the installation of seven public latrines in the Lumbini area, but without substantial additional funding, this program will do little to provide for the sanitation needs of the 10,000 people living in the IBS program area.

IBS is also installing drainage channels in 13 of the 17 villages. Four hundred and seventy-two feet of drainage channels have now been installed in Sonbarshi and 1450 additional feet of drainage channels are under construction in Mahuwari, Khambe, Mahilwari, Dhodahawa, Sujandihawa, Ramawapur, Sonbarsha, Shivagadiya, Bhagatpurwa, Bagwanpur, Mujuhana, and Lamtihawa. This program should effect a greater portion of the Lumbini population than the latrine installation program, but additional drainage alone will not serve the sanitation needs of village residents.

These deficiencies in sanitation provision are troubling in light of many recent studies that have pointed to the importance of sanitation provision in achieving health benefits from water and sanitation programs (Esrey, 1996). Recognizing the need for improved sanitation and hygiene, the third component of the CDC's Safe Water System program incorporates behavior modification techniques designed to both encourage the adoption of household chlorination and promote hygiene and sanitation behaviors that can lead to improved health (CDC, 2001). Although this component of the Safe Water System approach was not attempted in Lumbini as part of the Lumbini Household Chlorination Pilot Study, hygiene and sanitation education programs are already in place in the area through IBS and the IBS women motivators.

Health benefits from sanitation provision are unlikely to be realized in Lumbini in the near future because funding for additional infrastructure improvements in Lumbini is limited. Villagers in Lumbini may benefit from expanded hygiene and sanitation education programs designed to encourage behaviors that can improve current practices and perhaps achieve health benefits in the absence of proper sanitation facilities. These education programs should build on the programs already in place in Lumbini and should be combined with a thorough user education program for household chlorination designed to encourage the adoption of chlorination products and train villagers in the proper use and handling of household chlorination systems.

10.1 User Education Programs for Household Chlorination

The inadequate free chlorine residuals measured in stored water during the Lumbini Pilot Study evaluations, combined with the lack of bacterial contamination removal in several participating households, raises questions about whether villagers in Lumbini are using household chlorination products properly. Although the IBS women motivators acted as educators throughout the Chlorination Pilot Study and were available to assist villagers with the use of Piyush disinfectant and storage vessels, a formal education program to accompany the pilot study was not established. The performance of household chlorination as a treatment technology, in terms of chlorine residual maintenance, and bacterial removal may be improved by the establishment of an accompanying user education program. After they have received proper training, this program should be run by the IBS women motivators because of their links to the village communities and because of their pre-established role as educators in these communities.

The user education project should incorporate both motivational and educational components. Motivational components should teach villagers about the purpose of household chlorination and encourage them to use household chlorination products to treat water for their families. This goal will be particularly relevant if Piyush disinfectant becomes a consumer product in Lumbini, and demand generation becomes necessary. Educational components should teach villagers how to use the Piyush disinfectant and storage vessels properly to insure that household chlorination produces safe water for participating households. Specific messages that should be incorporated in the user education program include (CDC, 2001):

Causes of Waterborne Disease

- Waterborne disease is caused by contaminated water
- Water can be contaminated in many ways
- Contamination is caused by bacteria, which are too small to see
- Even clear water can be contaminated

Purpose of Piyush Disinfectant and Storage Vessels

- Kills contamination in water
- Prevents diarrhea and other water-borne diseases
- Keeps stored water free of contamination

Acquiring Piyush Disinfectant and Vessels

- Where Piyush and vessels are available
- How much Piyush and vessels cost

Proper Use of Piyush Disinfectant

- Always add 3 drops for every liter of water
- Stir, and wait 30 minutes before consuming water
- Store Piyush indoors, in a cool dark place
- Keep out of reach of children
- Discard unused Piyush after _ months*

* Investigations into the self-life of Piyush are ongoing (Morganti, 2002).

Proper Use of Storage Vessels

- Clean vessels at least once a week with soap and water
- Keep lid secure
- Use spout or pour to dispense water, never dip hands or utensils

Use of Chlorinated Water

- Use chlorinated water for drinking
- Use chlorinated water to wash and prepare food
- Use chlorinated water to wash hands
- Use Piyush year-round, not just during the rainy season
- Carry chlorinated water for consumption outside the home

It should also be emphasized to users that household chlorination is a means to prevent waterborne disease and diarrhea, but it is not a cure. Users should be encouraged to seek medical help if they or their children fall ill in spite of household chlorination efforts. Household chlorination cannot substitute for medical treatments for dehydration and waterborne disease such as oral rehydration solutions and antibiotics.

10.2 Hygiene and Sanitation Education Programs

When funding for sanitation facilities is limited, sanitation can often be improved through education programs that do not require the financial commitment of infrastructure installation (Churchill, 1987). This approach may be ideal for Lumbini where limited funding has been provided for sanitation provision and infrastructure improvements already under construction may take several years to complete. Even if current construction projects in Lumbini are successful and funding for the construction of additional latrines is obtained, the presence of proper sanitation facilities does not necessarily translate to health improvements without the presence of accompanying sanitation education programs. One study conducted in a Mozambican refugee camp in Malawi, found that although many residents had access to private household latrines, sanitary conditions in these facilities were not always ideal. The presence of feces on the floor of a latrine increased the risk of diarrhea among children under 5 when compared to households with a clean latrine and more than negated the positive health effects of latrine ownership (Roberts, 2001). This highlights the central role of education in the reduction waterborne disease.

10.2.1 Benefits of Education Programs

Several recent studies have pointed to the potential health benefits that can be obtained through educational programs. Significant reductions in waterborne disease, particularly among children, can be achieved with educational interventions. A study in Guatemala found a 14 percent reduction in diarrhea cases among children under six in households that received hygiene education when compared to households that did not receive the education. A handwashing education program for both staff and children conducted in day care centers in the United States lead to a 48 percent reduction in diarrhea incidence over the 10 month study (Briscoe, 1987).

Benefits have also been observed from hygiene and sanitation promotion in Safe Water Systems Programs. In October 1999, the SWS approach was used as a method for reducing the incidence of diarrheal disease in squatter settlements in Karachi, Pakistan. The Karachi study also included an investigation of the benefits of hand washing with antibacterial soap and a comparison of the effects of hand washing with chlorinated water supplies and hand washing with contaminated municipal water and showed that hygiene behaviors such as handwashing can be effective even when water quality remains questionable. In Karachi, twenty-five of the intervention homes received a supply of "Safeguard" antibacterial soap and were instructed to use their chlorinated household water for hand washing. Twenty-five control households received the "Safeguard" soap and used unchlorinated tap water for hand washing. Hand rinse samples collected during unannounced meal-time visits 3 to 6 weeks into the study showed reductions in the presence of fecal coliforms in both sets of "Safeguard" users, indicating that hand washing with antibacterial soap can be effective with both chlorinated and non-chlorinated fecally contaminated water supplies (Luby, 2001).

The Karachi case demonstrates the role of hygiene promotion in complementing water provision or treatment projects, including Safe Water Systems Programs. Similar health benefits may be achieved in Lumbini through the use a hygiene and sanitation education program designed to encourage desirable hygiene practices.

10.2.2 Developing a Hygiene and Sanitation Education Program in Lumbini.

The first step in the establishment or expansion of hygiene education and behavior modification programs in Lumbini is a determination of the level of hygiene and sanitation education already taking place in Lumbini through IBS and the women motivators and a thorough evaluation of the current status of local knowledge. IBS and the MIT-Nepal Water Project should collaborate on the expansion project, drawing off the local knowledge and experience of the IBS staff, and the technical expertise of the MIT-Nepal Water Project team, to develop a program that meets the needs of Lumbini villagers.

Preliminary work should also evaluate potential channels of communication and determine the most appropriate venue and mode of communication for hygiene and sanitation education in Lumbini. Venue options include the IBS health, village visits, and area schools. Potential communication modes include face-to-face contact, formal or informal education programs, posters, pamphlets, and public forums. The IBS women motivators currently conduct both formal education programs and face-to-face education programs through meetings at the IBS health clinic and village visits. The MIT-Nepal

Water Project may be able to expand on the success of these programs by partnering with IBS to create visual posters or pamphlets that can promote hygiene and sanitation practices in areas that are not frequently reached by current education programs.

Once preexisting knowledge and attitudes have been evaluated and appropriate venues and communication channels have been identified, key messages or target behaviors should be selected. Participants in an education program must understand how waterborne disease is transmitted in order to understand why certain hygiene and sanitation practices are desirable. One example of a traditional tool for explaining the fecal-oral route is the F-diagram, shown in Figure 10.1. This diagram provides a visual explanation for how waterborne disease can be passed from one individual to the next.

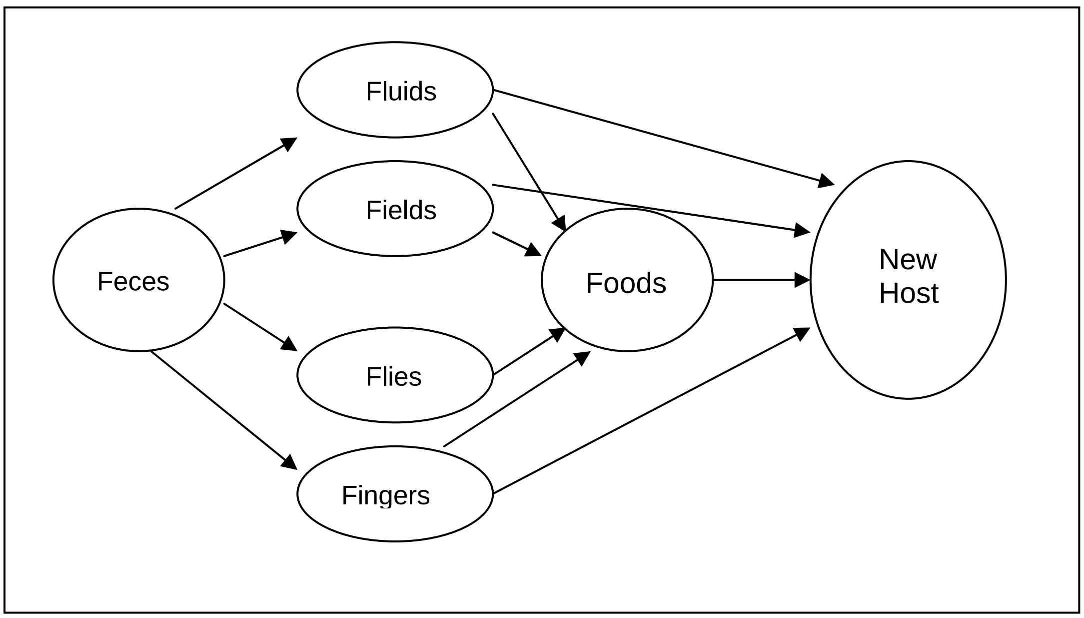

Figure 10.1: The f-diagram (adapted from UNICEF, 1999)

The f- diagram is often used by educators during participatory hygiene and sanitation programs to help people identify ways to break the chain of transmission from feces to host. Practices identified by the f-diagram include,

- Proper disposal of feces
- Handwashing with soap or ash, especially after stool contact
- Protection of source water
- Fly and pest control
- Food hygiene

All of these practices can be beneficial in the prevention the waterborne disease and should be encouraged, but the f-diagram can be used as a tool to identify practices that break the chain of transmission as early as possible and prevent fecal material from entering the environment. The practices that are typically identified as being able to break the chain of transmission between feces and the environment (fluids, fields, flies, fingers) are proper feces disposal and handwashing, thus these practices are often given priority in hygiene education programs.

The f-diagram is an example of a tool commonly used by hygiene and sanitation educators who work with local people to identify and address risk practices in their communities. Many similar tools exist, and a wide range of hygiene and sanitation education program have been implemented throughout the developing world. The expansion of educational programs in Lumbini should draw off these experiences as well as the experience of IBS staff. Without knowing the specific content of the hygiene and sanitation education programs already established by IBS, it is difficult to make suggestions for expansion or improvement. The MIT-Nepal Water Project may wish to examine the IBS programs more carefully to use these programs as a model for future education programs in Nepal, and determine how the MIT-Nepal Water Project can assist IBS with these programs.

10.2.3 Hygiene and Sanitation Education as an Accompaniment to Infrastructure

One of the concerns about hygiene and sanitation education is that risk practices cannot be eliminated without the presence of infrastructure improvements such as latrines and safe water supplies that allow households to transform the education they receive into safe practices. The UNICEF School Sanitation and Hygiene Program refers to these components as *enabling factors*, "Increasing students' knowledge about health and disease prevention should only be part of the story. When knowledge is supported by enabling factors, desirable changes may occur in the school setting and in the community. This stresses the importance of combining hygiene education with the construction of water and environmental sanitation facilities . . . (UNICEF, 1998)"

Thus, education programs in Lumbini should not be viewed as a substitute for infrastructure improvements such as the construction of public latrines or other sanitation facilities. Education programs should be considered an interim approach to sanitation in Lumbini until additional funding is obtained for infrastructure improvements. This should not imply that education programs should be discontinued when sanitation facilities are installed. Rather education programs should continue to encourage the proper use of sanitation facilities. As was seen in the Lumbini Household Chlorination Pilot Study, technological improvements will not be effective if user education programs, such as the one described in Section 10.1 are not developed to accompany them.

Education programs can also have a substantial effect on the adoption of technologies or sanitation facilities. A pilot project conducted in Et Alto Bolivia in 1997 found that the percentage of people who installed sanitation facilities in their homes doubled among household that received hygiene education, with 70 percent of these households installing bathrooms, versus just 35 percent of households that did not participate in the hygiene education program (Foster, 2001). Similar effects of education on technology adoption have been seen in Safe Water System programs. A program in rural Kenya that involved considerable education campaigns and social marketing initiatives found that adoption rates of disinfectant solution were over 30 percent in these regions, compared with typical adoption rates of 5 to 15 percent in projects in other countries, where education was not emphasized (Makutsa, 2001). When sanitation facilities have been installed in Lumbini, education programs can shift their focus to encourage the regular use and maintenance of these facilities.

CHAPTER 11 CONCLUSIONS

11.1 Conclusions and Recommendations

The Lumbini Pilot Study successfully established household chlorination as a socially acceptable approach to water treatment in Lumbini, Nepal and created a high level of brand recognition and demand for Piyush chlorine disinfectant in the region. Although health surveys showed reductions in waterborne disease among participants, the Lumbini Pilot Study fell short of its expected reductions in microbial contamination in stored water. This failure was likely due to improper household use of both disinfectant and storage vessels. These shortcomings can be remedied through enhanced education programs designed to teach users the benefits of household chlorination and the proper use and handling of household chlorination systems. Whenever possible user education programs should be combined with more general sanitation and hygiene education programs designed to encourage behaviors that will enhance the heath benefits of household water treatment programs.

Now that household chlorination has been established as a socially acceptable approach to water treatment in Lumbini, the programs reach should be expanded to include more villagers in the region. In order to complete this expansion in a sustainable manner, full or partial cost-recovery should be explored for some components of the program. To assess the potential for user contributions in Lumbini and set prices for Piyush disinfectant and storage vessels, “willingness-to-pay” assessments should be made. If cost-recovery appears possible, program expansion should be encouraged. If cost-recovery appears unrealistic, the International Buddhist Society and other program sponsors should evaluate the potential for continued program subsidies and determine if expansion is still desirable.

Based on the success of the Lumbini Pilot Study, household chlorination may be appropriate for other regions of Nepal. Populations in Nepal that could benefit from this approach include residents of urban Kathmandu, who depend on municipal water supplies that are intermittently available and rarely chlorinated to adequate levels, and residents of the hills districts who often depend on surface water sources. Additional pilot studies in urban Kathmandu and the Hills Districts may be desirable to assess the appropriateness of household chlorination in these regions and determine if demand for chlorination products exists.

The Lumbini Household Chlorination Pilot Study represents the first implementation project for household water treatment conducted by the MIT-Nepal Water Project. The field implementation of technology in developing countries is challenging and inherently different from laboratory scale testing. It requires the support and collaboration of local organizations, ongoing interaction with users and continued program adjustments in order to be successful. The experience gained through this initial implementation project should guide the MIT-Nepal Water Project as it moves forward with additional implementation programs for bacterial and arsenic removal technologies.

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APPENDIX A

Instructions for Preparation of 10ml IDRC H_2S Presence Absence Tests

Instructions for Preparation of 10ml IDRC H_2S Presence Absence Tests

Materials:

11ml glass vials with caps
Permanent Marker
Absorbent Paper (Kleenex, Filter Paper, Toilet Paper etc.)

Reagents:

Bacteriological peptone	40.0 g
Dipotassium hydrogen phosphate	3.0 g
Ferric ammonium citrate	1.5 g
Sodium thiosuphate	2.0 g
Sodium lauryl sulphate	0.2 g

If proper lab facilities are not available in the field, pre-weighed bags of each chemical can be prepared in advance to facilitate media preparation in the field.

Preparation:

1. Add the bacterial peptone to 100ml of distilled water or non-chlorinated boiled tap water. Stir continuously until dissolved.

2. Add the remaining chemicals, stirring until dissolved.

3. Measure 10ml of water into an 11ml vial. Mark the water level with a permanent marker and use this vial to add 10ml marks to the remaining vials. This will for accurate allow for 10 ml sample collection in the field.

4. Place a sufficient amount of absorbent paper (~ 2cm x 3cm) to absorb 0.5 ml of media in each vial.

5. Add 0.5ml of media to each vial.

6. Loosely cap the vials and autoclave for 15 minutes at 115°C and place in a hot air oven to dry at 55°C. Alternatively, the loosely capped vials can be placed in a hot air oven at 70°C for 60 minutes to sterilize and dry.

7. After sterilization, tightly cap the vials and store in cool, dry place.

Media Testing:

1. Test the media by adding a small amount of contaminated water (a very small amount of fecal matter in water can be used for this purpose). If this test is negative, the batch of media should be considered defective and should not be used.

2. Test the media again using distilled water or boiled tap water. If this test is positive, the batch of media should be considered defective and should not be used.

Collecting and Testing Water Samples:

1. Wash hands before beginning the test.

2. Uncap the vial, being careful not to touch the inside of the cap or the vial opening.

3. Fill the vial directly with sample water to the 10 ml mark. If water is collected in another container, make sure the container is clean and sterile and keep the water sample cool until it can be added to the test vial. Samples should be added to the test vial as soon as possible, and within four hours after collection.

4. Label each vial with the location and date of sample collection

5. Keep the vial at approximately 35°C for 48 to 72 hours. If the vial turns black, the sample is positive for H_2S bacteria. If after 72 hours the vial remains yellow, the sample can be considered negative for H_2S bacteria.

Disposal and Reuse:

1. Samples should be disposed of properly to avoid spreading bacterial contamination. Samples can be sterilized by emptying vial contents into a bleach solution and cleaning vials thoroughly, alternatively vials and their contents can be boiled for 20 minutes to sterilize.

2. Vials should be rinsed thoroughly to removal traces of bleach and should be sterilized before reuse.

APPENDIX B

Lumbini Household Chlorination Pilot Study Evaluation Interview Questionnaire

Lumbini Household Chlorination Pilot Study Evaluation
Interview Questionnaire

<u>Household Information</u>

1. How many people are in you household?
   Adults
   Children < 15
   Children < 5

<u>Source Water & Pretreatment Practices</u> *(Sample Source Water)*

2. Is your water always clear? Is it ever cloudy or turbid? If so what time of year does this occur?
3. Do you filter the cloudy water? Or do you settle and decant it?

<u>Water Chlorination, Handling and Consumption Practices</u> *(Sample Household Water Supply)*

4. How much Piyush (Calcium Hypochlorite Solution) are you using?
5. How long ago did you disinfect the water I am sampling?
6. How long do you wait, after adding Piyush, before you consume the water?
7. How long does the water sit after disinfection? Typically? Maximum?
8. How many buckets of water do you disinfect per day?
9. What do you use the disinfected water for? What don't you use it for? Do you collect other water that is not disinfected?
10. Do you bring chlorinated water with you when you leave the home?
11. If not, what kind of water do you consume outside of the home?
12. Do you wash your water container? How often? With what?
13. Do you have an area where family members wash their hands? Do you have soap for this? How often do family members wash hands? Before cooking? Before eating? Before drawing water from the storage container?
14. What kind of sanitation facilities does your family have?

<u>Project Acceptance - Social Acceptability of Chlorination</u>

15. How much additional time does it take you to disinfect your water?
16. Do you find disinfection difficult?
17. How do feel about the taste and smell of your disinfected water? Will everyone in your house consume it?
18. What does the chlorine do? Do participants understand the purpose of water chlorination?
19. How did learn about this study? Who taught you how to use the Piyush? Did they explain to you what the Piyush does and why it is important?
20. Would you be willing to pay a small amount for the bucket and Piyush Supply?
21. Do you know of other families who want to try chlorination?

Perceived Health Effects

22. Have you or anyone in your family had episodes of diarrhea in the last month?
23. How many individuals? Adults or children?
24. How often?
25. Has your family had more or less episodes of diarrhea since you began disinfection?

Alternative Treatment Options

26. Are you aware of a training session given 2 years ago by Peter Moulton, board member of the International Buddhist Society and a friend of Bhikkhu Maitri's, in solar disinfection (SODIS)? Did you ever practice this type of water treatment? If yes, why did you discontinue it?

27. In Kathmandu, many families boil and filter their water. Do you ever boil your water to purify it? Do you ever boil and filter your water to purify it? Have you ever used a candle filter in your household?

28. Have you ever seen the Biosand filter? If yes, would you be interested in trying this approach?

29. Of these 3 types of household water treatment, which would you prefer to use in order to assure that your family has safe water: chlorination (as per the Lumbini Pilot Study), boiling and filtering with a candle filter, or use of the Biosand filter?