MICROBIAL CONTAMINATION AND REMOVAL FROM DRINKING WATER IN THE TERAI REGION OF NEPAL

by

Meghan Kathleen Smith
BS Chemical Engineering, 1999
Johns Hopkins University - Baltimore, MD

Submitted to the Department of Civil and Environmental Engineering
In Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

An assessment of the extent of microbial contamination of tubewells in the Terai region of Nepal and of the incidence of waterborne diseases in the area was performed. To address the microbial contamination an investigation of the effectiveness and acceptability of two household point-of-use water treatments was performed: practical household solar disinfection (SODIS) and a microfiltration unit (the Corning CerCor Ceramic filtration unit). The performance of the technologies was assessed along with the acceptability and appropriateness of the technologies for use in Nepal.

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Thanks Mom, Dad, Grandma, and Pap for being there yesterday, today and tomorrow.

"Life's a journey not a destination."
It's been fun MEngers.

MIT Nepal Team: back row left to right: Tse Luen Lee, Susan Murcott, Timothy Harrison, Bhikku Maitri, Nathaniel Paynter, and Dr. Lee Hersch.
Front row left to right: Meghan Smith and Jesse Hurd

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1 INTRODUCTION

1.1 NEPAL

The Kingdom of Nepal situated between India and China is facing a drinking water crisis. Nepal, a country with a long history of self-imposed isolation, is in need of international assistance to help solve its extreme water issues (Britannica, 2001). Located on the southern slopes of the Himalayas the geography of Nepal is extreme with altitudes ranging from the heights of Everest (8,848 m) to near sea level at the plains (152 m). The Himalayas have historically blocked China's access to the rich Indo-Gangetic plains of India, and have isolated Nepal from the world.

The country covers an area of 147,181 km^2, approximately the size of the state of Wisconsin, of which 20 percent is farmable land. The people of Nepal are intimately tied to the land; agriculture employs 88% of the population and provides for more than one half of the household income. The average Nepalese income is 250 US$ per year. This economic restriction complicates the drinking water problem; neither the government nor the citizens have sufficient resources to solve the water crisis.

FIGURE 1.1: MAP OF NEPAL AND NEIGHBORING COUNTRIES

Nepal, like neighboring India has experienced a population explosion. The current population of Nepal tops 23 million and is growing at a rate of 2.5% (CIA, 2001). The country has one of the highest population densities in the world, 149.2 persons per km^2, compare to the United States population density of 28.4 persons per km^2 and India with a population density of 310.8 persons per km^2 (Britannica, 2000). This high population density makes a solution to the drinking water problem urgent and difficult (NEWAH, 2001). The great number of people and the poverty are the first things you notice when arriving in the country. Poverty in both rural and urban areas is a major problem. The World Bank estimates 42% of the population, nearly 9 million people, live below the poverty line (<1 US$ per capita per day). The intense poverty, illiteracy, malnutrition, and health problems have all affected the quality of life in Nepal. (NEWAH, 2001)

1.2 THE DRINKING WATER CRISIS

Around the world people are facing a crisis due to water pollution and the inequitable distribution of water and sanitation resources. In developing and emerging nations according to the United Nations Environment Program (UNEP, 2001):

- A child dies from a water related disease every eight seconds;
- Three million people every year world-wide die of diarrheal diseases, such as cholera and dysentery;
- Fifty percent of the people in developing and emerging countries suffers from one or more water related diseases;
- Eighty percent of the diseases in the developing world are caused by contaminated water;
- Fifty percent of the people on Earth do not have access to adequate sanitation.

These statistics are indicative of a diminishment and/or a tragic loss of human life. Many people are unable to carry on productive lives; both their social and economic development is undermined by the prevalence of water borne disease, lack of water, and lack of sanitation[1]. Women and children, the elderly, and the immuno-compromised in developing countries are affected the most by the water crisis. Children, the elderly and immuno-compromised individuals are highly susceptible to waterborne illnesses, and less likely to recover, while women bear most of the burden of collecting water for their families, a burden that may require the expenditure of hours of effort. Malnutrition and the lack of health services compound the problem. The United Nations declared the 1980's as the UN International Drinking Water Supply and Sanitation Decade (IDWSSD) with the goal of providing clean water and sanitation to the 1.6 billion people without clean water and the 2.0 billion people without sanitation. In 2001, eleven years after IDWSSD, the situation has not improved, in fact due to the continuing rises in the populations of developing nations now nearly 1.7 billion people do not have access to

[1] Klaus Toepfer, executive director of the United Nations Environment Program (UNEP)

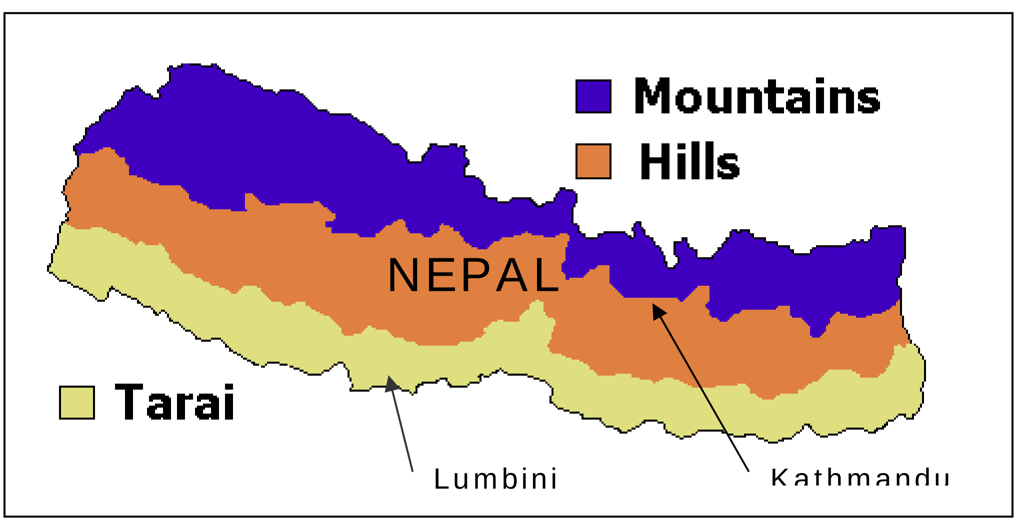
clean water and 2.4 billion people do not have adequate access to sanitation (WHO, 2001).

What is the nature of the drinking water crisis in Nepal? People do not have access to clean drinking water and as a result, use contaminated sources. It has been estimated that in Kathmandu alone (Population one million people) 250,000 people suffer yearly from water borne disease (Shrestha, 2001). In the cities and in rural areas the populations suffer from microbial and arsenic contamination and from insufficient supply. When the cities in Nepal have access to a piped water supply, it may only be available for a few hours in the morning and again for a few hours in the evening. Many of the public water supplies of the major cities: Kathmandu, Biratnaga, and Pokkara have tested positive for fecal contamination (Shrestha, 2001). The government is unable to update these aging facilities and the pipe networks along with the treatment facilities are deteriorating (Shrestha, 2001).

1.3 Rural Areas

The rural populations in Nepal can be divided by geographic location (see Figure 1.2) into those that live in the flat Terai region in the south near India and those that live in the country's mountains and hills.

FIGURE 1.2: REGIONS OF NEPAL



Over eighty percent of the total population lives in the country's rural areas. The incidence of waterborne illness in the rural areas is a result of contamination both at the source and at the household level through poor sanitation and hygiene practices. The mortality for children under five is 104 deaths per 1,000 live births. One out of every three of these deaths in children under five is due to waterborne disease (35 waterborne deaths/1000 live births for children under five). Stunting is also widespread problem as a result of waterborne diseases in infancy and childhood, which do not allow children to retain essential nutrients during diarrheic episodes (UNICEF, 2000). The effect of having endemic stunting and waterborne disease is also psychological; people may not realize that life can exist independent of these diseases because they have always lived with them. In some instances, endemic diseases that Terai people had learned to live such as malaria (water insect vector disease) had protected and isolated the Terai populations until the 1950's and the advent of DDT.

A 1996 United Nations (UN) Human Development Report indicates there has been improvement in the rural water situation in Nepal over the past two decades. In 1981, it was reported that 6.6% of the rural population had access to a safe water supply, while in 1996 after the International Drinking Water Supply and Sanitation Decade the percentage rose to 43% (WHO, 2001). Despite this rise, less than half of the rural population has access to safe drinking water and only 14% has access to adequate sanitation (World Bank, 2001). This rise in water access, especially in the Terai region, is due in part to the effort of many international aid agencies, government agencies, and non-governmental organizations (NGO's) in installing tubewells in rural areas. These groups have not been as successful in the implementation of sanitation in the rural areas.

1.4 Sanitation in the Terai

Sanitation is defined as the safe management of human excreta (WEDC, 2000). Sanitation has not been widely implemented in the Terai; only 14% of rural Nepalese have access to sanitation. Latrines are more common in the hill regions, than in the Terai, nearly 75% of households in the hills have a latrine (NEWAH, 2001). Fields (*maldham*), rather than latrines, are used in the Terai region. Villagers routinely use the agricultural fields for defecation; this practice is probably both convenient, because the fields surround every village, and practical because it fertilizes the fields. However, the practice is not an effective way to dispose of human wastes because through run-off and direct contact fecal matter can contaminate water and spread diseases.

Latrines have not become widespread in the Terai, in part, due to the higher cost of installation in this region and in part due to a lack of perceived need. Soil conditions in the Terai require that latrines in the area have a pit lining which increases the cost of construction (NEWAH, 2001). Terai villages are typically located in the middle of agricultural fields with often only a meter separating the fields, the houses, than animal living quarters and/or the wells each family has a limited amount of land resources. Latrines need to be located away from water resources to avoid contamination, currently in the villages water sources (tubewells), livestock quarters, and living spaces are intimately situated. The villages need to be reorganized to implement sanitation and to protect their watersheds. Additionally lack of awareness and extreme poverty combine to result in a low demand in the region for latrines (NEWAH, 2001).

In the larger towns in the Terai, large storm drainage ditches line the streets next to the sidewalks. The ditches are approximately half a meter wide and two-thirds of a meter deep. During the dry season, trash collects in the drainage ditches and it is not unusual for townspeople to use the ditches as latrines.

1.5 DRINKING WATER SOURCES

1.5.1 In the Terai

Ground water accessed via tubewells is the major source of water in the Terai Region of Nepal. The tubewells range from private, one-family wells to village wells, which are used by several families and anyone who passes by. Until recently when international aid agencies, government agencies, NGO's, and private citizens began installing the tubewells, people relied on shallow hand dug, uncovered wells, rivers, and open collection ponds. Typically, deeper tubewells have less microbial contamination when they are properly installed and maintained. A proper tubewell should have both a cement cover with a tight seal around the well base and a drainage ditch flowing away from the well. (Shrestha, 2001) Well priming should also be performed using only boiled water or water known to be pathogen free, and not the water from nearby ponds, as is commonly used in the Terai. Even if water does not become contaminated at the source, it may be contaminated sometime during the chain of events before it is consumed. Dirty hands, improper storage, and unsanitary collection methods can all result in the microbial contamination of drinking water.

1.5.2 In the Kathmandu Valley

In the Kathmandu Valley, the population explosion over the past fifty years since 1950 has put a tremendous strain on the valleys water resources. Currently the demand for water in the valley exceeds the piped supply and people are resorting to groundwater sources, trucking water, and to traditional water sources, such as waterspouts located throughout the city. People tend to use these traditional sources because they are reliable, but a major problem with people using these traditional waterspouts is their perception that the water is pure. They believe that these traditional sources are free from contamination and safe to drink, when in reality a bacteriological study of twenty-one waterspouts in Kathmandu by the Environmental and Public Health Organization (ENPHO) found all the spouts had fecal, ammonia, and nitrate contamination. The increased groundwater extraction, above the critical abstraction rate, has resulted in an annual one-meter drop in the water table below the valley (Shrestha, 2001).

1.5.3Seasonal Variations

People in both the rural and urban areas of Nepal expend large amounts of time and energy to procure water for their daily needs. The situation is complicated by the two seasonal extremes of the monsoon and the dry seasons when the availability and quality of water shift to extremes. During each of the different seasons, people must shift their water and sanitation habits to accommodate the changing water quantities and qualities. Different treatment technologies may be required in each season as the high levels of turbidity experienced during the monsoon season may overwhelm certain water treatment processes. The increased precipitation and flooding of the monsoon season result in an increase in the fecal contamination of water during this time of the year and correspondingly an increase in the incidence of waterborne disease. During the dry season, microbial water quality is better, but certain wells and water sources may dry up and other less favorable water options may have to be utilized. (Shrestha and Sharma, 1995)

1.6 Project Motivation Overview

Last year, a group of Masters of Engineering (M.Eng) students studied the water situation in Nepal. The group evaluated water quality, coagulation, filtration, and disinfection technologies. They were motivated to identify and assess point-of-use treatment technologies that were used in Nepal. The results of their studies are summarized below.

One member of the team, Junko Sagara, investigated water filtration. She identified and assessed the Nepalese candle filter, the Indian candle filter, and the Industry for the Poor (IPI) granular activated carbon (GAC) filter. Her results are summarized in the table below.

Figure 1.3: Summary of Sagara Filtration Study Results

Filter	Flow-rate (L/hr)	Microbial Removal (H^2S)	Microbial Removal (*E. coli*)	Turbidity Removal Efficiency	Cost (US$)
Nepalese	0.24	No	No	94.3%	3.00 – 3.75
Indian	0.30	No	Yes	96.2%	8.60 – 23.20
IPI (w/Cl)	19.0	Yes	Yes	94.2%	15.00(in Haiti)

Her conclusions were that even though the IPI filter was effective, the parts for the IPI filter were not available in Nepal and the other two filters had slow flow rates and did not remove microbial contamination. Sagara concluded that filtration was not a viable option for water purification in Nepal unless a disinfection process accompanied it.

Amer Khayyat (M.Eng 2000) studied the possibility of using solar disinfection (known by the acronym SODIS) in Kathmandu, and he concluded that the effectiveness of the treatment system is seasonally dependent and the feasibility would need to be studied at different locations throughout the country due to the prevalence of microclimates in Nepal (Khayyat, 2000). Additionally, Peter Moulton, the founder of the NGO Global Resources Institute (GRI), has been working on introducing SODIS to the Terai region of Nepal.

Kim Luu's (M.Eng, 2000) investigation into introducing coagulation to Nepal as a water treatment option highlighted an important aspect that is often ignored: acceptability. Coagulation using alum proved to be effective in the field, but villagers seemed unwilling to accept the technology because of the added labor and time. The acceptability of a technology was as important as the effectiveness of the technology because if people are unwilling to use the technology it will not be adopted.

FIGURE 1.4: STUDY RESULTS OF NEPAL 1999-2000 MIT M.ENG GROUP

1. Parts for the IPI filter were not available in Nepal;
2. Nepalese and Indian filter flowrates were too slow;
3. Nepalese and Indian filters do not remove microbial contamination;
4. Chlorination and solar disinfection need further study in Nepal before a confident recommendation can be given for implementation;
5. Social acceptability needs to be determined for each technology.

The problems identified and the results presented (Figure 1.4) by these researchers in Nepal motivated the current study. A well survey of seven villages in the Lumbini District was conducted to further quantify the extent of microbial contamination of drinking water in the area. Interviews with Nepalese and observations of their water and sanitation habits were performed to gain knowledge and understanding of what technological solutions would be acceptable to the Nepalese. The current study also investigated a filtration technology with a high flowrate and the potential to remove microbial contamination: the Corning CerCor filter. In addition, a study of SODIS in Lumbini, Nepal, intended to add to the knowledge of its effectiveness SODIS in Nepal in the hope that sufficient data could be gathered to recommend the technology.

2 WATER QUALITY

2.1 PHYSICAL PARAMETERS

Taste, color, odor, turbidity are all physical parameters that can affect the aesthetics which determine whether people will use a source of water for drinking purposes. The color of water can be an indicator of the presence of organic compounds (humic and fulvic acids), iron and other metals. It can sometimes also be an indicator of industrial effluents. There is no health standard set for the color of drinking water. Typically, water is considered acceptable to drink by people when the color is below 15 TCU (true color units). It is often dependent on the personal tastes of people in the region and on what is available. Taste and odor of water can also be indicators of contamination. They can originate from natural organic processes, treatment processes, such as chlorination, they can be the result of hazardous contamination, or they can develop during storage and distribution. There is no specific health guideline set for taste and odor of drinking water and it is dependent upon the range of acceptability for taste and odor of the consumer. In Nepal, the presence of iron in the groundwater is most likely to affect the aesthetics of the water. (WHO, 1993)

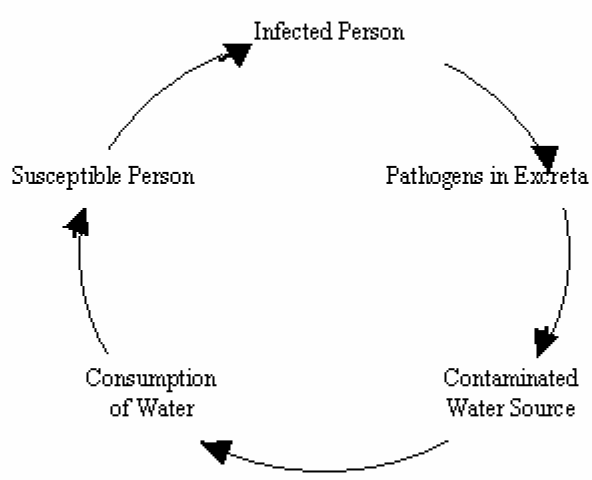
Turbidity is a physical parameter than can be an indicator of microbial contamination of water. The presence of turbidity can stimulate bacteria growth in water. "Turbidity is caused by the presence in water of particulate matter, such as clay, silt, colloidal particles, and plankton and other microscopic organisms, and is a measure of the water's ability to scatter and absorb light. This depends on a number of factors, such as the number, size, shape, and refractive index of the particles and the wavelength of the incident light (*WHO, 1993*)." The surfaces of these particles have adsorbed nutrients, which can enable the bacteria on the particles to have a faster growth rate than they would in suspension.

A major problem with turbidity is that it can impact the effectiveness of disinfection. The suspended particles that cause turbidity can protect the bacteria from the disinfectant, in effect, increasing the chlorine and oxygen demand of the water. Surface waters tend to have higher turbidities than groundwater. The WHO guidelines recommend that the level of turbidity is ≤ 5 NTU (nephelometric turbidity units). (WHO, 1993)

2.2 PATHOGENS IN WATER

The microbial contamination of water can lead to the transmission of infectious diseases. Pathogens are shown to be present in water in most incidences of water borne disease, either due to contamination of the source, no treatment, or to a failure of treatment. These waterborne illnesses are transmitted via a fecal-oral route from animal or human excreta (see Figure 2.1), from insect bites, or cutaneous (dermal) contact. When infected humans or animals fecally contaminate water, consumption of that water can transmit disease. Contaminated water used for drinking, cooking, teeth brushing, or even washing can all cause infection. (WHO, 1993)

FIGURE 2.1: DIAGRAM OF FECAL-ORAL DISEASE CYCLE



Water-borne diseases with a significant impact on human health that can be transmitted via the fecal-oral route, through insect bites and from cutaneous contact are summarized in Figure 2.2 below. These diseases can result from the use of fecally contaminated water, inadequate water supply, inadequate sanitation, and from insects that require water during part of their life cycle. Pathogens of particular concern are *E. coli*, *Salmonella*, *Giardia*, *Cyrptosporidium*, *Shigella*, and *Vibrio cholerae*. These pathogens occur all over the world, but certain areas, such as developing countries are more prone to waterborne disease outbreaks.

FIGURE 2.2: DISEASES RELATED TO WATER AND SANITATION

Group of Diseases	Disease	Route Pathogen Leaves Host	Route Pathogen Infects Individual
Diseases which are water borne	Cholera	Feces	Oral
	Typhoid	Feces/Urine	Oral
	Infectious Hepatitis	Feces	Oral
	Giardiasis	Feces	Oral
	Amoebiasis	Feces	Oral
	Dracunculiasis	Cutaneous	Percutaneous
Diseases which are Associated with Poor hygiene and water scarcity	Bacillary Dysentery	Feces	Oral
	Enteroviral Diarrhea	Feces	Oral
	Paratyphoid Fever	Feces	Oral
	Pinworm (Enterobius)	Feces	Oral
	Amoebiasis	Feces	Oral
	Scabies	Cutaneous	Cutaneous
	Skin Sepsis	Cutaneous	Cutaneous
	Lice and Typhus	Insect Bite	Insect Bite
	Trachoma	Cutaneous	Cutaneous
	Conjunctivitis	Cutaneous	Cutaneous
Diseases Related to Inadequate Sanitation	Ascariasis	Fecal	Oral
	Trichuriasis	Fecal	Oral
	Hookworm	Fecal	Oral/ Percutaneous
Diseases with Part of Life Cycle of Parasite In Water	Schistosomiasis	Urine/Feces	Percutaneous
Diseases with Vectors Passing Part of Their Life-Cycle in Water	Dracunculiasis	Cutaneous	Percutaneous

Table adapted form World Health Organization, Water and Public Health Seminar Packet 2000, pg. 2.

How long pathogens remain viable in water after they leave their host varies with the pathogenic organism. Typically, the pathogens lose their viability and ability to infect exponentially with time. The most important factor that affects the pathogens persistence in water is temperature. Increasing temperature accelerates the decay rate of the microorganisms and the decay effects can be exacerbated by the presence of ultraviolet radiation from sunlight near the water surface (WHO, 1993). The persistence of pathogens in water is presented in Figure 2.3. Parasites and pathogens that cause a high infectivity or are able to persist for a long time in water such as enteroviruses and *salmonellae* are especially effective at transmitting water borne illness. Typically, pathogens with a low persistence in water such as *Vibrio cholerae* and *Shigella spp.* will be more easily transmitted via food or human-to-human contact. In addition to persistence in water, the resistance of a pathogen to chlorine is also of interest and is summarized in Figure 2.3. It is important to know the resistivity of an organism to chlorine because chlorination is the main mode of water disinfection in many countries.

FIGURE 2.3: PROPERTIES OF WATER-BORNE DISEASE PATHOGENS IN WATER

PATHOGEN	HEALTH SIGNIFICANCE	PERSISTENCE IN WATER SUPPLIES (A)	RESISTANCE TO CHLORINE (B)	RELATIVE INFECTIVE DOSE (C)	IMPORTANT ANIMAL RESERVOIR
BACTERIA					
Camplobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Pathogenic Escherichia coli	High	Moderate	Low	High	Yes
Salmonella typhi	High	Moderate	Low	High	No
Other salmonellae	High	Long	Low	High	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	High	No
Yersinia	High	Long	Low	High (?)	No
Pseudomonas aeruginosae	Moderate	May Multiply	Moderate	High (?)	No
Aeromonas sppl	Moderate	May Multiply	Low	High (?)	No
VIRUSES					
Adenoviruses	High	?	Moderate	Low	No
Enteroviruses	High	Long	Moderate	Low	No
Hepatitis A	High	?	Moderate	Low	No
Enterically transmitted non-A, non-B hepatitis virus, hepatitis E	High	?	?	Low	No
Norwalk Virus	High	?	?	Low	No
Rotavirus	High	?	?	Moderate	No (?)
Small Round Virus	Moderate	?	?	Low (?)	No
PROTOZOA					
Entamoeba histoytica	High	?	?	Low	No

Giardia intestinalis	High	Moderate	High	Low	Yes
Cryptosporidium parvum	High	Moderate	High	Low	Yes
HELEMINTHS					
Dracunculus medinensis	High	Moderate	Moderate	Low	Yes

? - not known or uncertain
[a] Detection period for infective stage: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month
[b] When the infective stage is freely suspended in water treated at conventional doses and contact times. Resistance moderate, agent may not be completely destroyed.
[c] Dose required to cause infection in 50% adult volunteers: May be one infective unit for some viruses.
[d] From experiments with human volunteers
[e] Main route of infections is by skin contact, but can infect immunosuppressed or cancer patients orally
Table adapted from: WHO Guidelines for Drinking Water Quality, 2nd ed. Vol. 1 - Geneva.WHO, 1993. pp 8-29

2.3 INDICATOR ORGANISMS

The probability that a person will become infected by a water pathogen cannot be deduced from the pathogen concentration in water. Infections from pathogens are a function of the virulence of the pathogen and the susceptibility of the host. As a result, there is no lower limit for the allowable levels of pathogens in water. Any water intended for consumption or cooking should be free of all pathogenic organisms. Pathogen-free water can be obtained from protected pathogen-free sources and/or produced by an effective water treatment process.

To determine if water is free of fecal contamination and pathogens, indicator organisms are monitored. The indicator organisms are chosen because they are present in higher levels in contaminated waters than the pathogens, because they can be readily cultured, and finally because the cost of monitoring them is less expensive than monitoring the actual pathogens. Just as the name suggests, the presence of indicator organisms indicates the presence of the pathogenic organisms.

Indicator organism must fulfill certain requirements:

1. Should be present in high numbers in contaminated waters;
2. Should be present in the feces of both humans and warm blooded animals;
3. Their presence and persistence in water, along with water removal by treatment, should be similar to those of the actual pathogens

E. coli and coliform bacteria are often used as indicator organisms for fecal pollution in water. They are the best choices of indicators when resources are limited. However, their absence does not fully ensure that the treated water will be free of pathogens. Enteroviruses, dormant *Cryptosporidium, Giardia,* and amoebas are more resistant to disinfection. (WHO, 1993)

A group of organisms that are commonly used as indicators of fecal contamination are coliform bacteria. Coliform bacteria are part of the Enterobacterceae family, but are a group of organisms that are arbitrarily defined in the United States by the following conventions: aerobic and facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with gas formation within forty hours at 35°C. Coliform bacteria in the United Kingdom are defined as gram-negative, oxidase-negative, non-spore-forming rods capable of growing aerobically on agar containing bile salts and able to ferment lactose within forty-eight hours at 37°C with the production of both acid and gas (Lynch, 1988). Total coliform bacteria were originally believed to indicate the presence of fecal contamination, however total coliforms have been found to be widely distributed in nature and not always associated with the gastrointestinal tract of warm-blooded animals. They are still widely used as indicator organisms for water quality.

Coliform bacteria such as *Citrobacter fruendi* are found in feces and the environment. In the environment, they are commonly found in surface waters and are from decaying plants, soil, or nutrient rich waters. Since they can be found in the environment in water that has not been fecally contaminated they are a better indicator of treatment efficiency than of fecal contamination. The bacteria should not be detectable in treated drinking water. To ensure these bacteria are indicating fecal microbial contamination they can be used as monitors in conjunction with *E. coli* or other indicator organism tests such as hydrogen-sulfide (H_2S) producing bacteria. (WHO, 1993)

The ability to grow at an elevated temperature (44.5°C) separates fecal coliform bacteria from the total coliform bacteria; they are a more accurate indicator of fecal contamination by warm-blooded animals. Fecal- coliform bacteria are detected by counting the pink-red colonies that grow on a 0.65 μm filters placed on mFC agar incubated in a 44.5°C oven for 22-24 hours (Lynch, 1988). The presence of fecal coliforms in water indicates that fecal contamination of the water by a warm-blooded animal has occurred.

Escherichia coli (E. coli) is a member of the fecal coliform group of bacteria and is distinguished by its inability to break down urease (Lynch, 1988). *E. coli* is commonly found in the gastrointestinal tract and feces of warm-blooded animals. Fecal contamination by animals is a well-documented source of *E. coli*. *E. coli* is abundant in both human and animal excreta at levels that can exceed 10^9 organisms per gram. The World Health Organization states the *E. coli* is the most specific indicator of fecal and animal pollution, however, there has been some recent evidence that in tropical regions *E. coli* might arise naturally in surface water that have not come into contact with human feces (WHO, 1993). The World Health Organization mandates a water quality guideline of zero *E. coli* per 100ml of water sample. No 100ml water sample should test positive for either *E. coli* or total coliform for any water that is to be used for drinking. Water treatment can ensure that the risk of waterborne illness is negligible if an adequate source protection and/or treatment program is implemented.

No easy and reliable tests have yet been developed for the accurate detection of viruses and parasites such as *Giardia* and *Cryptosporidium* in water. For parasites and viruses, it may only take one organism to cause an illness. The best method of prevention in these cases is to use a source water that is known to be free of fecal contamination, and to ensure a sufficient residual level of disinfectant in storage and distribution systems. (WHO, 1993)

2.4 INDICATOR ORGANISM CORRELATIONS

Research to determine what are the best organisms (H_2S producing bacteria or total coliform/*E. coli*) to indicate fecal contamination has been conducted, but the results are still under debate. H_2S producing bacteria have been associated with fecal contamination of water and were tested for in the current study because there is evidence that in tropical locations, such as Nepal, native *E. coli* species may be present in pristine water sources that are not fecally contaminated (Kromoredjo, 1991). Studies were performed by Grant and Ziel (Ziel, 1996), Manja, Maura, and Rao (Manja, 1982) and International Development Research Center (IRDC) to determine if the presence of H_2S producing bacteria could be associated with the presence of fecal contamination and correlated with the presence of *E. coli* and total coliform bacteria.

Grant and Ziel's work show a good correlation between the presence of H_2S producing bacteria and fecal coliform. Their work did not show as strong a correlation between H_2S producing bacteria and total coliform until the concentrations of total coliform exceeded 40 CFU/100ml. The researchers hypothesized that the findings indicated that H_2S producing bacteria was a better indicator of fecally contaminated waters than total coliform since it seemed to be able to indicate the presence of bacteria with fecal origins while total coliform may give positive test results with the presence of non-fecal origin bacteria.

Work done by the IDRC contradicts the work of Grant and Ziel because their work indicates that H_2S producing bacteria correlate better with total coliform than fecal coliform. The contradiction between the two sets of researchers results is partially explained by looking at the types of bacteria that were isolated in the IRDC tests. *Citrobacter fruendi* were isolated in eight-five percent of the IRDC positive tests. As previously noted *Citrobacter fruendi* can be from both fecal and environmental sources. IRDC found that the lowest range of detection for H_2S tests ranged from as low as 7 CFU/100 ml to more than 250 coliform CFU/ 100ml (they found 20% of samples at this level did not give a positive result). Positive H_2S tests also occurred in waters where no fecal coliforms were present.

These test results indicate that H_2S producing bacteria are best used to indicate contamination/ in waters with little chance of having environmental coliforms, such as deep wells and treated water. The microbial data collected in this study will be analyzed to determine the correlations between the microbial tests for water in Nepal.

2.5 METHODOLOGY

2.5.1 Microbial Testing

The indicator organisms chosen for testing in both the field work in Nepal and for lab work conducted at MIT were H_2S producing bacteria, total coliform, and *E. coli*. The HACH Company manufactures Presence/Absence (P/A) tests for all three of these organisms and these were the tests that were used in this study. The total coliform P/A test requires a 100ml sample of water be combined with a reagent ampoule containing methylumbelliferyl-β-D-glucuronide (MUG). The resulting purple mixture is then incubated for 24 to 48 hours at 35°C. If during the incubation time the mixture turns yellow, the test is positive indicating the water sample contains total coliform bacteria. The MUG reagent can detect the presence of *E. coli* by fluorescence under long-wave ultraviolet (UV) light.

To detect H_2S producing bacteria two different testing methods were used: HACH most probable number (MPN) and a homemade H_2S test the IRDC has developed (Module 7, 1998). The HACH MPN test may be used as an MPN test or as a P/A test. A 100ml sample can be divided between five 25ml vials, and a reagent pillow is added to each of the vials. The vials are then incubated for 24 to 48 hours at 30°C. The tests will turn from yellow to black to indicate the presence of H_2S producing bacteria. The most probable number of bacteria present in the 100ml sample is determined statistically from the number of vials that are positive out of the five. The test may also be used as a P/A test by mixing one 20ml sample and one reagent pillow in a 25ml bottle and incubating. Once again, if the sample turns black the test is positive. The sensitivity of the MPN tests is 1 colony forming unit (CFU)/ 100ml, the sensitivity of the P/A is less than the MPN test and is 1 CFU/20ml (5 CFU/100ml)

The IRDC test was used in the field to test its reliability in field conditions. The tests were prepared in the field in Nepal and used during fieldwork. The cost of the IRDC test is only $0.13 per test in comparison to $0.67 per test for the HACH version (Murcott, 2001). This difference in cost can make monitoring water quality easier in developing countries where money for testing is scarce. The effectiveness of the IRDC test in detecting H_2S producing bacteria will be assessed by comparison with the HACH MPN test. The recipe and preparation directions can be found in the Appendix I.

It is sufficient to use P/A for H_2S bacteria, total coliform bacteria, and *E. coli* bacteria under field conditions in Nepal because the allowable number of bacteria per 100 ml of sample by WHO standards is zero. With such simple testing, we generally knew if the water was microbially safe or not. However, enumeration would be useful in determining the extent of contamination. The use of a standard enumeration technique such as membrane filtration would allow colonies of bacteria to be counted and cultured for identification using specialized media. These types of tests are more expensive and are not feasible to use in a rural setting in Nepal due to the sporadic electric supply and lack of clean lab space.

During the microbial testing a novel incubator designed by Amy Smith of MIT was field-tested. The device utilizes a phase-change material that changes from liquid to solid at 35°C, body temperature. The device was practical for field conditions because it did not need an electric power supply to provide heat. The incubator was boiled in water until the internal temperature reached an even 35°C, at which point the phase-change material changed from a white waxy solid to a clear liquid. The incubator was able to keep samples at this temperature for over twenty hours with proper insulation. Once the material was visibly hard and white again and the temperature in the incubator falls, the incubator can be reheated to the proper temperature again by boiling.

2.5.2 Turbidity Testing

Turbidity in the field and at MIT was measured using both a HACH 2001P Portable Turbidimeter^{TM} and a HACH Pocket Turbidimeter. The instruments provided turbidity measurement in Nephlometric Turbidity units in a range on 0.1 to 400 NTU. (Products for Analysis, 2001)

3 FIELD WORK IN NEPAL

3.1 FIELD SITE SELECTION

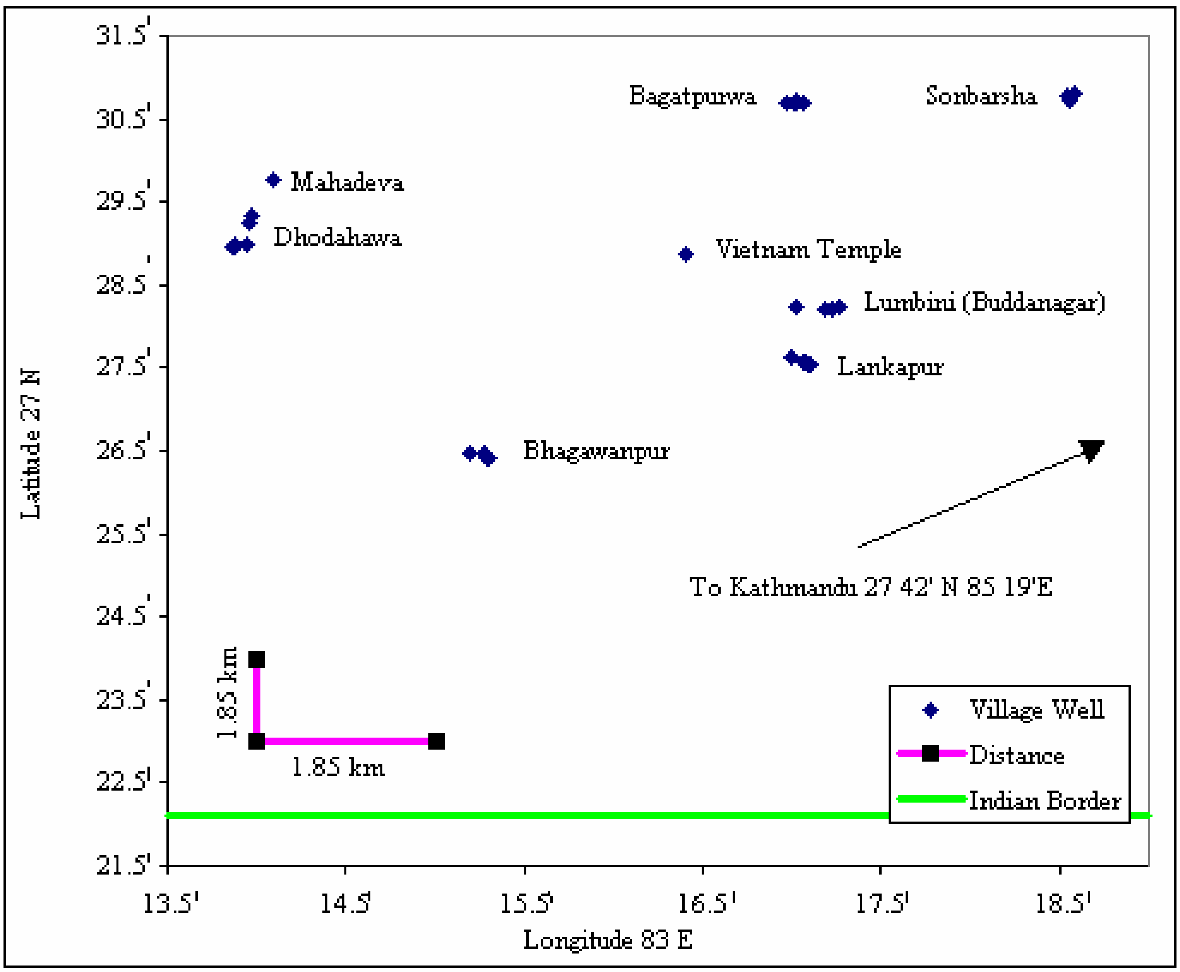
The group of students, Meghan Smith and Timothy Harrison, accompanied by Dr. Lee Hersh, a retired Corning Corporation chemist and MIT Water Project volunteer, spent two weeks in Lumbini located in the Terai, near the Indian Border studying microbial contamination of tubewells and microbial removal technologies. A local NGO, Crossflow Nepal, runs a village health program in the Lumbini District and provided services and information to facilitate the studies. Bhikku Maitri, head of Crossflow and Chairman of the International Buddhist Society (IBS), operates the free medical clinic in Lumbini. He assisted the previous year's M. Eng. students with their project in Nepal. He provided the current students with information, interpreter skills and acted as our guide and host. The doctor at the free health clinic, Dr. Mallick, was a source of medical information. A survey of microbial contamination of village tubewells and water use issues was conducted in seven of the district villages: Lumbini, Lankapur, Mahadeva, Bhagawanpur, Dhodahawa, Sonbarsha, and Bhagatpurwa. Practical household solar disinfection (SODIS) experiments were performed on the roof of the health clinic in Lumbini.

Dr. Mallick is the sole health care provider for all the villages in the study. He receives his health information from the individuals he treats daily in his free clinic in Lumbini, from village visits, and from the Crossflow Nepal Health motivators. Crossflow Nepal is the local NGO that organizes the water, health, and sanitation developments in the area villages. The organization employs six Nepalese women motivators. The job of the motivators is to visit assigned villages and schools and educate villages on health, water, and sanitation practices. The organization has succeeded in installing tubewells in most of the local villages, and has been training village women on health, water, and sanitation. The group is planning to implement sanitation in the villages via latrine installation in the near future.

3.2 Village Well Survey

Lumbini, a rural town in the Terai region of Nepal, was visited in January 2001 along with six neighboring villages: Bhagawanpur, Sonbarsha, Bhagatpurwa, Dhodahawa, Mahadeva, and Lankapur[2]. Lumbini and the neighboring villages lie just 10 km from the Indian border and share both cultural and geographic similarities with India. There are sixty-two villages total located in the Lumbini area. The village and well locations of this study are graphed in Figure 3.1.

FIGURE 3.1: VILLAGE AND WELL LOCATIONS



2 The International Buddhist Society hosted our fieldwork in Nepal and Bhikku Maitri (IBS Chairperson) hosted the researchers in Nepal. Their efforts towards providing the people of the Lumbini District with safe water, improved health, and sanitation provided a foundation and motivation for the project.

The purpose of the fieldwork was to assess the levels of microbial contamination in village tubewells, observe water and sanitation practices, and to investigate several possible household treatment options. The well surveys both assessed the physical condition of the wells, and the microbial quality of the water. Local people were observed to gain an understanding of water usage and possible routes for contamination of the water sources and drawn water.

FIGURE 3.2: VILLAGE SUMMARIES

Village	Number of Households	Population	Average Household size	Number of wells tested	Wells positive for Total Coliform	Percent of wells positive for H2S (all wells tested)
Bhagawanpur	35	275	7.8	6	1/2 tested	(2/6) 33%
Sonbarsha	118	710	7.2	4	3/4 tested	(1/4) 25%
Bhagatpurwa	125	800	6.4	5	1/1 tested	(3/5) 60%
Dhodahawa	69	488	7.1	7	1/2 tested	(6/7) 86%
Mahadeva	21	158	7.5	1	0/0 tested	(1/1) 100%
Lankapur	24	315	13.1	5	3/3 tested	(5/5) 100%
Lumbini (Buddanagar)	15	50-60	4	5	0/0 tested	(3/4) 75%
Total	407	2801		33	9	21
Average	58.1	400.1	7.2	4.7	(9/12) 75%	(21/32) 66%

The wells tested in the villages were a combination of private and public wells. Overall, the public wells, put in by the NGO's, IBS and the Nepal Red Cross were newer and in better condition than the private wells. In general, the public wells were in good working order, had proper cement cover pads, good drainage, were located away from animals and huts, and were at least 170 feet deep. The private wells (see Figure 3.4), on the other hand, were often only thirty feet deep, were located proximally to animal shelters, had algae growing on the spouts, and were much older than the public wells. Most of the public wells are less than five years old and many were just installed by IBS in the past two years. IBS and Nepal Red Cross installed all the public wells except one, which was installed at the Lankapur Health Center by the government. Seventeen of these public wells (65.4%) tested positive for H_2S producing bacteria. The private wells had a slightly higher but similar incidence of contamination. Of the eight private wells tested, six tested positive for H_2S producing bacteria (75.0%). The average depth of the private wells was 49.2 feet, while for the public wells the average depth was over twice as deep at 122.3

feet. Even though the average depth of the public wells was significantly deeper than the average depth of the private wells, the percentage that were microbially contaminated was only 10% lower

FIGURE 3.3: PRIVATE WELLS TESTED

Village	Total Wells Tested	# Private Wells Tested	# Tested Positive for H2S Bacteria	Average Well Depth (feet)
Bhagawanpur	6	1	0	80
Sonbarsha	4	0	0	
Bhagatpurwa	5	2	1	85
Dhodahawa	7	3	3	30
Mahadeva	1	1	1	40
Lankapur	5	1	1	30
Lumbini (Buddanagar)	5	0	0	0

FIGURE 3.4: A PRIVATE WELL (LEFT) AND A COMMUNITY WELL (RIGHT)

The cost of drilling a well varies according to well depth. It is less expensive to drill a shallower well, but often the water is of poorer quality. Drilling a well costs 35 Rs/ft (0.48 US$/ft[3]) for the first forty feet and 50 Rs/ft (0.69 US$/ft) each foot thereafter (Maitri, 2001). PVC for the wells cost 100 Rs/m (1.38 US$/m). Artesian wells are the deepest wells and their total cost averages 50,000 Rs/well (695.0 US$/well) while other wells typically cost near 20,000 Rs/well (278.0 US$/well) (Maitri, 2001). In addition, non-artesian wells require a pump plus a contract with a local mechanic since a pump typically requires repair every three to five months. As a lubricant during drilling animal dung sludge is generally used rather than a bentonite slurry, which would be used in the United States (Maitri, 2001). This practice could account for some of the contamination in the aquifers initially, but should not account for permanent contamination since the enteric bacteria can only survive for a limited time in the environment outside a host.

Overall, thirty-four wells were tested in the villages (see Appendix II for a complete table listing all wells, global positioning coordinates, test results, well depths, and detailed descriptions). Each well was tested for H_2S producing bacteria and nine of the wells were also tested for total coliform bacteria and *E.coli*. (All wells were not tested for total coliform and *E. coli* because there was a shortage of the P/A reagent for those tests.) Of the thirty-four wells included in the study, 57% tested positive for H_2S producing bacteria, 82% tested positive for total coliform bacteria, and 47% tested positive for *E. coli*.

During the course of the well survey, many open wells were encountered in the district villages. These open wells are hand-dug with brick-lined interiors. The typical well had a six-foot diameter, was flush with the ground, and had a water level 15 to 25 feet below ground level. The wells often had visible debris floating in the water. Villagers using buckets with rope attached to the handles drew water from the wells for various purposes. The open wells were often located adjacent to the newly installed tubewells. Villagers have been informed not to use these open wells, but during the course of the study, we witnessed numerous villagers drawing water from the open wells anyway. Only one of

[3] Exchange rate April 21, 2001 – 72 Nepalese Rupees = 1 US$.

these open wells was tested and it tested positive for H_2S producing bacteria, *E. coli,* and total coliform bacteria. No further wells were tested because the wells had visible debris in the water and since they were flush to the ground which made them susceptible to collecting surface run-off containing human and wastes, it was assumed that all such open wells were microbially contaminated. Previous investigations of open wells by Peter Moulton in the area support this contamination hypothesis (Moulton, 1999).

3.3 WELL CASE STUDIES

In the villages, we observed people using the nearest water source, for convenience, regardless of its quality. Local organizations, health employees, and motivators stress to villagers not to use certain wells identified as contaminated, but we found people using them anyway. In one village, Lankapur, the local village health chairman was found to be using a well with clearly contaminated water. The well was directly downhill next to his cattle stalls, with only a few bricks around it but no cover, and the water was yellowish in color. It was a shallow well of only 30 feet. The local health NGO has stressed to the villagers to only use the deeper wells, of approximately 140 feet depth, for drinking water. During an interview, the local health official indicated that he was aware that he and his family should not be using this well, but it was very close to his house and convenient to draw water from. The water from this well tested positive for H_2S producing bacteria, total coliform, and E.coli.

Just beside the village of Lankapur is a new government-run Health Clinic that specifically treats patients with HIV and tuberculosis (TB). This Clinic's tubewell was also only 30 feet deep and was found to be positive for E.coli, total coliform, and H_2S producing bacteria. Our guide, Bhikku Maitri, indicated that the government does know it should provide deeper wells for the health clinics, but it is more expensive to drill deeper wells. Contaminated water at health clinics is a major concern, especially because many of the illnesses people experience in the Terai are water borne and the area also has a high incidence of immuno-compromising diseases, such as HIV and hepatitis. Patients with HIV have been found to be more susceptible to illness from waterborne pathogens, both those from water contamination and those that are naturally occurring (WHO, 1993). Exposure to pathogens, such as *Cryptosporidium*, by immuno-competent individuals may not result in symptoms, or when symptoms do occur they are flu-like and usually go away in a few weeks; however, the same exposure for an immuno-compromised person can mean death (Mortimer, 2001).

3.4 Public Health in Lumbini, Nepal and the Surrounding Villages

Figure 3.5: Incidence of Waterborne Disease in the Selected Villages

Village	Population	Diarrhea Average cases/ month 1999	Abdominal Pain Average cases/month 1999	Amoebiasis Average cases/ month 1999	Diarrhea Cases January, 2001	Abdominal Pain Cases January, 2001	Amoebiasis Cases January, 2001
Bhagawanpur	275	**54**	**37**	**40**	69	69	41
Sonbarsha	710	135	75	80	**177**	**177**	**105**
Bhagatpurwa	800	87	103	110	70	95	42
Dhodahawa	488	210	80	100	26	24	6
Mahadeva	158	**31**	**21**	**23**	**21**	**21**	**24**
Lankapur	315	**61**	**42**	**45**	78	78	47
Lumbini (Buddanagar)	50-60	**11**	**7**	**8**	**13**	**13**	**8**
Total	2801	589	365	406	454	477	273
Average	400.1	84.1	52.1	58	64.9	68.1	39
Incidence Cases per 100 people		21.0	13.3	14.5	16.2	17.0	9.7

The data is taken from a report prepared by Dr. Mallick and GRI on the use of solar disinfection in Lumbini. Dr Mallick compiled disease data before SODIS implementation in nine Lumbini District villages and collected data in the nine villages after SODIS implementation. Three of the villages included in Dr. Mallick's study were included in the current study: Sonbarsha, Bhagawanpur, and Dhodahawa. The actual numbers of disease cases were taken for theses villages from Dr. Mallick's data and the numbers of cases for the other villages, not included in Dr. Mallick's study, were calculated from the average incidence of disease in the district. The average incidence of disease in the district was calculated using Dr. Mallick's data collected on the occurrence of each disease in the nine villages included in his study. The actual data (number of cases) from Dr. Mallick's study are in black in the figure above while the cases calculated from the incidence of disease in the district are shown in red.

The incidence of diarrheal disease in 1999 from Dr. Mallick's data in the nine area villages of his study (cases/100 persons) ranged from 13.3 to 31.4 with the average at 19.5. In total, 1087 of the 5573 people in the nine villages of his study had experienced diarrheal episodes during that month. The range for incidence of abdominal pain was 8.3 to 18.5 and the average incidence was 13.3. In total during the month, there were 741 cases of abdominal pain amongst the 5573 people. The incidence of amoebiasis ranged from 11.3 to 26.1 cases per 100/ persons with an average incidence of 14.4. In total there were 804 cases of amoebiasis reported out of 5573 people in the villages during the month. In January 2001, Dr. Mallick provided the following incidences of diseases (cases/100persons): Amoebiasis 15-20, diarrhea 25-50, abdominal pain 25-50, and skin diseases 40. This data was used to calculate the number of expected cases in January 2001 for the villages where direct data on the actual number of cases was not available (see Figure 3.5).

3.5 IS THERE ENOUGH WATER?

The previously stated purpose of the project in Nepal was to find a practical household water treatment option for villagers. The identified problems in Nepal were microbial and arsenic contamination of the water. The tubewells, put in by international aid agencies, government organizations, and NGO's, were intended to divert people from using the microbially contaminated surface water sources and to increase the water supply. Unfortunately, many of these tubewells have tested positive for microbial contamination. Data collected in the field in Nepalese villages and from interviews with Dr. Mallick indicate that another problem, water scarcity, still exists.

Skin conditions and infections that include lice, scabies, chronic itching, scratching, cracking, white spots, and patchy rashes ranked high among the health complaints of the villagers. In some villages over forty percent of the village population was suffering from such skin ailments (Mallick, 2001). These ailments are indicative that there is a water shortage in the area villages. These types of conditions are known as water washed diseases, as opposed to the water borne disease previously discussed. These diseases are the result of insufficient water supply and are closely linked to hygiene practices (see Figure 2.2) (DFID, 1999). Increasing the water quantity available to people for washing and drinking will subsequently decrease the incidences of these water washed diseases

The number of people competing for the fresh water resources is a great factor in water resource availability. Greater population size and standards of living increase the demand for finite quantities of water and intensify competition and tension among consumers. Often urbanization, industrialization and irrigation usage of water are unsustainable, and unless the usage patterns change, the situation will worsen. In the Terai, factors that effect water availability include seasonal precipitation fluctuations, population density, and agricultural irrigation. In the cities, such as Kathmandu, chronic water scarcity is the result of an inadequate public water supply system, population density, and water resource pollution.

Recently (December, 2000), an ambitious water supply project, the Melamchi Water Project, has been approved for the Kathmandu Valley (ADB, 2001). The project is proposed to address the water supply issues of the valley by diverting a portion of the flow (170 million liters per day) of the Melamchi River through a 26 km tunnel and constructing an expandable water distribution system and a 170 MLD (million liters a day) water treatment plant. The project is being designed so that it will be able to accommodate expanded capacity in the future when additional water diverted from the Yangri and Larke rivers.

The Melamchi Water Project is a good example of the water scarcity problem that exists in Nepal today. Overall, the country has abundant freshwater resources; possessing just 0.4% of the world's population it has 2.3% of the world's water resources, just not in the same places that its people are located. In 1990, the renewable annual freshwater available per person in Nepal was estimated by the World Resource Institute to be 8,686 m^3 compared to the United States 9,913 m^3 and India's 2,464 m^3 of renewable annual freshwater. It appears from this data that Nepal should not be experiencing water shortage problems. But the water problems that exist in Nepal today as a result of seasonal fluctuations, the inability of people to store water, deforestation, and the location of rural villages and urban centers away from the water resources. The water shortage problems in Nepal will only grow worse as the population continues to grow, Population Action International estimates that the freshwater resources per capita in Nepal will be reduced to 4,488 m^3 in 2025 when its population is projected to reach 37.8 million by the United Nations.

The impacts of improved water quality and increased water availability are greatest when they are implemented in tandem. Figure 3.6 summarizes the impact of improvements in water quality, increased water availability, increased sanitation in diarrhea morbidity reduction (WHO, 2000). The table illustrates that the highest reduction in morbidity is achieved when improvements in water quality, availability, and sanitation are concurrent.

FIGURE 3.6: PERCENTAGE REDUCTION IN THE DIARRHOEA MORBIDITY RATE ATTRIBUTED TO IMPROVEMENTS IN WATER SUPPLY OR EXCRETA DISPOSAL

Type of Intervention	Number of Studies	Percentage Reduction Median	Range
All	53	22	0-100
Water Quality Improvements	9	16	0-90
Improvements in Availability	17	25	1-100
Improvements in Availability and Quality of Water	8	37	0-82
Improvements in Excreta Disposal	10	22	0-48

Table excerpted from Water and Public Health, World Health Organization Seminar Packet 2000

3.6 MICROBIAL DATA CORRELATIONS

Microbial test data collected in the Lumbini District by the author and microbial data collected by Tse Luen Lee (Lee, 2001) in Tansen and Nawalparasi were analyzed to determine test correlations. The data and correlations from both researchers are presented in Figure 3.7.

FIGURE 3.7: MICROBIAL TESTING CORRELATIONS

Test Group Number Test Type		Test Type	Correlation	Number of Water Sources Tested	Number of tests Results That Did Not Correlate	Data Collected By
1.0	HACH Total Coliform	HACH H_2S	0.44	17	6/17 (35%)	Smith
2.0	HACH Total Coliform	HACH H_2S	0.64	19	4/19 (44%)	Lee
3.0	HACH Total Coliform	HACH *E. coli*	0.77	23	3/23 (13%)	Smith
4.0	HACH Total Coliform	HACH *E. coli*	0.826	42	4/42 (9%)	Lee
5.0	HACH H_2S	HACH *E. coli*	0.73	15	2/15 (13%)	Smith
6.0	HACH H_2S	HACH *E. coli*	0.79	35	5/35 (14%)	Lee
7.0	HACH H_2S	IRDC H_2S	0.51	32	9/32 (28%)	Smith

In both data sets, the strongest correlations were between the HACH total coliform and HACH *E. coli* (Test groups 3 and 4) and between HACH H_2S and HACH *E. coli* (Test groups 5 and 6) in both sets of data. In test group 3, three of the twenty-three test results did not agree and the three tests results were positive for total coliform but not *E. coli*. Lee's correlation data between these two tests was slightly higher at 0.83. For test groups 5 and 6 the total number of tests in both studies combined was fifty; of these fifty tests seven test results did not agree (14%). Of the seven tests that did not agree, five tested positive for *E. coli* but not H_2S producing bacteria (71.4%), and two of the seven tests tested positive for H_2S but not *E. coli*.

The correlation between the HACH total coliform and HACH H_2S was the lowest correlation at 0.44. Six of the seventeen tests in test group 1 tested positive for total coliform but not H_2S producing bacteria. Lee's data (test group 2) has a higher correlation at 0.64, but it was also the lowest correlation of all his tests. In both data sets, all tests that gave a negative test result for total coliform also tested negative for H_2S producing bacteria.

The correlation between the HACH H_2S producing bacteria test and the IRDC H_2S producing bacteria test (test group 7) was lower than expected (0.51) of the thirty-two tests nine of the test results did not match (28%). Of these nine test results that did not match eight (89%) tested positive for H_2S producing bacteria using the HACH test, but not the IRDC tests, and only one of the tests tested positive using the IRDC but not the HACH test. These two tests were expected to have the highest correlation because they were testing for the same organisms, unlike the other tests. The low correlation can be partially explained because the HACH test used a greater testing water volume 20ml and the IRDC test had a 10 ml testing water volume. The HACH test appears to be a more sensitive tests; enumeration testing should be performed to determine if the HACH test will detect a lower level of CFU/water volume.

4 CHOOSING A WATER TREATMENT TECHNOLOGY FOR A DEVELOPING COUNTRY

4.1 POINT-OF-USE WATER TREATMENT

The poor economic and political state of Nepal means that its rural population will not have access to a piped water supply at any time in the near future. The government is unable to develop the infrastructure needed to fund and maintain such piped water supply systems. This leaves source protection measures, community-based small systems, and point-of-use water treatment at the household scale as the best options to ensure access to clean water. The choice of point-of-use water technique should fulfill the following criteria (Lehr *et al*, 1980; Shultz *et al*, 1984):

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

The most popular current point-of-use water treatment in Nepal for those who can afford it is filtration with candle filters followed by boiling. Household disinfection mechanisms in use in Nepal today include boiling water, filtering, and limited use of chlorination. Boiling water uses scarce energy reserves in the villages, fuel sources are both firewood and dried animal dung. One kilogram of wood is required to boil one liter of water and average drinking water consumption in Nepal ranges from 4-10 L/person/day[4]. Thus, an average family of eight would require 32-80 kg wood/day (Paynter, 2001)). The Terai region has limited lumber resources as a result of extensive deforestation and the use of the alternative fuel source, dried animal dung, diverts nutrients vital for agriculture from the fields.

The Point-of-use technologies are household treatment options. The advantage of treating water at the household level rather than at the community level is the lower capital cost, even though economies of scale and capital cost sharing can perhaps more readily raise the capital for community systems than for the household options. There is no question at the household level of who is responsible for operation and maintenance of the system. At the community level there can be a problem with care and maintenance of the system since individuals might not feel a strong sense of ownership and responsibility. When dealing with individual households people will not become jealous of freeloaders, or of people who use the system but do not pay. Failure of a household system will affect only a small number of users and not the entire town. Household treatment is not always the best option, but for Nepal at this time in many areas, it may be the most practical option.

4.2 SUSTAINABLE, APPROPRIATE, AND ACCEPTABLE TECHNOLOGIES

A sustainable technology is affordable, acceptable, and understandable to the users and can be properly operated and maintained (O&M) by the users (DFID, 1999). Users must be educated in problems that could occur in the future with the technology and be prepared to handle them and able to obtain any necessary spare parts; it is favorable that in-country supplies and parts can be used for O&M repairs. Training is the variable that can ensure the success or failure of a project. Sustainable training requires that there be a system in place to ensure properly trained people replace the people initially trained when

[4] (http://almashriq.hiof.no/lebanon/600/610/614/solar-water/unesco/35-46.html page1)

those people move on or leave the project. Designing a technology so that it can be standardized is also an important factor in ensuring sustainability.

An appropriate technology is a sustainable technology but not necessarily a low cost technology (DFID, 1999). An appropriate technology is a technology that fulfills all the requirements or criteria selected for a technical solution to the problem at hand. Somewhat in contrast to the DFID definition, an *appropriate technology,* or *appropriateness,* has four components as defined by Schumacher (1973):

1) The technology must be of simple design and easily produced;
2) It must be low cost;
3) It must use local, easily accessible materials;
4) It must have a rural focus.

Two important factors in identifying an acceptable technology for a given area are a social analysis and the incorporation of social issues through public participation in planning and development. A social analysis may collect various types of information both demographic and cultural on households and villages including:

- Size,
- Population,
- Sex and age distributions,
- Socio-economic status,
- Race, ethnicity, and language,
- Hygiene practices,
- Social customs and norms,
- Perceptions of clean and pure,
- Perceptions on health and healing,
- Privacy issues,
- Life-cycle,
- Water use habits, such as bathing, washing, and drinking,

- Gender issues,
- Various other cultural issues.

Acceptability of a technology is something that if overlooked can result in the failure of implementation of the selected technology because it may not fit into the social or cultural framework of the community even though the technology has proven to be effective.

4.3 REMOVAL TECHNOLOGIES

Removal technologies that are currently used in Nepal are filtration and disinfection. It is a common practice, for those that can afford it, to use a candle filter for particle removal and boiling for disinfection. The theories behind the practices are not always apparent to the people who are using these technologies. Many people interviewed in Nepal were under the incorrect assumption that the candle filter was removing all the contamination from the water. Hotels, restaurants, monasteries, temples, and other establishments set out candle filtration units for people to get drinking water from, under the assumption that the filtered water was “pure”. As shown by Sagara (2000) the candle filters do not provide disinfection, only a reduction in turbidity. Proper use of the candle filter, to ensure microbially free water, requires boiling the water before or after filtration, or to use colloidal silver applied directly to the candle filter. The practice of boiling water was found to be common in Nepal and the practice of using colloidal silver treated candle filters to provide disinfection was nonexistent in Nepal. The theories behind filtration and disinfection are outlined below. In the following two chapters two water treatment technologies that were evaluated are presented: the Corning CerCor ceramic membrane filtration unit and SODIS.

4.4 FILTRATION THEORY

Filtration is the most commonly used water treatment process in water treatment plants. Suspended particles, typically measured as turbidity, are significantly decreased in filtered water or "filtrate." Particles are removed during filtration as a result of any one or combination of the following mechanisms: mechanical straining, sedimentation, flocculation, adsorption, and/or biological metabolism. (AWWA, 1999)

Filters can be used without the addition of coagulant chemicals, making filters an appropriate option for countries in which coagulant chemicals are either unavailable or expensive. In order to ensure microbial removal through filtration it should be combined with a disinfection process. In the revised Surface Water Treatment Rule (SWTR), the USEPA mandates that some form of disinfection be combined with filtration for surface waters (EPA, 1989). Boiling the water in combination with filtration is a disinfection process often used by the educated middle class in Kathmandu and in the urban areas of Nepal. This method results in pathogen-free water but has a high energy cost that is beyond the means of many people.

Ceramic candle filters are a water-treatment option that has been adopted and promoted by several groups, such as Potters for Peace (http://www.cc.cc.ca.us/pfp/Pfpfilter.htm) and Ceramiques d'Afrique, as a viable household treatment option in developing countries (http://www.geocities.com/ceramafrique). Local artisans are employed to manufacture the ceramic candle filters. Currently, the candle filter of Indian or Nepalese origin is the main method of filtration employed in Nepal. The shortcomings of the candle filter identified by Sagara prompted the current investigation into other methods of filtration such as the BioSand Filter (Lee, 2001) and CerCor filter.

Filtration is defined as the removal of all particles. Pore size is often used to classify filters (see Figure 4.1 for filtration pore and particle sizes).

FIGURE 4.1: SIZE SPECTRUM OF WATERBORNE PARTICLES AND OF FILTER PORES

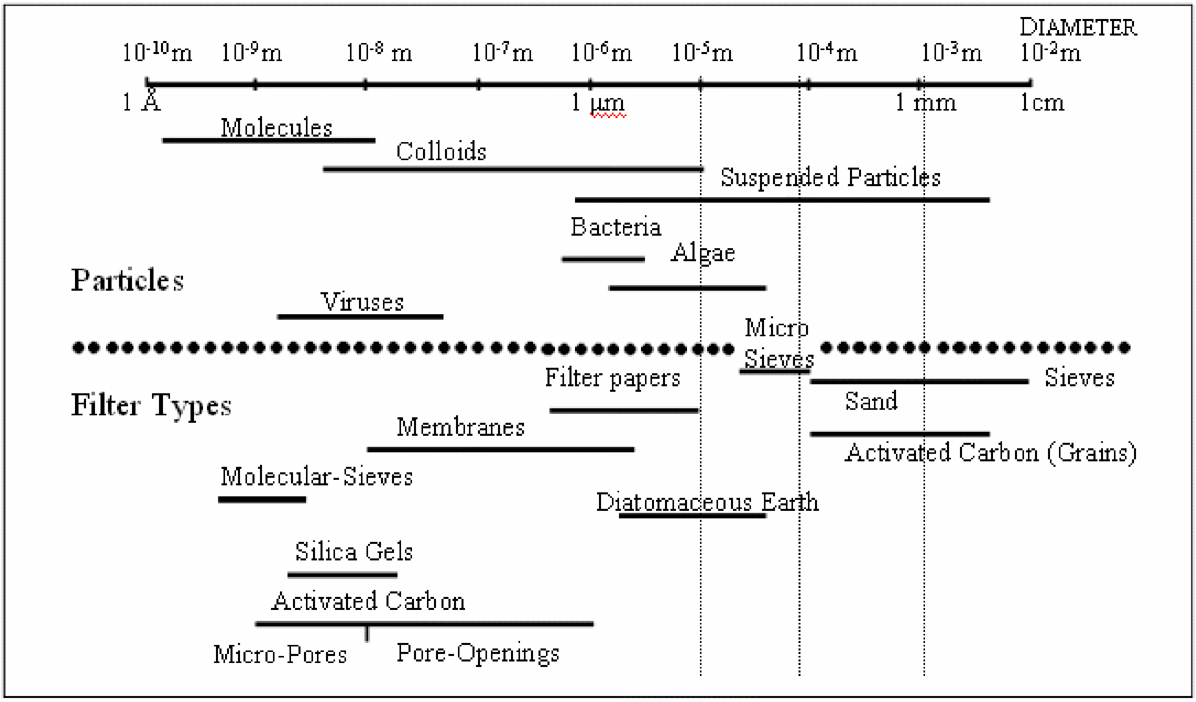


Figure adapted from W. Stumm. Environ. Sci. Technology 11. 1066 (1977)

A filter that removes particles too small to be seen by the naked eye performs microfiltration. Ultrafiltration is the removal of particles in the molecular size range and finally dialysis membranes remove ions. Microfiltration is a type of filtration that is capable of removing microbial contamination; the Corning CerCor filter is a good example of a microfiltration unit. There are two forms of microfiltration: crossflow separation (Figure 4.3) and dead-end filtration (Figure 4.2). During crossflow filtration, the fluid flows parallel to the filter membrane. There is a pressure differential across the filter membrane which causes the flow of some of the fluid through the membrane. Fluid that does not cross the membrane continues flowing through the filter and exits the other end. Crossflow operation is employed during filter cleaning (Figure 4.4), for prefiltration, or it is used to separate a fluid from a process stream. The other method, dead-end filtration, also known as perpendicular filtration, involves the addition of an endcap which forces all flow out of the filter across the filter membrane. Particles that cannot pass through the pores in the filter membrane remain contained in the filter body.

This type of process is used to remove particles from a fluid, usually as a final filtration step. The Corning CerCor filter employs the dead-end process during operation and the crossflow process during the cleaning process.

FIGURE 4.2: DEAD-END MICROFILTRATION DIAGRAM

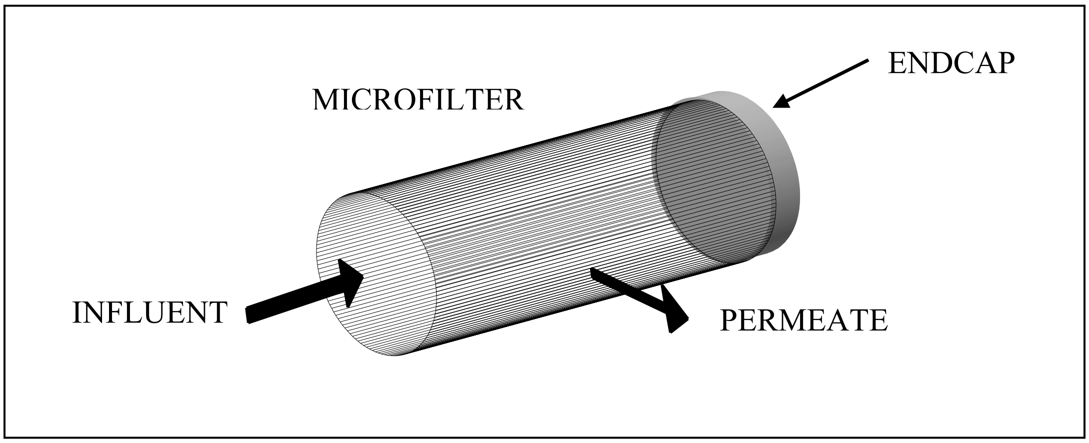


FIGURE 4.3: CROSSFLOW MICROFILTRATION DIAGRAM

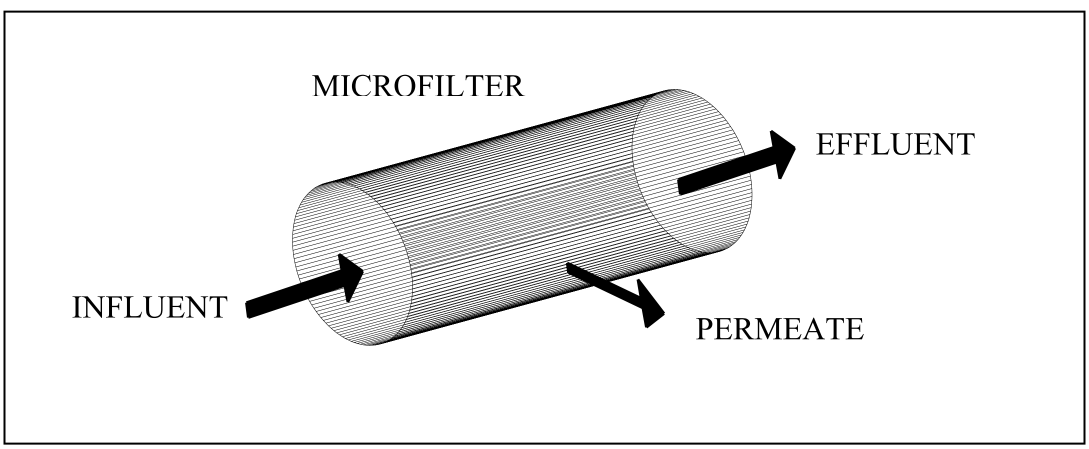
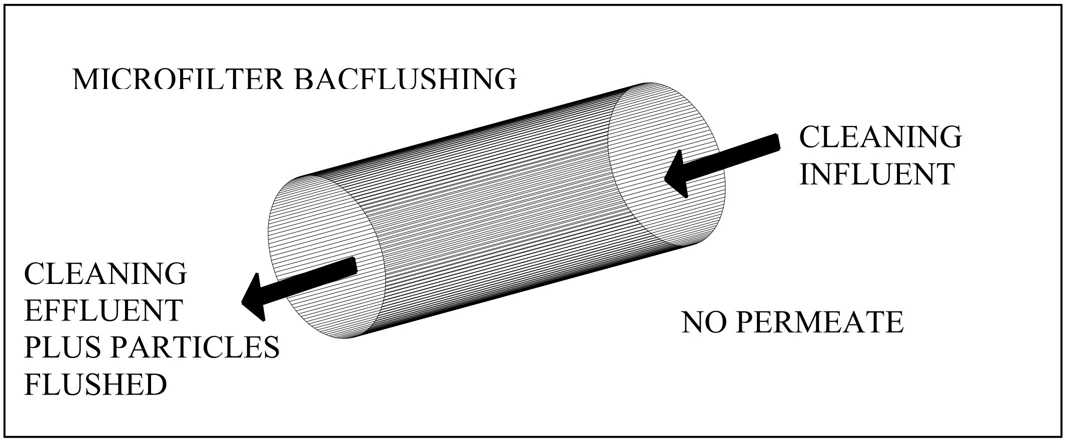


FIGURE 4.4: MICROFILTRATION CLEANING (BACKFLUSHING) DIAGRAM



4.5 DISINFECTION THEORY

Microbially contaminated water needs to be disinfected before consumption. The primary goal of water disinfection is the removal of pathogenic microorganisms from drinking water. Disinfection can be achieved using physical, chemical, or biological methods to reduce the incidence of water-borne diseases and prevent disease outbreaks. Several popular disinfectants are chlorine, ozone, chlorine dioxide, UV radiation, and heat.

Around the world, the main disinfectant process used for water treatment is chlorination, a well-studied and accepted practice. In the cities of Nepal with public water supplies, such as Kathmandu, Biratnaga, and Pokhara, chlorination is used, however, sometimes infrequently and ineffectively (Shrestha, 2000). In Nepal, since liquid chlorine is not readily available for purchase, the only form of chlorine available to local people is bleaching powder. Bleaching powder is much more difficult to use for water disinfection than liquid chlorine. The powder does not readily dissolve into liquids and must be put through several processes to get a useable bleaching solution, with an appropriate concentration, such as 0.5% chlorine. A local NGO in Nepal, Environmental Public Health Organization (ENPHO), has developed such a manufacturing process to produce a liquid chlorine solution with low chlorine content from this bleaching powder. (Shrestha, 2000) Despite this venture to introduce chlorination to Nepal, the practice has not yet become widespread because of lack of supply and public awareness (Water Quality and TX, 2000).

An alternative to chlorine disinfection is solar disinfection (SODIS). This is a unique point-of-use water treatment that can be easily implemented in developing countries both in urban and rural areas. One of the concerns of chlorine disinfection that is not a problem with SODIS is the formation of harmful disinfection by-products. Chlorination forms trihalomethanes (THMs) in water during disinfection and THMs have been shown to cause cancer (AWWA, 1999). The alteration of the taste and smell of chlorinated water is also something that people do not like. SODIS does not chemically alter the taste or smell of water.

5 CORNING CERCOR CERAMIC MEMBRANE FILTRATION UNIT

5.1 CERCOR

One option investigated for use in Nepal was the Corning CerCor ceramic membrane filter. The goal of the CerCor study was to evaluate the filter's ability to remove all microbial contamination from drinking water. Additionally, an assessment was made as to what kind of maintenance would be required of the filter to determine if the filter would be an appropriate option for use in Nepal

The CerCor microfiltration unit provides a significantly higher flow rate (18.0 L/hr) than the candle filters. The higher flow rate is due, in part, to the higher operating pressure (20 psi). The pore size of the filters is 0.2 µm, much smaller than the pore size of the hand-made candle filters resulting in the removal of microbes. Once the filter becomes clogged it can be cleaned for re-use. (Drury, 2000)

FIGURE 5.1: COMPARISON OF CERAMIC CANDLE FILTER AND CERCOR FILTER

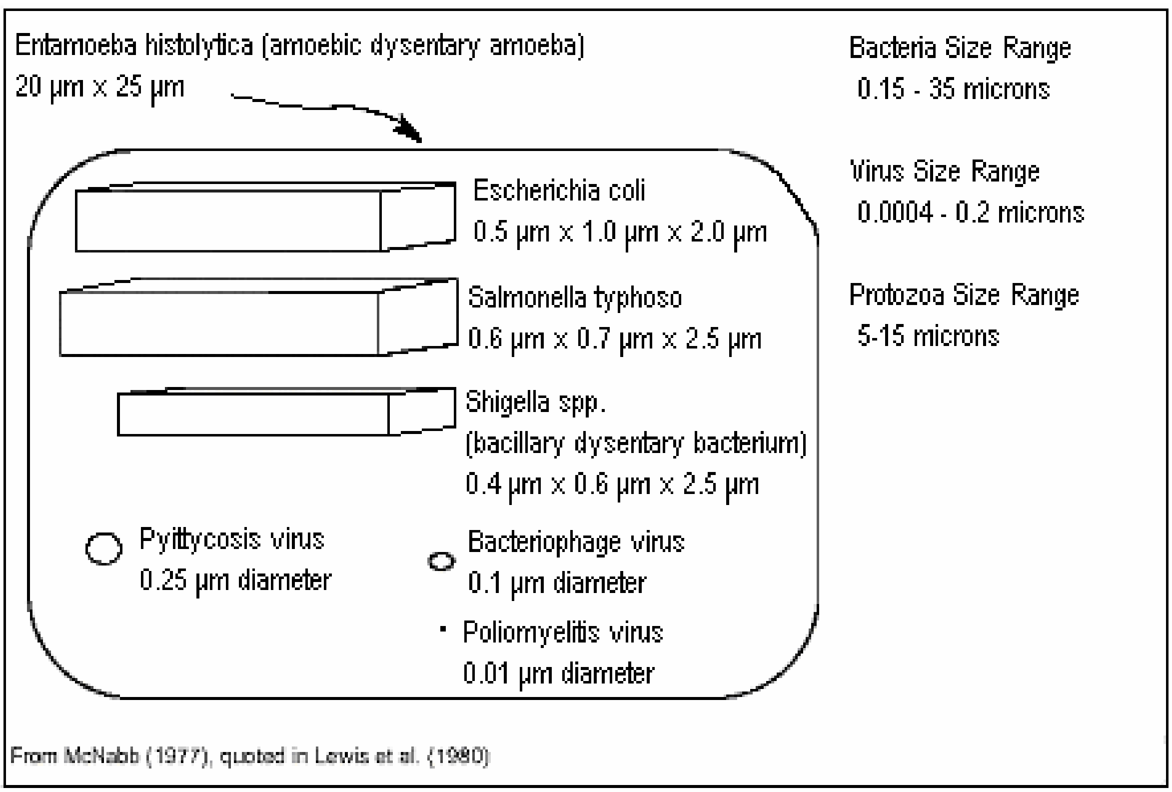
Filter	Pore Size	Flow-rate	Study Operating Pressure
Candle Filter	20-30 µm	0.3 L/hr	0.7 psi
CerCor Filter	0.2 µm	18 L/hr	20 psi

5.2 FILTER PORE SIZE

Water filters, such as the CerCor, remove organisms and particles larger than their pore size by physical straining. Pathogen sizes cover a large range from 0.0004 to 35 microns.

The Figure 5.2 provides a comparison of pathogen sizes. From Figure 5.2 it is evident that the 0.2 micron pore size of the CerCor filter should be sufficient to filter out all pathogens greater then 0.2 microns in size, which includes most bacteria and protozoa, but is not small enough to filter viruses. A pathogen of specific concern with respect to water-borne illness is giardia, which causes giardiasis. This pathogen is effectively filtered out with a filter pore size of 4.0 microns. Filtering is an important water treatment process because Giardia cysts, Cryptosporidium, and Cryptosporidium oocysts are resistant to chlorination and can only be effectively removed by filtration (Mortimer, 1998).

FIGURE 5.2: COMPARISON OF PATHOGEN SIZES

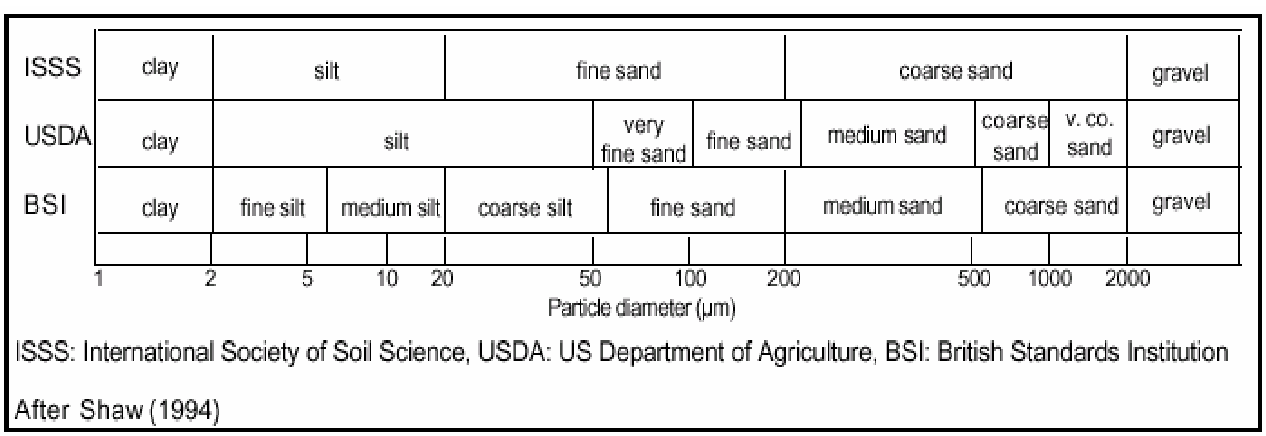


A microfiltration device, such as the CerCor filter, is an optimal choice for pathogen removal due to its small pore size, but this small pore size also has drawbacks. A microfilter is more prone to clogging than filters with larger pores, and subsequently water that is very turbid should be pre-filtered before it is microfiltered to avoid excessive, frequent cleaning and de-clogging.

For use in health clinics and schools in rural Nepal, without public water supply, sand and other soils would have to be removed from the pumped groundwater before it is sent though the CerCor filter. The rural health clinics and schools, with indoor plumbing, typically have a tubewell with an electric pump attached to it in their backyards. The water is then pumped to a tank on the roof, to provide pressure for flow throughout the building. Attaching the CerCor filter directly to the pump and tubewell would present problems because of the amounts of sand and sediment that are carried by the pumped water. Water would have to be decanted in the tank and then pumped through the CerCor filter to avoid damaging the ceramic coating on the filter and to avoid clogging.

During testing 0.7 diameter kaolin clay was used to simulate turbidity in the lab. This particle size is much smaller than the average particle size of most soils as presented in Figure 5.3 below. From this figure it is evident that the 0.2 µm CerCor filter will effectively filter out all soil particles (size range 1- 2000 µm) present in the water, which will be present in high amount during the monsoon season when the water turbidity peaks.

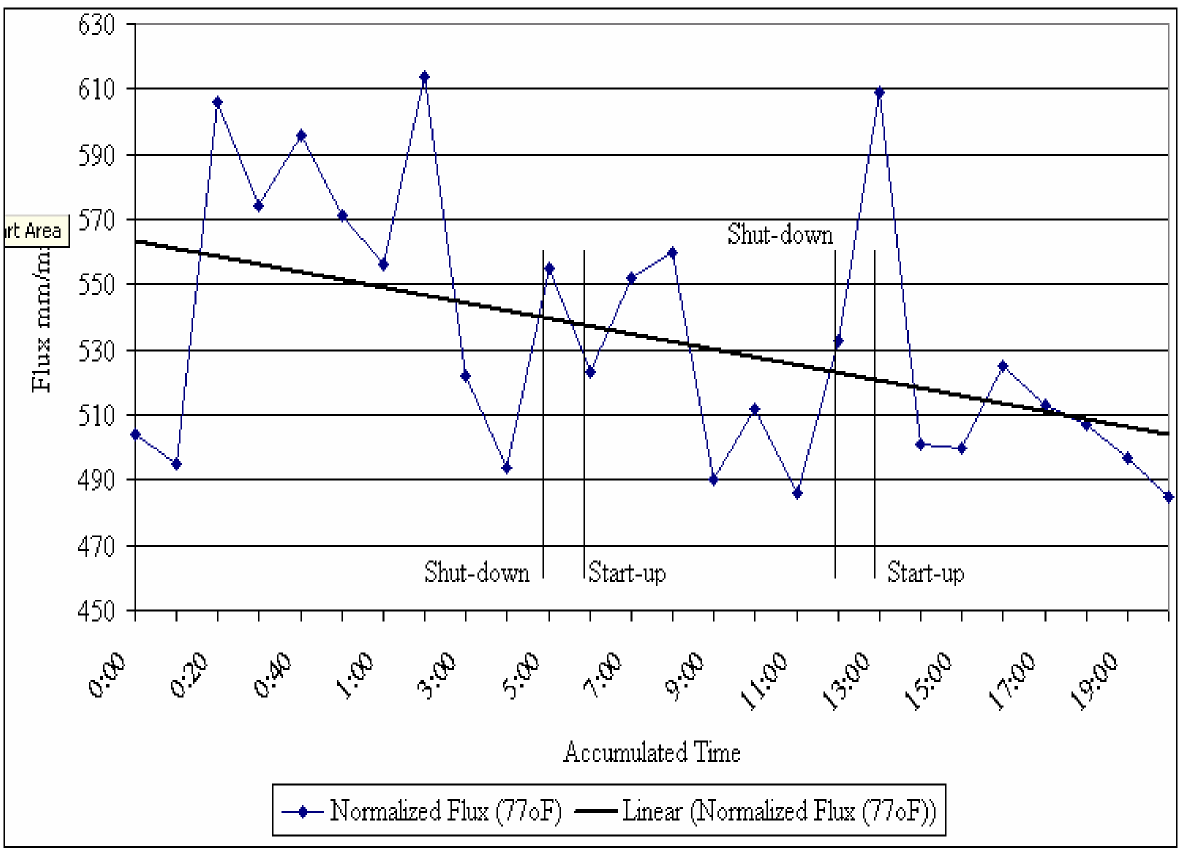
FIGURE 5.3: SIZE OF TYPICAL SOILS



5.3 SET-UP AND TESTING PLAN

The CerCor filter was tested at MIT with influent water from the Charles River in Cambridge, MA. The Charles River water tested positive for the three types of indicator organisms during the following tests: HACH PathoScreen™ H_2S, P/A Total coliform, and P/A *E. coli* Hach tests. The turbidity of the river water was in the range of 3-7 NTU. Corning Corporation had performed initial flux feasibility tests (Figure 5.4) for the filter, which showed satisfactory removal of turbidity and a flux performance of the lab scale filter at low pressures (13 psi). Two CerCor units were made available for use to the M.Eng program from Corning.

FIGURE 5.4: CORNING LOW PRESSURE FLUX DATA



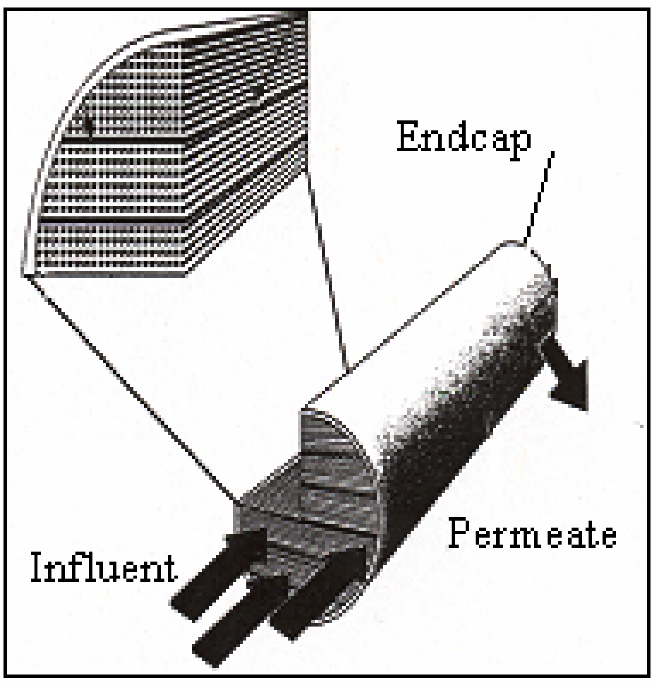
The lab-scale filter used in the study has the dimensions given in the Figure 5.5 below.

FIGURE 5.5: LAB SCALE-FILTER DIMENSIONS

Diameter	Length	Membrane Area/ Module
27 mm / 1.05"	305 mm/ 12"	0.13 m^2 / 1.4 ft^2

The filter is made from a ceramic monolith. A very thin ceramic coating, <100 μm, is applied to the monolith to create the 0.2 μm pore size. This technology results in a filter that can produce high flow-rates at low pressures. The filter was developed for use in food processing, solvent recovery, and in wastewater treatment plants.

FIGURE 5.6: CERCOR FILTER DIAGRAM



The filter was connected to a small pump (Sears Quality Water pump Utility Centrifugal Model S48HZEC11, 0.5 Hp, 9.4 Amp) at one end and the other end was capped off. Flow enters the filter through one end and since the other end has been capped, the flow is forced through the walls of the filter (i.e. dead-end microfiltration). The resulting permeate is collected and tested. The operating pressure was 20 psi, providing an average permeate flow of 18L/hr. Twenty-one trials using Charles River water determined the total coliform, *E. coli* and H_2S producing bacteria removal efficiency of the filter to be 100%. To determine failure time, tap water spiked with kaolin to artificially produce feed water with less than 40 NTU was run through the filter. After running for thirteen hours, (210L total) at greater than 40 NTU, the filter was successfully clogged.

5.3.1 Filter Cleaning and Maintenance

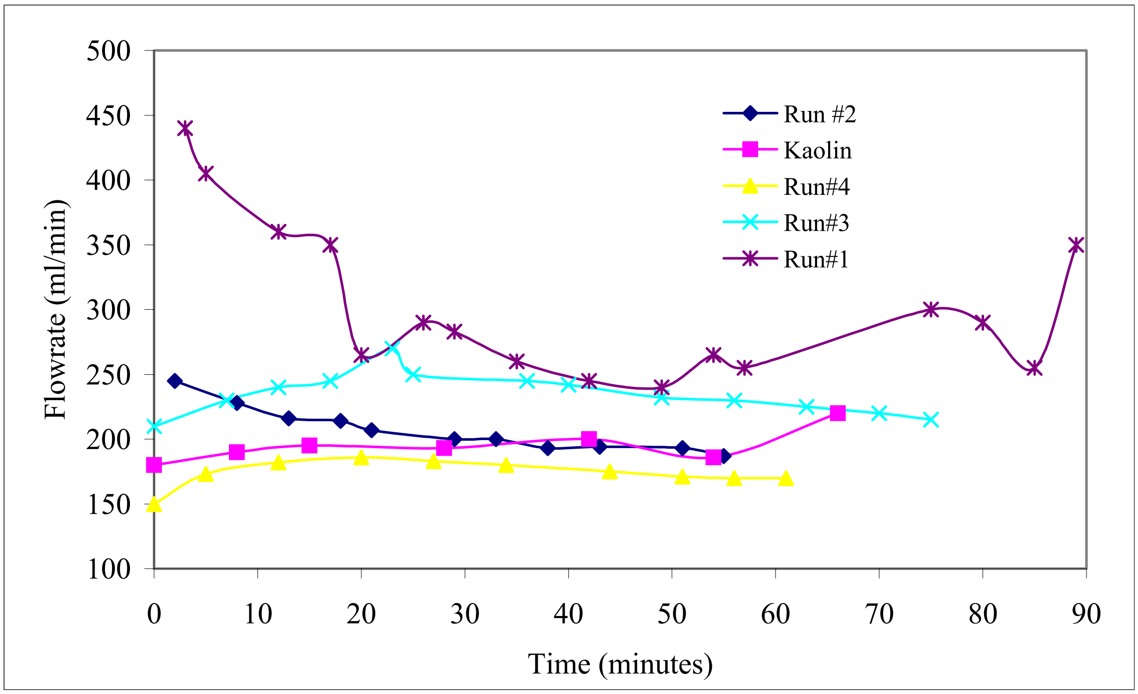
To lengthen filter life, intermittent back flushing was used to unclog the pores. First, the end cap was removed and the filter flow was reversed for thirty minutes, during such cross-flow operation there is no permeate flow. The flow was then reversed again for another thirty minutes. This back flushing operation should increase the life of the filter and extend the time between more comprehensive cleanings. The time between cleanings will also be influenced by the turbidity of the water. During the monsoon season when the water is very turbid, the filter would have to be cleaned frequently.

Developing a practical maintenance scheme that could be implemented in a developing country has proven to be a challenge. In industrial applications, the filter is cleaned with hot, >50°C, acidic or caustic solutions and industrial detergents (Ultrasil 25). It is not feasible that the filter would be cleaned with highly acidic or caustic solutions in Nepal. The filter should be cleaned at using the backflush configuration at low flow, using an ultrafiltered water and cleaner solution, a portion of the permeate should be saved and used for cleaning. Sodium hypochlorite at 200ppm should used to sanitize the filter, during each cleaning. (Corning, 1999)

5.4 RESULTS

The filter removed 100% of microbial contamination in the indicator tests. The tests were run at 20 psi, and resulted in an average flow rate of 18L/hr. The turbidity of the filtrate was near zero for all runs.

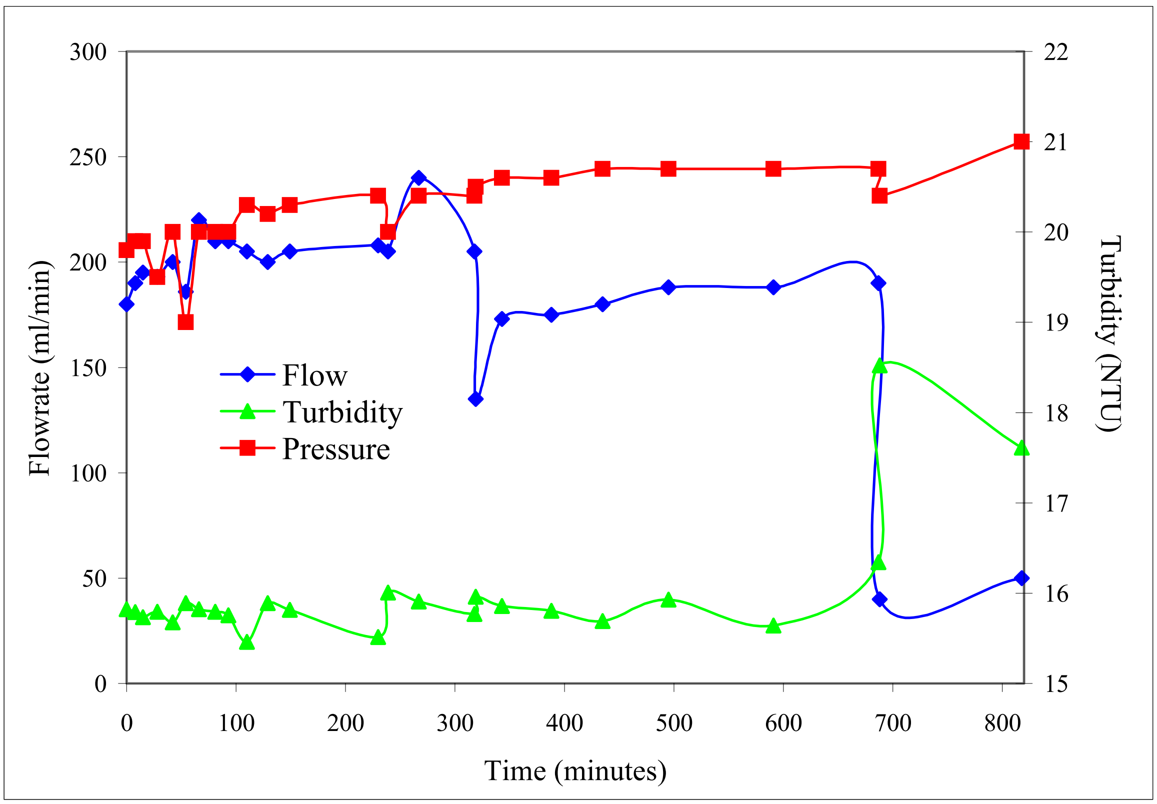
FIGURE 5.7: FLOW-RATES FOR VARIOUS CERCOR FILTER RUNS



The initial flow of the filter on the first run 440 ml/min was the highest flow achieved and as seen on the Figure 5.7 above, quickly dropped to 260 ml/min. A large number of pores must have been quickly blocked during the first run and back flushing or cleaning was unable to restore this high flow-rate. Back flushing between the second and third runs was able to achieve a higher flow-rate throughout the third run. There was no back flushing between the third and fourth runs and therefore the flow rates during the fourth run were subsequently lower than the flow rates in the third run.

During testing at MIT, the filter was run for thirteen hours with a 40 NTU flow. Kaolin was added to tap water to raise the turbidity to the 40 NTU level. The kaolin was 0.7 microns in diameter. During this run, the permeate flow and pressure remained steady as seen in Figure 5.8 .

FIGURE 5.8: FLOW-RATE, TURBIDITY, AND PRESSURE OVER TIME DURING THE 40 NTU KAOLIN RUN OF THE CERCOR FILTER



After 687 minutes (11.45 hours), the filter was turned off for the night. The next day when the unit was started up the flowrate was significantly decreased and the pressure increased. The 40 NTU water was not drained from the filter unit during shutdown, and during the night, the kaolin settled on the filter walls and blocked the flow when the unit was restarted.

5.5 BENEFITS AND DRAWBACKS

The filter was able to remove 100% of the indicator organisms in all tests and provided a high flowrate of 18L/hr thus achieving the criteria set for the filter as a result of the identified shortcomings of the ceramic candle filter.

Currently, the high cost of the filter (greater than 400 US$), and the maintenance required are the major drawbacks. It is a specialty product manufactured by the Corning Corporation for clarifying organic process streams, treating wastewaters containing solvents, reclaiming solvents, and recovering energy by recycling hot streams (Corning, 1999). This phase of testing that was meant to ensure the filter could remove the indicator organisms tested and could be adequately maintained.

Currently a suitable cleaning method for the filter in Nepal has not been identified. During industrial use the filter is often cleaned with hot acid or caustic solutions, but this will not be a feasible maintenance operation for Nepal. Further work with the filter needs to focus on more comprehensive microbial testing and on reducing the cost of manufacturing and designing a unit that can be easily installed and maintained. In Nepal the filter would best be utilized in a school, medical clinic, or at a pump once, the current issues are solved.

6 PRACTICAL HOUSEHOLD SOLAR DISINFECTION

6.1 SODIS THEORY

SODIS is the application of solar disinfection at the household level to treat small quantities of drinking water. The technique utilizes solar radiation to inactivate and kill pathogenic microorganisms, thereby disinfecting the water.

Microorganisms are sensitive to changes in both temperature and light. During SODIS, the infrared light of solar radiation increases water temperature. As mentioned earlier, water is commonly boiled or chlorinated in developing countries to remove pathogens if disinfection occurs at all, but pathogens can also be effectively killed when held at lower temperatures for longer times a technique known as heat pasteurization. For instance *Vibrio Cholera*, the microbe responsible for causing cholera, is effectively inactivated after one hour at 45° C (SODIS Tech. Notes, 1998). The UV-A light (wavelength: 315-400 nm) of solar radiation causes lethal changes in the nucleic acids of microorganisms. The major change induced are thymine dimmers which are unnatural bridges between proximal units of thymine in DNA, the bridge prevents enzymes that translate DNA from reading the genetic template correctly. Radiation with longer wavelengths does not effectively inactivate bacteria, and UV-B or shorter wavelength light is neither transmitted though the PET bottles well nor present in high amounts at ground level.

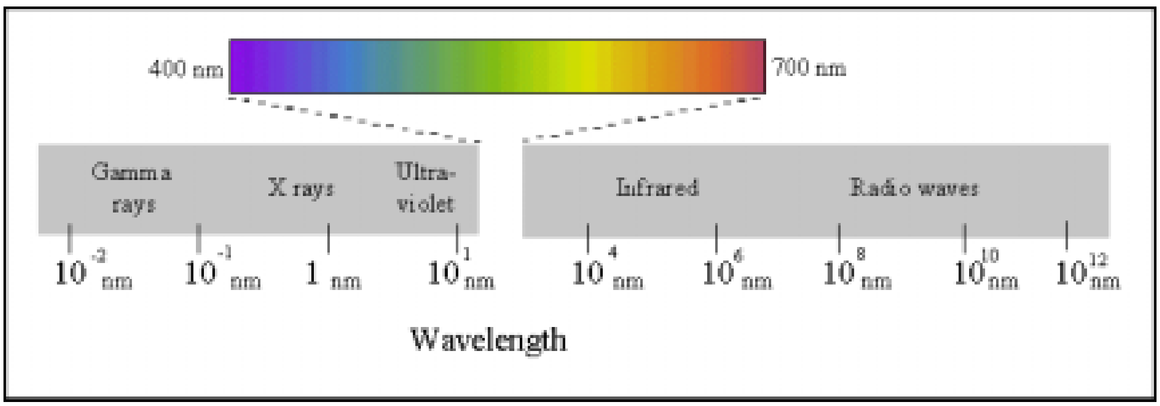
The synergistic effect of heat pasteurization and UV-A irradiation makes SODIS effective. For example, Martin Wegelin has found that without this synergistic effect it would take 5 hours of midday sun (555 W h/m^2) to inactivate *E. coli*. With the synergistic effect of raising temperature to 50°C *E. coli* is effectively inactivated in only one hour of midday sun (140 W h/ m^2) (Wegelin, 1994). The combination of both effects induces stress on the microorganisms, increases the effectives of disinfection, and makes

SODIS a viable water treatment option because disinfection occurs in ambient conditions and in short time. To determine whether or not SODIS is acceptable for any given region, it is important to look at the incident solar radiation.

6.2 SOLAR ENERGY

The sun bombards the earth and outer space with energy. The energy hitting the outer atmosphere of earth is considered to be 1.4 KW/m^2 and is known as the solar constant. The radiation from the sun is composed of gamma rays, X-rays, ultraviolet (UV), and infrared (IR) radiation. Solar radiation moves unchanged throughout the vacuum of space but is modified once it hits the earth's atmosphere. (Spiro, 1996)

FIGURE 6.1: THE ELECTROMAGNETIC SPECTRUM



The earth's upper atmosphere and clouds reflect much of the radiation hitting the earth. Albedo is the measure of reflectivity of the Earth's atmosphere and is estimated at 0.39 present. The radiation that is not reflected by the atmosphere is either scattered or is absorbed by the atmospheric gases. The scattering is of two types: selective and non-selective. Radiation with shorter wavelengths is selectively scattered by molecules with diameters smaller than the wavelengths of the radiation. Selective scattering reduces the available amount of radiation in the following order: far UV, near UV, violet, blue, green, yellow, orange, red, infrared. This is an important factor because air pollution, due to smoke, fumes, haze, and chemicals can increase selective scattering. Clear skies will have much less selective scattering than cloudy or polluted skies. Selective scattering is also at a minimum in the afternoon. This can be visualized since the sky is blue in the afternoon during sunrise and sunset the sky has a reddish hue. The blue light is selectively scattered because it must travel thought the atmosphere in a longer path length than when the sun is directly overhead at noon. (Spiro, 1996)

Non-selective scattering is the same for all wavelengths of radiation and takes place in the lower atmosphere. It is caused by particles with diameters greater than ten times the size of the wavelength. Dust, fog, smoke, and clouds can all cause non-selective scattering. Since all wavelengths of light are scattered by these particles fog, smoke and clouds are all white, unless a colored chemical or gas is present. (Spiro, 1996)

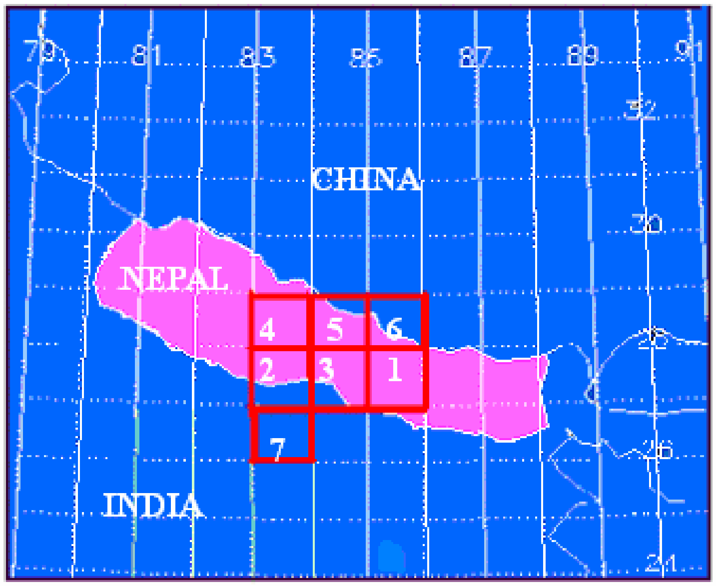
The atmosphere that reaches the surface of the earth is mostly above 300nm. The available radiation falls in the far UV-B (300-315nm), near UV-A (315-400nm), visible (400-700nm) and IR (700-14,000nm) range. The shorter wavelength radiation (200-300nm) is effectively absorbed by the ozone layer. This is important because radiation <300nm destroys living tissue. (Spiro, 1996) The amount of light reaching the surface will depend on season, cloud cover, latitude, and atmospheric pollutants. Most of the light at ground level is direct solar radiation at noon, but earlier and later in the day and with increasing cloud cover, the amount of indirect or diffuse radiation can increase to 20% of the total. Diffuse radiation is the radiation scattered by the atmosphere and/or reflected off the ground. Specifically, in Nepal, scattering of light by fog, clouds, and pollution will be an important issue to address. In the Terai region of Nepal, heavy morning fogs can last well past noon, and in Kathmandu, extensive pollution fills the valley from motor vehicles in the early morning and greatly effects air quality.

6.3 Applicability of SODIS in Nepal Looking at Available Solar Energy

To determine if there is sufficient solar radiation for SODIS in Nepal, it is necessary to look at the climate, insolation ($kW/m^2/day$), and geographic location. An important factor for determining if SODIS will be an effective treatment option for an area is the available solar energy. Latitude is a good indicator of the available solar energy for a given location. Between 15 ^oN and 35 ^oN latitude are the most favorable regions for SODIS. Nepal is located in this region between $26^o22'$ N and $30^o27'$ N latitude and $80^o4'$ and $80^o12'$ E longitude on the southern slopes of the Himalayas. Even though the whole country of Nepal lies in this region, the altitudes and heterogeneous terrain may make certain areas unfavorable for SODIS.

Data on the amount of electromagnetic energy (solar radiation) incident at the surface of the earth, insolation ($kW/m^2/day$), was obtained from NASA Langley Atmospheric Data Center for various regions in Nepal (NASA, 2001). The data was a ten-year average and was available for one-degree longitude by one-degree latitude areas. Seven areas were chosen that represented the various geographies of Nepal, the Terai, the hills, and the mountains. The areas are highlighted in Figure 6.2 below. The threshold insolation level for effective SODIS is 500 W/m^2; locations with incidence of solar radiation above this threshold should be viable locations for SODIS implementation

FIGURE 6.2:REGIONS OF NEPAL WHERE AVAILABLE SOLAR ENERGY WAS CALCULATED



Area 1 = Kathmandu Valley
Area 2 = Terai and Hills
Area 3 = Terai and Hills
Area 4 =Hills and Himalayas
Area 5 =Himalayas
Area 6 =Himalayas
Area 7 =Indian Terai

Insolation (kW/m^2/day)
Amount of electromagnetic energy (solar radiation) incident on the surface of the earth

The data from NASA was a ten-year average for an average day each month of the year. The data was available for an average year, a minimum year, and a maximum year. In the figures below the maximum, minimum, and average insolation amounts are shown for an average year in each area.

FIGURE 6.3: MINIMUM INSOLATION PER CALENDAR MONTH TEN-YEAR AVERAGE

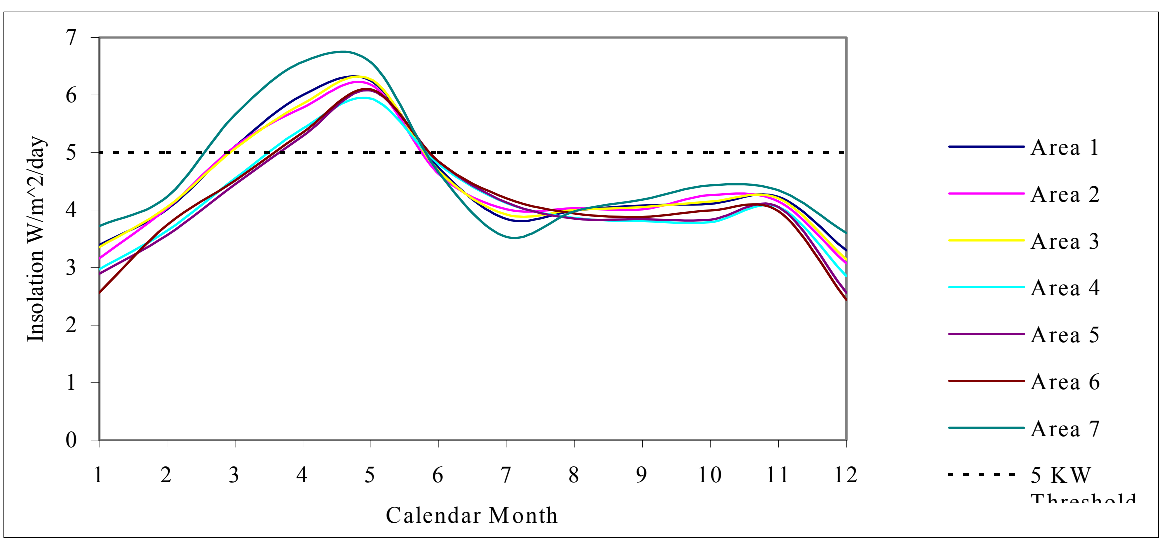


FIGURE 6.4: MAXIMUM INSOLATION PER CALENDAR MONTH TEN-YEAR AVERAGE

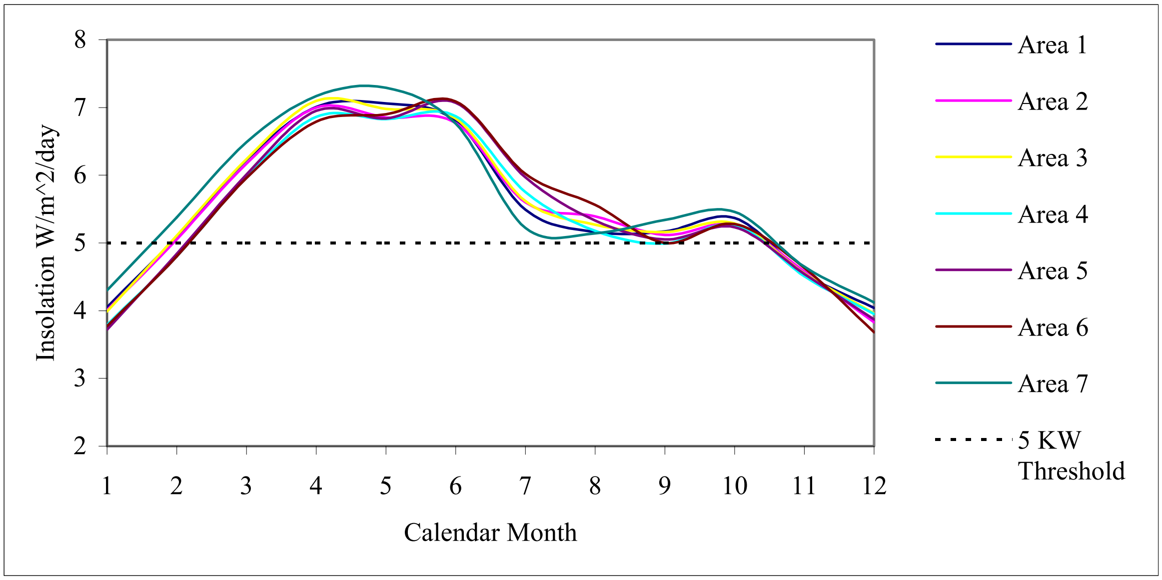
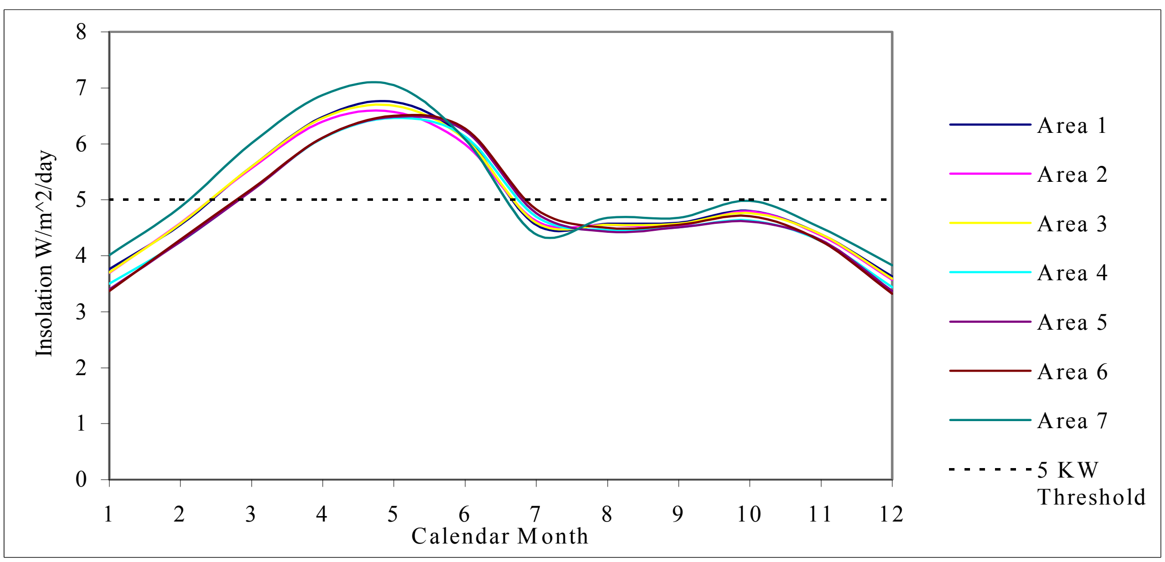
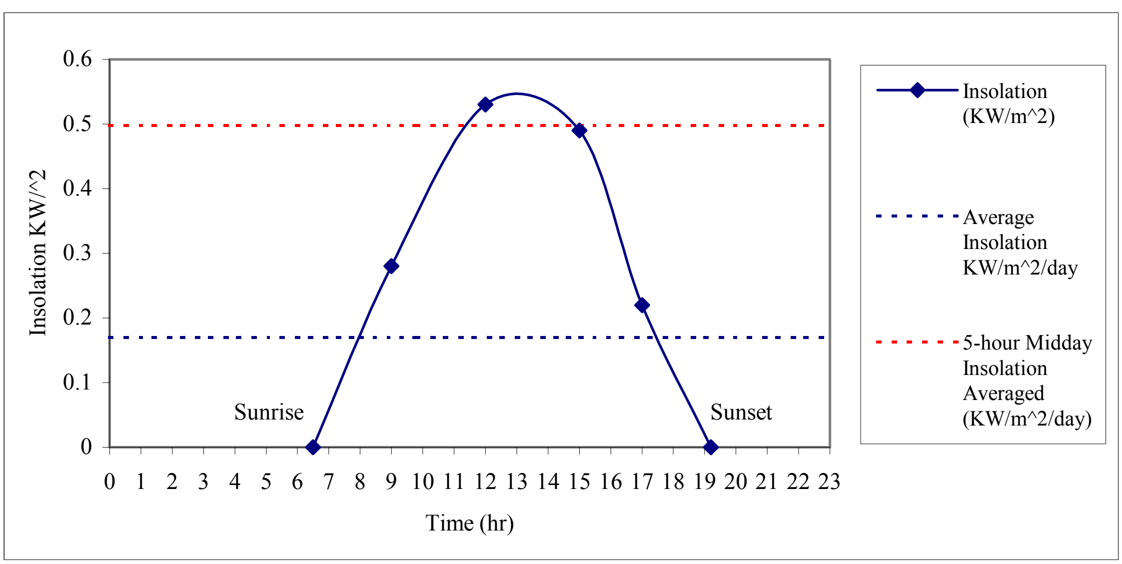


FIGURE 6.5: AVERAGE INSOLATION PER CALENDAR MONTH TEN-YEAR AVERAGE



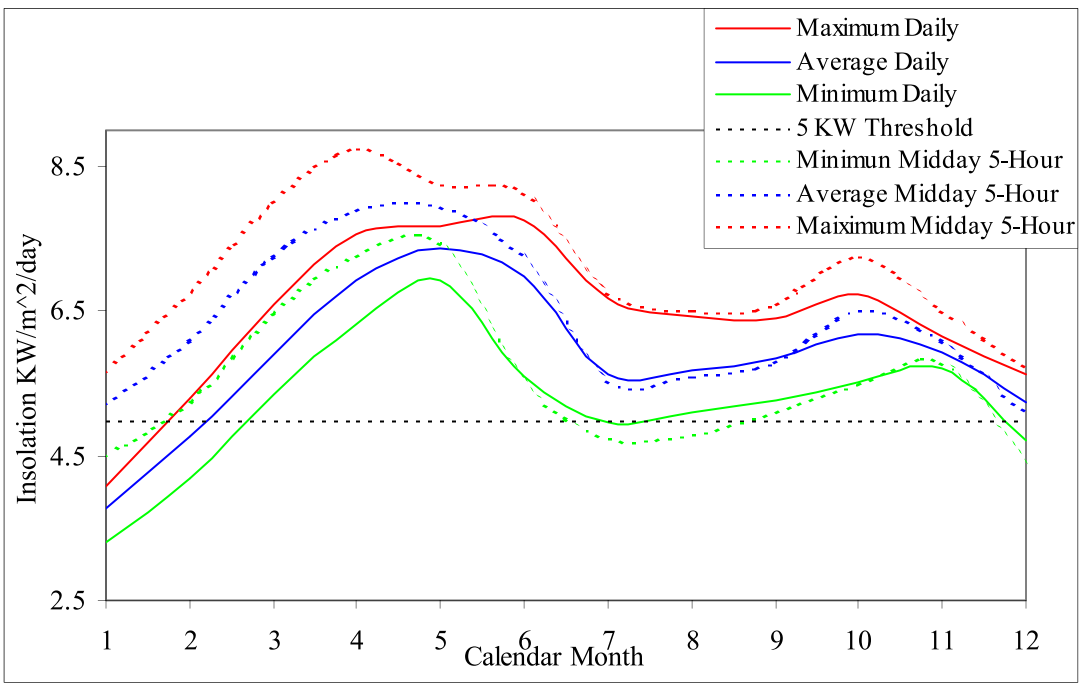
The figures illustrate that the insolation is similar in areas selected for the study. Area seven, the Indian Terai, a region just south of Lumbini, has the highest insolation at all times of the year except during the monsoon season. Looking at all areas during June and July on the all the figures, the effect of the monsoon season is evident. The increased cloud cover during this season reduces the amount of radiation that can reach the surface due to non-selective scattering. The insolation is much lower in these months than in the preceding or following months. During the monsoon season and in the winter months of January and December SODIS will be most likely to be ineffective. The above figures do not present a good picture for the applicability of SODIS in Nepal because few of the months are above the threshold level for SODIS of 500 W/m^2 (SODIS Tech. Notes, 1998). Since, the insolation is averaged over the course of the day the insolation on these figures is much lower than the highest amount that would be reached each day. Over the course of a day, the insolation is at a minimum at sunrise and sunset and reaches a peak in the mid-afternoon (see Figure 6.6). Peter Oates (Oates, 2001) developed a program to calculate the average insolation available at the five peak hours. As a general rule, the peak insolation at noon is three times the averaged insolation for the day (Geschend, 2001). Both the average insolation for the day and the averaged five-hour insolation for the day are indicated in the figure 6.6. The maximum insolation is 0.53 KW/m^2 at noon and the average insolation for the day is 0.17 Kw/m^2, which corresponds to the general rule that the insolation at noon is three times the average insolation for the day. For the average day chosen, below the five-hour average is just at the threshold for SODIS.

FIGURE6.6: AVAILABLE INSOLATION DURING AN AVERAGE DAY IN LUMBINI



Using the NASA data for the maximum, average, and minimum available insolation for an average day each month for Nepal, the curves for the average insolation for these five midday hours were calculated using the Oates method. The curves were averaged over the seven regions selected because the variability between the regions was minimal. The resulting curves are shown in Figure 6.7.

FIGURE 6.7: MAXIMUM, MINIMUM, AND AVERAGE INSOLATION CALCULATED FOR THE FIVE-MIDDAY HOURS IN COMPARISON TO THE MAXIMUM, MINIMUM, AND AVERAGE FOR THE FULL DAY.



Looking at the 5-midday hours, when the incidence of solar radiation hitting the Earth is highest, Nepal is above the SODIS threshold a majority of the time. For the five-midday hours data the calculated curves fall below the threshold only during the minimum expected insolation in January. This is a large contrast to the data for the whole day in which all three curves, the minimum, the maximum, and the average, fall below the threshold level for the months of January, and February.

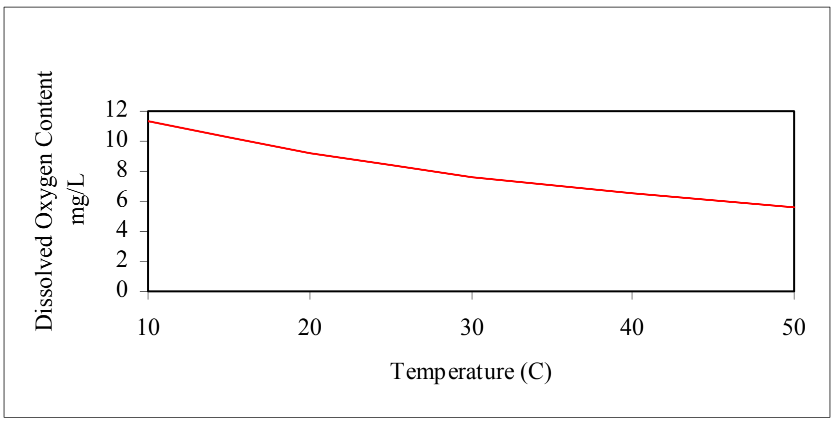
Other factors such as cloud cover, rainfall, and ambient temperature also affect the effectiveness of SODIS. The temperature range in Nepal depends on location and varies for each of the three major regions: the mountains, the hills, and the Terai. Spring and summer temperatures are +40^{o}C in the Terai and 28^{o}C in the Hills. During the winter the range of temperatures in the Terai range from 7^{o}C to 23^{o}C while in the hills, the range is from below freezing to 12^{o}C (Thamel.com). At the higher mountain elevations temperatures are much colder. From rainfall data of the neighboring Indian states Uttar Pradesh and Bihar the annual rainfall in the Lumbini area is estimated at 160-200 cm per year with an estimated three-fourths of this total occurring during the June-September monsoon season (http://www.mapsof india.com). The amount of rainfall effects the available radiation at the Earth's surface because rain clouds will block and scatter radiation and keep it from reaching the Earth's surface. Greater rainfall occurs on the southern slopes of the Himalayas in Central Nepal due to orographic lifting and much (<250mm) less occurs northeast of the mountains near the Tibetan plateau. (Thamel.com)

The Kathmandu Valley of central Nepal is a bowl-shaped valley surrounded by the lesser Himalayas (2,122m in average height) (Shrestha, 2001). Like the rest of Nepal, nearly three quarters of the annual rainfall (1245 – 2984 mm/yr) falls during the monsoon season in June through September when the average temperature is 23C. The cooler months of the dry season (December to February) is 11°C.

6.4 PHOTO-OXIDATIVE DISINFECTION

Aside from the UV-A light directly absorbed by the organisms, oxygen compounds also absorb the radiation. This process creates highly reactive oxygen free radicals and hydrogen peroxides. The reactive oxygen compounds oxidize the microorganism causing an effect known as photo-oxidative disinfection. This process creates highly reactive oxygen free radicals and hydrogen peroxides that inactivate the pathogens initially present in the water. The oxygen compounds are short-lived intermediates that do not provide a residual disinfectant. Photo-oxidation can be increased by ensuring water is fully saturated with oxygen before it is set out in the sun for treatment. Shaking the bottle vigorously directly after collection will increase the dissolved oxygen content of the water. It is important not to shake the bottle during SODIS because as temperature raises the amount of oxygen that can be dissolved in the water deceases, this is described by the temperature dependence of the Henry's Law constant. In the figure below the dissolved oxygen level in the water is greatest at lower temperatures. (Atkins)

FIGURE 6.8: DISSOLVED OXYGEN CONTENT AT VARIOUS TEMPERATURES

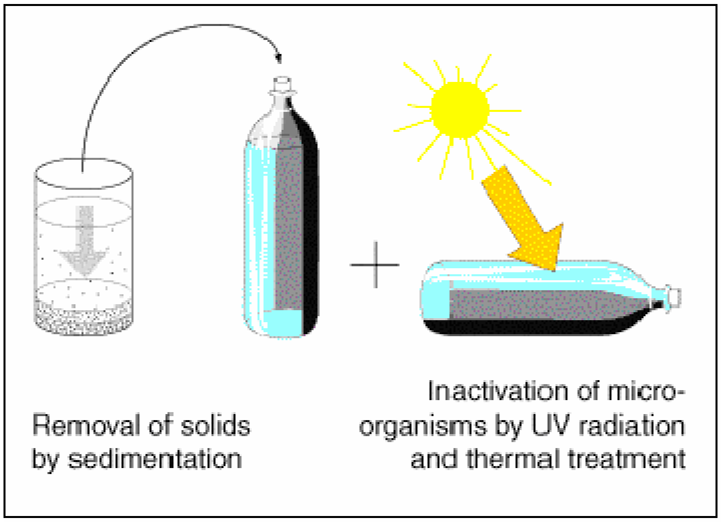


6.5 SODIS SET-UP

SODIS is carried out in glass or plastic bottles. The typical clear plastic soft drink or bottled-water bottle from any store is appropriate, but clear materials with high light transmittance are the best choice for SODIS treatment containers. PET (polyethylene terephtalate) drinking water bottles are a good choice and are readily available in Nepal. It is important that the bottle is in good condition since excessive scratching reduces that amount of light that can reach the water reducing disinfection effectiveness. It is also important that the water have a turbidity level below 30 NTU because the suspended particles scatter light, reducing the amount of light penetrating into the bottle.

Additionally, the bottom half of the bottles can be painted black to increase light absorbance and hence increase the water temperature.

FIGURE 6.9 SODIS SET-UP



Water is collected in the morning and put into the SODIS bottles. To increase the dissolved oxygen content the bottle can be capped and vigorously shaken when half full and then it can be completely filled. The bottles should be set out in an area that receives full, sun such as on a roof. It is important that the bottles remain in full sunlight throughout the treatment and do not become covered by shade. Depending on weather conditions and geographic location the bottles should remain in the sunlight for anywhere from four hours on a sunny day to two full days when the sky is overcast (SODIS Technical notes, 1998).

If the turbidity of the bottles is >30NTU, the water should either be decanted or filtered. A simple filtration method that can be applied easily to the water is cloth filtration. A 2-log reduction has in the number of *Vibrio cholerae* has been achieved using sari material as a cloth filter. The material is readily available throughout Nepal and the surrounding countries. *Vibrio cholerae* tends to stick to phytoplankton in the water

6.6 RESULTS

SODIS data collected by the author, MIT M. Eng. Student Meghan Smith, in Lumbini, during January 2001 and data collected by Harvard School of Public Health doctoral student, Cathy Pham, in Kathmandu, during the monsoon season June and July 2000, indicate that SODIS should be a viable treatment option. In Lumbini, in January 2001, fourteen tests were performed. The technical effectiveness of SODIS was evaluated on the following basis: tests of source water must be positive for both H_2S producing bacteria and total coliform bacteria, and the resulting treated water must test negative for both types of bacteria. The author's works showed one day of SODIS was 92% effective, while two days of SODIS was 100% effective, and the Pham data from Kathmandu showed a similar trend; one day of SODIS was not sufficient to provide clean water the effectiveness of one day of SODIS was only 54% (Pham, 2000). Two days, however, again provided 100% effectiveness.

FIGURE 6.10: SODIS IN LUMBINI USING THE SOLAR MIRROR AND BLACK SHEET METAL

This finding that two days of SODIS should be required on all days somewhat contradicts the recommendations that are provided by the Swiss Federal Institute for Environment and Technology (EAWAG) (the organization most actively researching and promoting of the SODIS, under the direction of Peter Wegelin). Wegelin recommends the following exposure time: five hours under bright sun or up to 50% cloudy sky, or two consecutive days under 100% cloudy sky. Having people ascertain when the sky is more than 50% cloudy is a complication to implementing SODIS that carries with it an uncertainty. It seems more appropriate to instruct villagers to expose SODIS bottles to two days of sunlight before use. This would eliminate the error in villagers guessing the solar exposure time required for each bottle as a result that day's weather. It is also the technically correct recommendation based on the two sets of data provided in this thesis for two regions and seasons of Nepal. Moreover, our recommendation of two days of SODIS is also confirmed by the recent work in Haiti by Oates (Oates, 2001).

The data collected by Cathy Pham provided insight on the influence of bottle size and volume on the effectiveness of SODIS. Her tests were carried out using bottles of several of the major drinking water companies in Nepal: Bisleri, Thirst-Pi, and YES. The data collected in Lumbini, investigated the use of a solar mirror and black painted metal as surfaces to lay the bottles on in the sun (Figure 6.3). The solar mirror increased the amount of light passing through the bottle by reflection, by increasing the amount of light though the bottle SODIS should be more effective on days with lower solar energy. The black metal will help the water reach a higher temperature. For all tests, the bottles on the black tarp reached a water temperature that was five degrees higher on the black metal surface than the water temperature of the bottles on the solar mirror. All Lumbini tests were carried out in one-liter Bailley water bottles.

The data collected during these two times of the year in Nepal, the dry and the monsoon seasons, are very important because they represent the technical limits of SODIS in the regions of Nepal tested. These two times of the years are when SODIS is least likely to work, due to rainy weather conditions blocking solar radiation and because of lower temperatures. The monsoon season in Nepal is an important time of the year to collect data. The increase in cloud cover due to the frequent rain showers has the potential to limit SODIS during this time of the year, a time when the water supply has increased turbidity, and when many other treatment options are overwhelmed. Since SODIS was found to work in both challenging times of the year, it is suggested from a technical, performance point of view that it can be implemented and prove to be effective year round.

6.7 Benefits and Drawbacks In Nepal

SODIS offers a practical, effective water treatment method that can be easily implemented. By providing people with clean water SODIS implementation can reduce the incidence of waterborne disease with little capital investment beyond initial training and monitoring expenses. Since SODIS does not rely on the addition of chemical its does not alter the taste of water and is a sustainable option for people in developing countries. In addition, SODIS enables people to use surface water sources that had been previously been abandoned in favor of tubewells due to microbial contamination.

Despite the many benefits of SODIS, there are still some factors limiting its widespread use. SODIS is useful only for treating small volumes of water on a household scale. A typical Nepalese family in Nepal has from five to eight family members drinking 4-10 L water/day the average family would then need to irradiate anywhere from twenty to eight liters of water. Using 1.5 L bottles, the required number of bottles is from thirteen to fifty-three bottles per day for a family. SODIS is also dependent on solar radiation and inclement weather can decrease effectiveness. There are plenty of opportunities for error in the process and people must be thoroughly trained in the use of SODIS at its introduction. Moreover, because there has been some evidence of bacteria re-growth, further testing is still required to determine the nature of this re-growth and to recommend limits on storage time.

6.8 SODIS Acceptability/Appropriateness

In Lumbini, people the author talked to seemed to be very receptive to using SODIS. During a meeting with the Professional Nepalese Women's Association in Kathmandu, women pleaded with the researchers to find something simple, and easy to help people get clean water. The President of the organization, Mrs. Ambica Shrestra, pleaded with the researchers to collect enough data on SODIS so that it can be recommended to use as a water treatment option. The women stressed the importance of a technology that is simple, easy to implement, and will not require additional work for the women.

Sending mixed messages to the villagers is an issue that also needs some consideration. With the installation of the tubewells, villagers were informed not to use other sources of water fro drinking and to only use the tubewell water. Now the message is going out to villagers that the tubewell water cannot be considered safe for drinking and it must be treated before consumption.

There are some cultural notions that need to be addressed when implementing SODIS in Nepal. The first is *juto*, or the idea that bottles used by someone else are sullied. Secondly is the notion of *basi,* or stale water. These cultural factors need to be addressed during the initial introduction of SODIS to people in Nepal. There is also a distinction between *sopha pani* or clean water and *sudha pani* or purified water.

6.9 SODIS Implementation

SODIS implementation in the Lumbini District will require an organization such as Crossflow Nepal to supervise the implementation including training and bottle distribution.

FIGURE 6.11: PLASTIC BOTTLES COLLECTED FOR SODIS IN LUMBINI

Peter Wegelin, the Watsan Partnership Project (WPP), and the Swiss Agency for Development conducted a study of SODIS implementation in sixteen villages in Bangladesh in 1999-2000. Wegelin and the groups found that the seriousness and practice by which people use SODIS play an important role in the efficacy of SODIS. Such practices include placing the bottles in direct sunlight as opposed to shade, thoroughly cleaning the bottles, and the amount of training provided to the user. Through in-depth interviews with SODIS users they identified problems with the SODIS bottles that are summarized in Figure 6.12.

FIGURE 6.12: FREQUENCY OF EXPRESSED PROBLEMS WITH BOTTLES OR REASONS FOR EXCHANGING BOTTLES.

Problem or Reason for Bottle Exchange	Frequency (mentioned as problem)	Frequency (reason for exchange
Cap Loss	77.8% (34/45)	--
Smell	4.4% (2/45)	--
Color Loss	77.8% (35/45)	--
Deformation (cracking due to heat)	20% (9/45)	52.4% (11/21)
Dirty	11.1% (5/45)	33.3% (7/21)
Cracking due to roof fall	8.9% (4/45)	23.8% (5/21)
Transparency Loss	2.2% (1/45)	23.8% (5/21)
No Problem	11.1% (5/45)	--

Data from Wegelin M., et al, *SODIS –an Arsenic Mitigation Option?* , 2000 (http://phys4.harvard.edu/~wilson/Mitigation/SODIS_Paper.html) April 10, 2001 Source of Data was from in-depth interviews with Bangladesh SODIS users

In Bangladesh it was reported that SODIS usage was 2.3 bottles per person per day or for the typical family of five 12 bottles were used per day. Bottles were found to last from four to six months will regular SODIS usage and eventually would have to be discarded due to cracking, deformation, cap-loss, or scratching. Like Nepal, in regions where there are urban centers, tourist attractions, or as in the case of the Lumbini District monasteries where people consume bottled water the bottles are in great supply. Away from these attractions people may have a harder time finding enough bottles for SODIS.

Disposal of the old and broken bottles is an environmental concern of implementation, even though SODIS would spur an initial demand for these bottles that would divert them from the refuse piles where they would otherwise have ended up. Currently the refuse from the villages is nearly all biomass refuse that can be composted or consumed by scavenging animals, such as dogs, rats, and vultures. The addition of a large number of plastic bottles could cause a trash problem, but in reality the discarded bottles would probably be burned by the villagers to provide heat in the cold winter mornings and nights. It was commonly observed in January 2001 for such fires to use sawdust and old tires as fuel due to a lack of firewood.

Other issues with SODIS include the practicality of procuring the solar mirror, the black painted metal surface, and the black paint itself to paint the bottles. The solar mirror and black painted metal are useful in increasing the effectiveness of SODIS by increasing the amount of light in the bottles and increasing the water temperature. Unless the mirrors were donated to the villagers they would probably not be able to obtain them, and the black painted sheet metal might also be hard for people to obtain because no metal materials were observed in the villages outside of metal gagris (water carrying pots).

A factor that has so far impeded the implementation of SODIS is the fear of bacteriological re-growth. Wegelin has found that re-growth of pathogenic organisms should not be a great concern with SODIS. The pathogens are of enteric origin and are unable to survive the harsh conditions outside of the host's body.

7 RECOMMENDATIONS AND CONCLUSIONS

7.1 CONCLUSIONS AND RECOMMENDATIONS

The well survey of seven villages in the Lumbini District found 75% of the wells tested were contaminated with total coliform bacteria, and 66% of the wells tested were contaminated with H_2S producing bacteria. Contamination was found in all types of wells: deep wells (more than 150 feet), shallow wells (less than 150 feet), public wells, and private wells except for the artesian well. The high incidences of water borne disease in the area are due to well contamination, inadequate water supply, and a general lack of sanitation and hygiene. The well survey data indicates that a large proportion of the district wells are unsafe for use as drinking water sources, but they cannot all be avoided or abandoned for use as drinking water sources. To avoid abandoning these water sources methods to rehabilitate the wells such as shock chlorination should be investigated. Wells that cannot be decontaminated should be clearly marked, (i..e. painted red) so that it is obvious to people that the water from these wells should not be used for drinking.

From the microbial tests of the well survey a correlation between the indicator organism tests was performed. The best correlations were found between total coliform and *E. coli* (.83) and between H_2S producing bacteria and E. coli (.79). The organisms present in the wells that tested positive only for total coliform and not *E. coli* should be identified to determine if they are of fecal or environmental origins. Overall, the hydrogen sulfide producing bacteria test seemed like a good tests to use for a quick determination of what wells were contaminated. The IRDC H_2S producing bacteria was not as sensitive as the HACH H_2S producing bacteria test and increasing the testing volume of water should be able to increase the sensitivity of the test.

The treatment technologies, the CerCor filter and SODIS, that were investigated in this study where intended to fulfill the requirements of being technically effective, sustainable, and appropriate. By assessing the technologies by each of these criteria, it can be determined whether or not implementation of the specific technology as a water treatment process in Nepal will be viable.

The Corning CerCor filtration unit, able to remove 100% of microbial contamination was found to be a technically effective technology. The technology, however, failed to prove to be an appropriate technology because a cleaning and maintenance scheme that could be implemented in Nepal was not found. Further work on the CerCor filter as previously discussed is recommended to develop a filter that would be appropriate for use in Nepal. To be appropriate such a filter should remove 100% of microbial contamination, should be easily maintained, and should be within a price range that schools, hospitals, and health clinics can afford. The CerCor filter would likely be an acceptable technology in Nepal because the people in Nepal are familiar with and understand the technology of filtration, and they associate filtration as a technology that can provide clean water. For these reasons implementation of such a filter technology in Nepal should be very easy since filtration is an already accepted technology for water treatment.

Practical household solar disinfection (SODIS) fulfilled the requirements for technical effectiveness because it proved to be 100% effective in removing all microbial contamination with two days of treatment, both in Lumbini and in Kathmandu. This was confirmed by the fieldwork of the two researchers. SODIS is an appropriate water treatment technology for Nepal because it is simple, low cost, and effective. From interviews with Nepalese, the author found that the people of Nepal are willing to accept such a technology, and studies in neighboring Bangladesh by Wegelin, showed that the technology is acceptable to the Bangladeshi villagers. Practical household disinfection from the results of this study looks like it will be an effective, appropriate, and acceptable drinking water treatment for the Terai Region of Nepal.

The water, health, and sanitation training that the Nepal Crossflow motivators provide in the villages should be continued and expanded. Since the motivators are Nepalese women from the area, it is more likely that they can understand what people can achieve and what they will be willing to accept in terms of water and sanitation. The motivators also have a much clearer picture of the "actual" water, sanitation, and health practices of the villagers. When outsiders, such as researchers for the MIT Nepal Water Project, interview or observe villagers, there is always a sense that the villagers want to tell the researchers what they think the researchers want to hear. The villagers desperately want the help of international people who come and visit the area, and want the support and/or anything that could be gained from the interaction - an additional bucket, a piece of cloth, or future aid. During an interview, the author asked the Crossflow women motivators what the villagers in the district think of the researchers coming in to their villages and taking water samples. They replied " the villagers see themselves as meek cats and the researchers as elephants." In short, it is essential to work with the Nepalese and to find the best solution for them one that is sustainable and appropriate for Nepal.

A solution to the water crisis in Nepal will not come from the selection of a single technology, but rather it will come through the implementation of various water treatment technologies, the implementation of sanitation, and through the education of people on water, health, hygiene, and sanitation issues and practices. A technology that is identified as acceptable and appropriate in one region of Nepal could very well be not be appropriate and acceptable in another region, so it is essential to identify both the technical effectiveness of a technology and its acceptability and appropriateness in a given region.

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APPENDIX I

Instructions for Hydrogen Sulfide Media Preparation and Use

The following chemicals are dissolved into 100 ml of distilled water or boiled tapwater:

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

It is best to prepare pre-weighed bags of each chemical to use for preparation in the field.

1) Add the bacteriological peptone to 100 ml of distilled or boiled tap water, while stirring. When dissolved, add the remaining chemicals, while stirring until dissolved.
2) Put 10 ml of water into a 11 ml vial and then using a permanent marker, mark the water level. Empty the vial and use the mark on the vial to mark the remaining vials.
3) Place a sufficient amount of absorbent paper (toilet paper, tissues, or paper towel) to absorb 0.5 ml of media into each vial. This will generally be a piece of paper about 2 x3 cm. Then add 0.5 ml solution to each vial.
4) Loosely cap the vials and autoclave for 15 minutes. This can be done in a pressure cooker. Do not cover the vials with water.
5) After autoclaving, tightly cap the vials and store in a dark place.
6) Test the media by testing known contaminated water (a very small amount of fecal material in water can be used). This test should be positive. If this test is negative, repeat with another vial of media; if no tests are positive, the batch of media can be considered defective and should not be used.
7) In addition, test distilled or boiled water this test should be negative. If this test is positive, repeat with another vial of media. If no tests of clean water are negative then the media should be considered defective and not used.
8) To test water:
    a. Wash hands carefully before using the test.
    b. Uncap the vial without touching the inside of the cap or the vial opening.
    c. Fill the vial to the black 10 ml mark with sample water. If the sample water is collected in another container, make certain that container is clean and sterile. Keep the sample water cool and put the sample water in the vial as soon as possible after collecting it – no more than four hours after collection.
    d. Tightly cap the vial.
    e. Keep the vial at 35 C (approximately body temperature).
    f. If the bacteria are present, the vial will turn black within 24 hours. However, if the vial has not turned black in 24 hours, continue the test for another 24 hours and check again to see if it has turned black.
9) Before reusing vials, empty the contents into a bucket of bleach solution and clean them thoroughly. Rinse well to remove all traces of bleach.

APPENDIX II

VILLAGE NAME	WELL NAME Meghan	WELL NAME Tim	WELL LOCATION LAT	LONG	TYPE OF WELL	DEPTH feet	HACH	IRDC	Total Coliform	E.coli	COMMENTS
Bhagawanpur	BAGA113001	BAGAO1	N 27 26.476'	E 83 15.190'	Handdug	40	P	P			Depth to water 10 feet, no cover
Bhagawanpur	BAGA113002	BAGAT1	N 27 26.471'	E 83 15.269'	Tubewell	180	P	P	P	P	4th layer Alt. 315 feet, cement cover
Bhagawanpur		BAGAO2	N 27 26.425'	E 83 15.302'	Handdug	100	P	P			Handdug water level is 20 feet, no cover
Bhagawanpur	BAGA113003	BAGAT2	N 27 26.422'	E 83 15.292'	Tubewell	140-145	N	N			Pump and cement cover, put in in 1998 2nd phase village
Bhagawanpur	BAGA113004	BAGAT3	N 27 26.433'	E 83 15.283'	Tubewell	80	N	N			Private well, BCC chairman Mirgembra Shribava, cement cover, there is a handpump but the water is pumped from a pipe with a pump
Sonbarsha	SOEN114001	SOENT1	N 27 30.766'	E 83 18.542'	Tubewell	160	P	N	P	P	Cement cover and good drainage
Sonbarsha	SOEN114002	SOENT2	N 27 30.783'	E 83 18.569'	Tubewell		N	N	P	P	Near big old open well, near white temple, hanpump, cement cover and good drainage
Sonbarsha	SOEN115003	SOENT3	N 27 30.798'	E 83 18.584'	Tubewell		N	N	N	N	Handpump, near old brick open well, has cement cover and proper drainage
Sonbarsha	SOEN115004	SOENT4	N 27 30.721'	E 83 18.553'	Tubewell	195	N	P	P	P	Having some problems with water now, after the summer rains the well is like an artesian, cement cover with drainage near open brick dug well, near small elephant staues
Bhagatpurwa	BHAG115001	BHAGT1	N 27 30.694'	E 83 17.025'	Tubewell		P	N	P	P	Tubewell with cement cover, half of handle broken off the well, proper drainage, IBS
Bhagatpurwa	BHAG115002	BHAGT2	N 27 30.684'	E 83 17.064'	Tubewell		N	N	N	N	Tubewell with cement cover and proper drainage, IBS
Bhagatpurwa	BHAG115003	BHAGT3	N 27 30.714'	E 83 17.019'	Tubewell		N	N			DDC, tubewel with handpump, cement cover and drainage
Bhagatpurwa	BHAG115004	BHAGT4	N 27 30.690'	E 83 17.010'	Tubewell		P	P			Kisokurhard, handpump with cement cover, drainage, by barn which drains onto well cover, private well
Bhagatpurwa	BHAG115005	BHAGT5	N 27 30.691'	E 83 16.973'	Tubewell	90	N	N			Cement cover with drainage, handpump, facing barn
Bhagatpurwa	BHAG115006	BHAGT6	N 27 30.691'	E 83 16.973'	Tubewell	85	N	N			BuddaSidardo, private, cement cover and drainage
Dhodahawa	DHOD117001	DHODT1	N 27 28.976'	E 83 13.942'	Tubewell	30	P	P			SuckleKumar, near irrigation pond, 4m, Private well, children drink from, wash clothes at
Dhodahawa	DHOD117002	DHODT2	N 27 28.996'	E 83 13.876'	Tubewell	30	P	N			8m from cow barn, handpump with cement cover, plants encroching, algal growth on horizontal spout, Jugadave
Dhodahawa	DHOD117003	DHODT3	N 27 28.971'	E 83 13.876'	Tubewell	30	P	N			Balliram, Handpump horizontal spout, cement cover with drain under house, brick lined, roof drains onto

Dhodahawa	DHOD117004	DEODA1	N 27 28.954'	E 83 13.857'	Tubewell	350	N	N	N	N	IBS, Cement cover with drainage, Artesian
Dhodahawa	DHOD117005	DEODT4	N 27 29.260'	E 83 13.957'	Tubewell	170	P	N	P	P	IBS, handpump with round cement cover with drain 3m from irrigation pond, 1m from cow barn
Dhodahawa	DHOD117006	DEODT5	N 27 29.337'	E 83 13.968'	Tubewell	180	P	P			Red Cross well, cement cover with drainage, near older handpump well, woman using old well instead of this one 4m away, has darinage pond 4m away, does not always have water
Dhodahawa	DHOD117007	DEODT6	N 27 29.340'	E 83 13.970'	Tubewell	20	P	P			4m from Red Cross well, will have water when proximal well does not
Mahadeva	MAHA117001	MAHAT1	N 27 29.765'	E 83 14.098'	Tubewell	40	P	N			Private well 1m downhill from cowbarn, cement cover bad drainage down hill
Lumbini	LUMB117001	LUMBT2	N 27 28.230'	E 83 17.022'	Tubewell	35	N	N			Well right off road at Buddanagar junction, no cover just gravel, no cows, by dry irrigation canal
Lumbini	LUMB117002	LUMBT3	N 27 28.213'	E 83 17.191'	Tubewell	40	P	P			South side of street no cows, cement cover,
Lumbini	LUMB117003	LUMBT4	N 27 28.215'	E 83 17.231'	Tubewell	40	P	P			Cement cover, no cows, lots of trash near well
Lumbini	LUMB117004	LUMBT5	N 27 28.227'	E 83 17.271'	Tubewell	40	P	P			Cement cover, no cows
Vietnam Temple	VIET118001	VIETT1	N 27 28.863'	E 83 16.404'	Tubewell	180	N	N			Cement Cover, protected watershed, piped into monastery
Lankapur	LANK119001	LANKT1	N 27 27.558'	E 83 17.082'	Tubewell	180	P	N			IBS, handpump, cement cover, 5m from cow barn, pond 2m away
Lankapur	LANK119002	LANKT2	N 27 27.540'	E 83 17.086'	Tubewell	180	P	P	P	P	IBS, handpump, cement cover, drainage, downhill of potters, cows 8m away
Lankapur	LANK119003	LANKT3	N 27 27.533'	E 83 17.098'	Tubewell	180	P	P			Red Cross well, cement cover with drainage
Lankapur	LANK119004	LANKT4	N 27 27.557'	E 83 17.067'	Tubewell	30	P	N	P	P	Private, 0.5m from cow barn buffalo feces on well brick cover, pooling drainage on cover, water colored, well of village Health coordinator chairman uses it for drinking
Lankapur	LANK119005	LANKT5	N 27 27.637'	E 83 16.999'	Tubewell	36	P	P	P	P	Raised cement cover, very clean by stream in health center near Lankapur, well missing three bolts

N = Negative well
P = Positive well

APPENDIX III

Cer Cor 3/2/2001 T=25 C Charles River Water Turbidity =

Run 1					
Time		**Flow ml/min**	**Turbidity NTU**	**Time (minutes)**	**Flow ml/min**
0:00					
8:08	3	440		3	440
8:10	5	405		5	405
8:13	8		0.6	12	360
8:15	10		0.7	17	350
8:17	12	360		20	265
8:22	17	350		26	290
8:24	19		0	29	283
8:25	20	265		35	260
8:27	22		0.8	42	245
8:31	26	290		49	240
8:34	29	283		54	265
8:36	31		0.7	57	255
8:40	35	260		75	300
8:47	42	245		80	290
8:48	43		0.1	85	255
8:54	49	240		89	350
8:59	54	265			
9:02	57	255			
9:04	59		0		
9:10	75	300			
9:15	80	290			
9:20	85	255			
9:24	89	350			

RUN 2			
CRW initial turbidity 2.9 NTU			
Time		**Flow ml/min**	**Turbidity NTU**
6:45	0	250	
6:46	1		0.6
6:47	2	245	0.8
6:53	8	228	0.4
6:58	13	216	0.2
7:03	18	214	0.3
7:06	21	207	0.5
7:13	29	200	0.3
7:17	33	200	0.3
7:22	38	193	0.2
7:28	43	194	0.1
7:34	51	193	0.1
7:38	55	187	0.1

AFTER BACK FLUSHING

RUN 3		Bacteria at 10.07 and 10.40	
Time	**Time**	**Flow ml/min**	**Turbidity NTU**
9:47	0	210	0
9:54	7	230	0.1
9:59	12	240	0.1
10:04	17	245	0
10:10	23	270	0
10:12	25	250	0
10:23	36	245	0
10:27	40	242	0
10:36	49	232	0
10:43	56	230	0.1
10:50	63	225	0.1
10:54	70	220	0
10:59	75	215	0

RUN 4 NO BACKFLUSHING

		Bacteria at 7:40 nad 8:10		
Time	**Time**	**Flow ml/min**	**Turbidity NTU**	**Pressure**
7:24	0	150	0.4	18.3
7:29	5	173	0.3	18.9
7:36	12	182	0.4	19.4
7:44	20	186	0.3	19.5
7:51	27	183	0.2	19.6
7:58	34	180	0.4	19.7
8:08	44	175	0.3	19.7
8:15	51	171	0.3	19.7
8:20	56	170	0.4	19.8
8:25	61	170	0.3	19.7

KAOLIN RUN 1	Begin at 2:25 Tw=37 C Feed = 35.1 NTU					
Time	Time	Flow	Permeate NTU	Feed NTU	Pressure	
2:27	0	180	0	35.2	19.8	
2:35	8	190	0	33.9	19.9	
2:42	15	195	0	31.5	19.9	
2:55	28	193	0	34	19.5	
3:09	42	200	0	29	20	
3:21	54	186	0	38.2	19	
3:33	66	220	0	35.2	20	
3:48	81	210	0	34	20	
4:00	93	210	0	32.3	20	
5:17	110	205	0	19.7	20.3	
5:36	129	200	0	38.1	20.2	
5:56	149	205	0	35	20.3	
7:17	230	208	0	22	20.4	
7:26	239	205	0	43.1	20	
7:54	267	240	0	38.9	20.4	
8:45	318	205	0	33	20.4	
11:26	319	135	0.1	41.1	20.5	Turn off for the night
11:50	343	173	0	36.8	20.6	
12:35	388	175	0	34.5	20.6	
1:22	435	180	0	29.6	20.7	
2:22	495	188	0	39.8	20.7	
3:48	591	188	0	27.5	20.7	
5:24	687	190	0	57.6	20.7	
12:45	688	40	0	151	20.4	Next Day
2:55	818	50	0	112	21	

	Charles River Water					
Pre CERCOR	3/2/01 8					
	TEST	**Dilution**	**Test Read**	**Result**	**E.Coli**	**Color**
1	P/A TC	0	3-3-2001 2p	positive	positive	yellow
2	P/A H2S	0	3-3-2001 2p	positive		black
3	MPN H2S	10	3-4-2001 3p	negative		yellow
4	MPN H2S	10	3-4-2001 3p	negative		yellow
5	MPN H2S	10	3-4-2001 3p	negative		yellow
6	MPN H2S	10	3-4-2001 3p	negative		yellow
7	MPN H2S	10	3-4-2001 3p	positive		black
				1.1 /100 ml * 10	11	

CerCor Microbial Testing Data

Mpn	what	date	time	result	test	E.Coli
1	preCerCor	3/2/2001	8	negative	H2S	d=10
2	preCerCor	3/2/2001	8	negative	H2S	d=10
3	preCerCor	3/2/2001	8	negative	H2S	d=10
4	preCerCor	3/2/2001	8	negative	H2S	d=10
5	preCerCor	3/2/2001	8	positive	H2S	d=10
1		3/2/2001	8.15	negative	H2S	
2		3/2/2001	8.15	negative	H2S	
3		3/2/2001	8.15	negative	H2S	
4		3/2/2001	8.15	negative	H2S	
5		3/2/2001	8.15	negative	H2S	
	P/A CC	3/2/2001	8.15	negative	H2S	
1	CC	3/2/2001	8.45	negative	H2S	d=0
2	CC	3/2/2001	8.45	negative	H2S	d=0
3	CC	3/2/2001	8.45	negative	H2S	d=0
4	CC	3/2/2001	8.45	negative	H2S	d=0
5	CC	3/2/2001	8.45	negative	H2S	d=0
	P/A CC	3/2/2001	8.45	negative	H2S	
	P/A CC	3/2/2001	8.45	negative	H2S	
	P/A CC	3/2/2001	9.15	negative	H2S	
	P/A CC	3/2/2001	8.45	negative	TC	negative
	P/A CC	3/2/2001	8.45	negative	TC	negative
	P/A CC	3/2/2001	9.15	negative	TC	negative
	P/A CC	3/2/2001		negative	TC	negative
	P/A CC	3/4/2001	6.5	negative	H2S	
	preCerCor	3/4/2001	7.3	negative	H2S	
	preCerCor	3/4/2001	6	positive	TC	negative
	P/A CC	3/4/2001	6.5	negative	TC	negative
	P/A CC	3/4/2001	7.3	negative	TC	negative
	P/A CC	3/4/2001	7.3	negative	TC	
	P/A preCerCor	3/8/2001	10	positive	H2S	
4	preCerCor	3/8/2001	10	positive	H2S	d=1
5	preCerCor	3/8/2001	10	positive	H2S	d=1
3	preCerCor	3/8/2001	10	positive	H2S	d=1
	P/A preCerCor	3/8/2001	10	positive	TC	negative
1	preCerCor	3/8/2001		negative	H2S	d=1
2	preCerCor	3/8/2001		positive	H2S	d=1
	P/A CC		10.07	negative	H2S	
	P/A CC		10.4	negative	H2S	
	P/A CC		10.12	negative	H2S	
	P/A CC	3/9/2001	7.4	negative	H2S	
3	preCerCor	3/9/2001		positive	H2S	d=0
5	preCerCor	3/9/2001		positive	H2S	d=0
1	preCerCor	3/9/2001		positive	H2S	d=0
2	preCerCor	3/9/2001		positive	H2S	d=0

4	preCerCor	3/9/2001		negative	H2S	d=0
	CRW	pre CC	3/9/2001	positive	H2S	
	CRW	3/9/2001		positive	TC	
	CRW	3/8/2001		positive	TC	
	CC	3/8/2001		negative	TC	
	CC	3/8/2001		negative	TC	
	CC	3/8/2001		negative	TC	
	CC	3/9/2001		negative	TC	
	CC	3/9/2001		negative	TC	

APPENDIX IV

SODIS

#	Date of Test	Sample Taken	Type of Test	Test Result	Color	Source	Procedure	H2S or TC	E.Coli
18	1/13/2001	1/9/2001	HACH	negative	yellow	**front pump**	background	H2S	
14	1/13/2001	1/8/2001	HACH	negative	yellow	**tap bathroom**	background	H2S	
10	1/10/2001	1/8/2001	IRDC	postive	black	**tap bathroom**	background	H2S	
17	1/13/2001	1/8/2001	HACH	negative	yellow	**tap bathroom**	SODIS Black	H2S	
15	1/13/2001	1/8/2001	HACH	negative	yellow	**tap bathroom**	SODIS Mirror	H2S	
16	1/13/2001	1/8/2001	HACH	negative	yellow	**tap bathroom**	SODIS Mirror	H2S	
25	1/13/2001	1/10/2001	P/A HACH	negative	purple	**tap bathroom**	SODIS Mirror (2 cloudy days)	TC	N
88	1/19/2001	1/18/2001	IRDC	postive	black	**LUMB2118004**	PRESODIS	H2S	
12	1/10/2001	1/9/2001	P/A HACH	negative	purple	**front pump**	SODIS Mirror 10am-6pm Bottle 7	TC	N
28	1/15/2001	1/13/2001	P/A HACH	negative	purple	**front pump**	SODIS Mirror 12a-4:30p sunny	TC	N
13	1/10/2001	1/9/2001	P/A HACH	postive	yellow	**front pump**	pre-SODIS	TC	
24	1/13/2001	1/12/2001	P/A HACH	negative	purple	**front pump**	SODIS Black (1 cloudy day) 10am-6pm	TC	N
30	1/15/2001	1/10/2001	P/A HACH	negative	purple	**front pump**	SODIS Black 1 cloudy day 10am-6pm	TC	N
26	1/15/2001	1/13/2001	P/A HACH	negative	purple	**front pump**	SODIS Black 12a-4:30p sunny	TC	N
121	1/21/2001	1/19/2001	HACH	negative	yellow	**LANK119004**	SODIS Black	H2S	
127	1/21/2001	1/19/2001	HACH	negative	yellow	**LANK119004**	SODIS Mirror	H2S	
120	1/21/2001	1/19/2001	IRDC	negative	yellow	**LANK119004**	SODIS Black	H2S	
126	1/21/2001	1/19/2001	HACH	negative	yellow	**LANK119004**	SODIS Mirror	H2S	
116	1/21/2001	1/19/2001	HACH	postive	black	**LANK119004**	well sample	H2S	
119	1/21/2001	1/18/2001	IRDC	negative	yellow	**LANK119004**	well sample	H2S	
123	1/21/2001	1/19/2001	HACH	negative	yellow	**SODIS118**	SODIS Black	H2S	
118	1/21/2001	1/18/2001	HACH	postive	black	**SODIS118**	SODIS Mirror	H2S	
106	1/20/2001	1/18/2001	IRDC	negative	yellow	**11800LUMB2**	SODIS Black	H2S	
105	1/20/2001	1/18/2001	IRDC	negative	yellow	**11800LUMB2**	SODIS Mirror	H2S	
124	1/21/2001	1/18/2001	HACH	postive	black	**LANK119001**	well sample	H2S	
122	1/21/2001	1/19/2001	IRDC	negative	yellow	**LANK119001**	well sample	H2S	
125	1/21/2001	1/19/2001	HACH	negative	yellow	**LANK119001**	SODIS Black	H2S	

Data Collected in Kathmandu by Cathy Pham

WEATHER	SAMPLE #	DAY (2000)	SOURCE WATER	Time Start	0 hrs. SODIS	Temp (C)	4 hrs. SODIS	Temp (C)	23 hrs. SODIS	Temp (C)	48 hrs. SODIS
WEATHER overcast cloudy rain Kuleswor Stone Spout/Sump Well (samples collected at 10:30am at 25°C; incubation began at 11am) Kuleswor Kitchen Sink (samples collected at 10:30am at 25°C; incubation began at 11am)	2	6/21/2001	TAP WATER	6/21 3pm	P				N		
WEATHER overcast cloudy rain Kuleswor Stone Spout/Sump Well (samples collected at 10:30am at 25°C; incubation began at 11am) Kuleswor Kitchen Sink (samples collected at 10:30am at 25°C; incubation began at 11am)	3	6/21/2000	3 BISLERI TAP WATER	6/21 3pm	P		--		N		
WEATHER overcast cloudy rain Kuleswor Stone Spout/Sump Well (samples collected at 10:30am at 25°C; incubation began at 11am) Kuleswor Kitchen Sink (samples collected at 10:30am at 25°C; incubation began at 11am)	4	6/21/2000	4 BISLERI TAP WATER	6/21 3pm	P		N		N		
WEATHER cloud cover and light sprinkles in the morning; around 11:30am and onward-->bright blue skies and cumulous clouds; very hot around 3pm	10	6/22/2000	Kuleswor Kitchen Sink	6/22 12pm	P		P		--		
WEATHER cloud cover and light sprinkles in the morning; around 11:30am and onward-->bright blue skies and cumulous clouds; very hot around 3pm	11	6/22/2000	Kuleswor Stone Spout	6/22 12pm	P		N		--		
light rain in the very early morning; slightly overcast; around noon-->bright blue skies and only patches of gray clouds; directly above NWSC roof-->open sky; direct strong solar exposure; rain at 1pm Checked to see if P/A test would work without filter paper in each vial	28	6/30/2000	2 – tap water; Thirst-Pi bottle on black tarp	6/30 12pm	P	24		30	P	23	N

light rain in the very early morning; slightly overcast; around noon-->bright blue skies and only patches of gray clouds; directly above NWSC roof-->open sky; direct strong solar exposure; rain at 1pm Checked to see if P/A test would work without filter paper in each vial	29	6/30/2000	3 – tap water; Bisleri bottle on tar roof surface	6/30 12pm	P	24		30	P	23	N
light rain in the very early morning; slightly overcast; around noon-->bright blue skies and only patches of gray clouds; directly above NWSC roof-->open sky; direct strong solar exposure; rain at 1pm Checked to see if P/A test would work without filter paper in each vial	30	6/30/2000	4 – tap water; Bisleri bottle on tar roof surface	6/30 12pm	P	24		30	P	23	N
light rain in the very early morning; slightly overcast; around noon-->bright blue skies and only patches of gray clouds; directly above NWSC roof-->open sky; direct strong solar exposure; rain at 1pm Checked to see if P/A test would work without filter paper in each vial	31	6/30/2000	5 – tap water; 1.5 liter YES bottle on black tarp	6/30 12pm	P	24		30.8	P	24	N
light rain in the very early morning; slightly overcast; around noon-->bright blue skies and only patches of gray clouds; directly above NWSC roof-->open sky; direct strong solar exposure; rain at 1pm Checked to see if P/A test would work without filter paper in each vial	32	6/30/2000	6 – tap water; Bisleri bottle on black tarp	6/30 12pm	P	24		30.5	P	23.5	N

Weather conditions rain all morning; overcast; around 11am-2:30pm-->warm, strong sun even though overcast; rain at 3pm Water Source-NWSC Central Lab tap sink water (water main was shut off today so water from basin underneath sink was used as sample source)	36	7/2/2000	2 – sink tap water; Thirst-Pi bottle on black tarp	7/2 5pm	P	24			N		
Weather conditions rain all morning; overcast; around 11am-2:30pm-->warm, strong sun even though overcast; rain at 3pm Water Source-NWSC Central Lab tap sink water (water main was shut off today so water from basin underneath sink was used as sample source)	37	7/2/2000	3 – sink tap water; Bisleri bottle on tar roof surface	7/2 5pm	P	24			N		
Weather conditions rain all morning; overcast; around 11am-2:30pm-->warm, strong sun even though overcast; rain at 3pm Water Source-NWSC Central Lab tap sink water (water main was shut off today so water from basin underneath sink was used as sample source)	38	7/2/2000	4 – sink tap water; Bisleri bottle on tar roof surface	7/2 5pm	P	24			N		
Weather conditions rain all morning; overcast; around 11am-2:30pm-->warm, strong sun even though overcast; rain at 3pm Water Source-NWSC Central Lab tap sink water (water main was shut off today so water from basin underneath sink was used as sample source)	40	7/2/2000	6 – sink tap water; Bisleri bottle on black tarp	7/2 5pm	P	24			N		
light rain at around 5am; slightly overcast; early afternoon bright blue skies and a few gray clouds; open sky directly above NWSC roof; direct strong solar exposure; rain at 3pm	42	7/3/2000	2 – tap water; Thirst-Pi bottle on black tarp	7/3 4:30pm	P				P		N
light rain at around 5am; slightly overcast; early afternoon bright blue skies and a few gray clouds; open sky directly above NWSC roof; direct strong solar exposure; rain at 3pm	43	7/3/2000	3 – tap water; Bisleri bottle on tar roof surface	7/3 4:30pm	P				P		N

light rain at around 5am; slightly overcast; early afternoon bright blue skies and a few gray clouds; open sky directly above NWSC roof; direct strong solar exposure; rain at 3pm	44	7/3/2000	4 – tap water; Bisleri bottle on tar roof surface	7/3 4:30pm	P				P		N
light rain at around 5am; slightly overcast; early afternoon bright blue skies and a few gray clouds; open sky directly above NWSC roof; direct strong solar exposure; rain at 3pm	45	7/3/2000	5 – tap water; 1.5 liter YES bottle on black tarp	7/3 4:30pm	P				P		N
light rain at around 5am; slightly overcast; early afternoon bright blue skies and a few gray clouds; open sky directly above NWSC roof; direct strong solar exposure; rain at 3pm	46	7/3/2000	6 – tap water; Bisleri bottle on black tarp	7/3 4:30pm	P				N		N
Weather Conditions Raining all day; overcast; gray skies; cloud cover	48	7/6/2000	2 – tap water; Thirst-Pi bottle on black tarp	7/6/ 11 am	positve	21.5	N	29	P*		
Weather Conditions Raining all day; overcast; gray skies; cloud cover	49	7/6/2000	3 – tap water; Bisleri bottle on tar roof surface	7/6/ 11 am	positve	21.5	positve	28.5	N		
Weather Conditions Raining all day; overcast; gray skies; cloud cover	50	7/6/2000	4 – tap water; Bisleri bottle on tar roof surface	7/6/ 11 am	positve	21.5	N	28.5	N		
Weather Conditions Raining all day; overcast; gray skies; cloud cover	51	7/6/2000	5 – tap water; 1.5 liter YES bottle on black tarp	7/6/ 11 am	positve	21.5	N	29.4	P		
Weather Conditions Raining all day; overcast; gray skies; cloud cover	52	7/6/2000	6 – tap water; Bisleri bottle on black tarp	7/6/ 11 am	positve	21.5	N	29	P*		
WEATHER bright sunny day; bright blue skies; very hot	71	7/8/2000	6 – tap water; Bisleri bottle on black tarp	7/7 4:30pm	P	29		36 next aft	N		

WEATHER little rain in the morning then clear skies	73	7/9/2000	2 – tap water; Thirst-Pi bottle on black tarp	7.8 5:30pm	P	24		40 next aft	N	27	
WEATHER little rain in the morning then clear skies	74	7/9/2000	3 – tap water; Bisleri bottle on tar roof surface	7.8 5:30pm	P	24		38 next aft	P	27	
WEATHER little rain in the morning then clear skies	75	7/9/2000	4 – tap water; Bisleri bottle on tar roof surface	7.8 5:30pm	P	24		38 next aft	N	27	
WEATHER little rain in the morning then clear skies	76	7/9/2000	5 – tap water; 1.5 liter YES bottle on black tarp	7.8 5:30pm	P	24		40.5 next aft	N	28.6	
WEATHER little rain in the morning then clear skies	77	7/9/2000	6 – tap water; Bisleri bottle on black tarp	7.8 5:30pm	P	24		40.5 next aft	P	28	
WEATHER bright sunny day; bright blue clear, skies no clouds muggy	93	7/10/2000	2 – tap water; Thirst-Pi bottle on black tarp	7/9 5pm	P	24		40 next aft	N		
WEATHER bright sunny day; bright blue clear, skies no clouds muggy	94	7/10/2000	3 – tap water; Bisleri bottle on tar roof surface	7/9 5pm	P	24		38 next aft	N		
WEATHER bright sunny day; bright blue clear, skies no clouds muggy	95	7/10/2000	4 – tap water; Bisleri bottle on tar roof surface	7/9 5pm	P	24		38 next aft	N		
WEATHER bright sunny day; bright blue clear, skies no clouds muggy	96	7/10/2000	5 – tap water; 1.5 liter YES bottle on black tarp	7/9 5pm	P	24		40.5 next aft	P		

WEATHER bright sunny day; bright blue clear, skies no clouds muggy	97	7/10/2000	6 – tap water; Bisleri bottle on black tarp	7/9 5pm	P	24			P		
WEATHER cloud cover and light sprinkles in the morning; around 11:30am and onward-->bright blue skies and cumulous clouds; very hot around 3pm	18	6/23/2000	bagmati river on black tarp thirst pi	6/23 4:3pm	P		P		P		P
WEATHER cloud cover and light sprinkles in the morning; around 11:30am and onward-->bright blue skies and cumulous clouds; very hot around 3pm	19	6/23/2000	bagmati river tar roof surface bisleri	6/23 4:3pm	P		P		P		P
WEATHER cloud cover and light sprinkles in the morning; around 11:30am and onward-->bright blue skies and cumulous clouds; very hot around 3pm	20	6/23/2000	bagmati river tar roof bisleri	6/23 4:3pm	P		P		P		P
WEATHER cloud cover and light sprinkles in the morning; around 11:30am and onward-->bright blue skies and cumulous clouds; very hot around 3pm	21	6/23/2000	bagmati river black tarp 1.5l YES	6/23 4:3pm	P		P		P		P
Overcast light spinkles in the morning warm cloud cover 25C at 11 am cloud cover cleared around 2pm	22	6/24/2000	6-Bagmati River water hole on black tarp	6/23 4:3pm	P	28	P	37	P	45	

VITA

Meghan Smith was born in Washington thirty miles south of Pittsburgh, PA. She grew up on a sheep farm outside of Washington, PA. After graduation from McGuffey High School in June, 1995 she attended the Johns Hopkins University in, Baltimore, MD.

At Johns Hopkins Meghan studied chemical engineering and was president of Alpha Phi International Fraternity. During the summer of 1998 she interned at Refractory Composites, Inc. a vapor-deposition ceramics research company located in Glen, Burnie, MD. Meghan attained her bachelor of science in chemical engineering from Johns Hopkins University in May 1999.

In September 2000 Meghan entered the Masters of Engineering program in the Department of Civil and Environmental Engineering at MIT and participated in the Nepal Water Project.