CeraMIT Report of Activity Nepal: January 2003

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Executive Summary

According to the World Health Organization, nearly one sixth of the world's population lacks access to clean drinking water. Susan Murcott of the Massachusetts Institute of Technology (MIT) and her students have been studying this problem in Nepal for five years, including several engineering studies of existing ceramic water filters. This year, CeraMIT, a team of MIT graduate students of business and environmental engineering, conducted a study culminating in several recommendations for the development of a grassroots ceramic water filter business in Nepal.

First, we have recommended a prototype filter design. Much scientific testing will be required of this or any prototype before field testing is conducted. With any product design, there are tradeoffs, and the key considerations for our design were: microbial removal efficiency, flowrate, ease-of-use, durability, and cost. In addition to the paramount importance of microbial removal efficiency, we are particularly concerned with bringing cost to the lowest level practical, as our target market can not afford to spend much on our product. The prototype design we have recommended uses a disk-shaped ceramic filter, a two-vessel upper and lower high quality plastic container, a rubber gasket which encircles the disk, spring clamps, and a lid. Unfortunately we did not have sufficient time to solicit quotes from suppliers to assist in cost analysis of this filter, so we have included several suggestions for modifying the design to reduce costs. More details are found in Section 5.1.

Second, we have recommended an initial business organization. This effort has a solid resource in Hari Govinda Prajapati of Madhyapur Clay Crafts in Thimi Nepal as the filter element manufacturer and an assembler/distributor of the filter system. His entrepreneurial spirit and business acumen, as well as experience in this market, make him a prime choice for involvement in the business that results from this effort. In addition to owning his own pottery manufacturing business, he is also the chairman of the Nepal Ceramics Cooperative Society, an organization that could be instrumental in getting this product distributed outside the Kathmandu Valley. More details are found in Section 5.2.

Third, we have recommended that marketing concepts and techniques be considered throughout the development and marketing of this product. Education is an important component of any marketing campaign, and is especially relevant in our case in order to demonstrate to the public the link between water quality and health and hence the need or benefit of ceramic water filters. In addition, we feel it is important to develop a strong and trusted brand name that people will recognize as being of good quality. Also, NGOs can be instrumental in creating awareness of the product and educating the people. More details are found in Section 5.3.

Unfortunately, our time in Nepal was only four weeks, and this limited our ability

to study these issues in as much depth as is warranted. Consequently, we have included several recommendations for future work by organizations known to be working on ceramic water filtration units to help solve the water quality problem in Nepal and beyond. These recommendations include the conviction that more detailed testing and a more thorough marketing study must be done prior to field testing any prototype. Taken as a whole, these recommendations encompass what we believe is necessary to design and deploy a successful ceramic water filter product in Nepal or potentially other developing countries. More details are found in Section 5.4.

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1 Introduction

1.1 The Problem

Water is an essential element for life: both in terms of quantity and quality. Today, one sixth of the world's population, roughly 1.1 billion people, lack access to improved water supply, and two fifths, or 2.4 billion people, lack access to improved sanitation[1]. Nearly five million people in Nepal lack access to safe drinking water and nearly eighteen million lack access to improved sanitation according to the World Health Organization's 2000 Global Water Supply and Sanitation Assessment Report.[2]

Figure 1: Map of Nepal

When visiting and talking with many individuals and organizations in Nepal, however, it is readily apparent that more than five million people are *vulnerable* to problems with drinking water quality since the majority lack access to adequately treated water. Essentially, the infrastructure for supplying clean water is minimal compared to that in industrialized countries, leaving citizens to treat water on their own – if they can afford to or realize the need to do so. Most of the population relies on decentralized water supply systems such as tube wells, open wells, and stone taps connected to local reservoirs. While some of these water sources may be relatively clean, many are not and those that may be now are still quite vulnerable to contamination in the future as development proceeds and stress on the environment and water resources persists.

Considering the significant lack of water treatment infrastructure, there is an obvious need to treat water at a household or “point of use” level. There is really no other option at the present moment if citizens care to ensure that the water they are drinking is clean and free of microbial contamination or chemical contamination such as arsenic, which is a problem in the lower Terai region of Nepal.

Ceramic water filters offer one solution to improving water quality at the household level and thus reducing the risk associated with waterborne health problems. The ceramic filter was chosen as a potential solution because it is low cost, simple, and can be produced locally in Nepal and potentially in many other developing countries. Ceramic filters do have some disadvantages such as: low flow rates, varying microbial removal performance, and durability problems. Our project and the work of past and present MIT engineering students under the guidance of Susan Murcott has focused on understanding and minimizing these weaknesses as best as possible to determine the most appropriate and suitable ceramic water filter that could be used in Nepal and elsewhere throughout the world.

1.2 MIT-based Ceramic Water Filter Research

MIT has been working in Nepal since 1999 to help provide clean drinking water and improved sanitation to those in need. As part of this effort, CeraMIT, a joint Sloan-Engineering team, is working on developing a business model for creating a sustainable ceramics water filtration industry in Nepal. With its extreme poverty and tremendous geographical and cultural diversity in a small area, Nepal serves as a challenging proving ground for any product addressing the need for clean drinking water.

This year, CeraMIT conducted a three-week-long field study in Nepal culminating in several recommendations for the development of a grassroots ceramic water filter business in Nepal. While our visit to Nepal was too short to conduct a thorough study, we have tried to consider judiciously all of the technical and social parameters involved in the creation of a ceramic filter for point-of-use water treatment. Important issues that we have considered are:

- The appropriate ceramic media for the filter
- The appropriate shape of the filter media (candle, disk, flowerpot)
- The use of colloidal silver to enhance microbial removal
- The appropriate shape, size, and material for the containers
- How to minimize production and distribution costs
- How best to market the resulting product

This report will outline the market situation in Nepal, our research and work conducted in January, and the resulting recommendations. CeraMIT's work in Nepal focused primarily on product development; however, our recommendations also include preliminary suggestions on business organization and marketing methods, as well as recommendations for future work by MIT Researchers and other ceramic filter projects in Nepal.

2 Market Information

We identified four main market regions for water purification purposes: Urban Nepal, the Terai, the Middle Hills, and the Himalayas. The latter three categories represent the three broad geographic regions of Nepal: the Terai in the south, the Hills in the mid-region, and the Himalayas in the north. Each has its own unique requirements, but all share the problem of inadequate clean drinking water supply.

2.1 Urban Nepal

Urban Nepal is represented by only four major cities and an assortment of smaller towns. The largest city (by far) is Kathmandu, the capital city with over 700,000 residents. The others, Pokhara, Patan, and Bhaktapur, are noticeably smaller, but have many of the same water supply and sanitation problems. In total, urban residents represent only 10 to 15% of Nepal's 23 million people.

2.1.1 Water Characteristics

By all accounts, Kathmandu has the worst water quality in the country. The infrastructure to treat and deliver drinking water is sorely inadequate. The delivery and sewer systems were built in the 1890s, and much of this system has not had a major renovation since their installation.

The problems with the system are numerous. The available water supply is approximately 50 million liters per day (MLD), a fraction of the estimated demand of 170 MLD. Chronic shortages mean some water taps are only turned on for 1 to 2 hours per day, or even if they are supplied, pressure is very weak. Lines often form at taps in the morning to get the day's water. The water shortages are compounded by thousands of illegal taps on the water pipes. Residents who do not have access to municipal water will sometimes locate a municipal pipe, drill or break into it, and extract water with a small pump.

Getting enough water is only half the battle. The quality of the water that makes it through the system is often very poor. Much of the water that enters the system is never treated, and often unsafe to drink. The sewer pipes beneath the city are cracked and leak raw wastewater into the surrounding soil and groundwater. The century-old water delivery pipes are in equally poor shape; the water shortages create backpressure in the pipes, which draws dirt and untreated sewage into the water system. Tests of tap water in Kathmandu and other cities show dangerously high levels of fecal coliforms (FCs) and E. coli bacteria. For reference, see Sharma and Shrestha (1995)[3], Wolf (2000)[4], and WHO (1996)[5].

Furthermore, wastewater often goes untreated, or treatment plants are ineffective. In addition to household waste, local industry dumps waste directly into surrounding water sources, such as the Bagmati River, which runs through Kathmandu. A particular offender is the local carpet industry, which empties dye into the rivers at many different locations.

Water quality is of a cyclical nature in Nepal. The dry season begins in September, and quality is relatively good at that time. But little or no rain over the next nine months results in a buildup of waste and other pollutants. By April or May, the quality of the water is quite poor. When the rainy season hits in June, all of the built-up pollutants are washed into the local water sources, and water quality is at its worst anytime, anywhere in the country. This annual cleansing is well-known to the local people: the vast majority of water filters are sold during the three-month rainy season.

There is a solution in the works for the Kathmandu Valley. The Melamchi Water Project is an immensely expensive plan to divert water from the Melamchi Valley to the Kathmandu Valley, treat it, rebuild the distribution system, and provide wastewater treatment. This is an ambitious project, unprecedented in scale in Nepal. A 26-km pipeline through a mountain range, a water treatment plant, a sewage treatment plant, and a new pipe network beneath the city (and much of the valley) are all being planned. If successfully completed and managed properly, the project will provide an adequate infrastructure for the next couple of decades. It was originally to be completed in 2006, but the recent Maoist activity has delayed its start; project planners are now hoping for a 2007 or 2008 completion date.

In the smaller towns, there are similar problems with water quality, but without the aging-infrastructure issues. Open sewers are everywhere, often running within a meter of a water source. Public taps give way to open wells and tube wells, which are typically less safe than government-supplied tap water. Education on sanitation and health is poor, compounding a problem already made bad by close proximity and a lack of infrastructure.

2.1.2 Social / Religious Considerations.

The large cities are melting pots; every different culture, background, and religion is represented – meaning every possible religious, cultural, or socioeconomic issue will arise when trying to market a product to this population. The smaller towns tend to be more homogeneous, taking on the values of the regions in which they reside.

Family sizes in the cities, in our observations, were larger than in the countryside, especially among the urban poor. These larger families are crammed into much smaller homes; space is a very serious issue. Also, wealth varies from the *über*-rich to the very poor. Water filters have become something of a status symbol.

They are often purchased as wedding gifts, and are usually prominently displayed in the home.

2.1.3 Practical Considerations.

The lower class in the cities is a tough sell for a water filter. They have very little money (if any at all), and can often make significant health gains just with proper sanitation practices (provided an NGO or other entity is available to teach them). Education is generally better in the cities than in the hills, but the economic situation for the urban poor is the worst that we observed.

The middle and upper classes often already have household filtration systems. However, they (rightly) don't trust them, and boil their water as well as filter it. (For the record, most experts recommend that if both filtering and boiling are being performed, then it should be filtered first and then boiled.) It is important not to ignore these legacy systems when addressing the water problem; many consumers would be put off if they had to purchase an entirely new system, rather than a replacement filter element.

There is one other, much smaller issue. The Melamchi Water Project, if implemented properly, will eventually solve many of the existing issues. If the point-of-use solution isn't implemented in a timely fashion, consumers may choose to wait for the new system.

2.2 The Terai

The Terai is the strip of land along the southern border of Nepal. The only flat area in the country, it represents the northern limit of the Ganges flood plain, which dominates much of northern India. While it is only 15% of the landmass of Nepal, the Terai is home to roughly half of the population, and the number is growing.

The Terai has the most fertile farmland in the country. The "Breadbasket of Nepal", the Terai has become the most productive area of the nation in recent years. Nepal has an open border with India, and has a large population of Indian immigrants. This heavy influence from the south has resulted in a conservative, overwhelmingly-Hindu population.

The Terai is also home to the only highway that crosses Nepal from the east to the west. All other main roads, except the Kathmandu to Pokhara highway, are north-south offshoots. As a result, many of the goods that get shipped to the hills go through the Terai, even if they're being shipped from the Kathmandu Valley.

2.2.1 Water Characteristics.

The terrain in the Terai is dramatically different than in the rest of Nepal, and that holds true for the water supply sources as well. While most of the Hills and Himalayas are fed from springs, rivers, and streams the Terai has a predominant groundwater supply, and this is where a large percentage of the population gets its water. Thousands of tube wells dot the countryside; most range in depth from 20-200 feet.

As in the rest of Nepal, the primary concern of water quality in the Terai is bacteriological contamination. However, the Terai also faces additional challenges: arsenic and iron contamination. These are recent discoveries, and research is underway to determine the extent of the problem. However, in some areas of the Terai, these issues are quite serious.

In general, the Terai water supply differs from the Hills and Himalayan water supplies in that the quantity of water is less of a concern for residents than quality. The aforementioned tube wells are numerous, and the water table remains high enough to provide residents with water throughout the year. Groundwater is also typically cleaner than surface water, but testing has revealed that it too does not always meet the WHO Microbial Guidelines for drinking water.

2.2.2 Social / Religious Considerations.

The Terai is widely viewed as the most conservative region of the country. The caste system is a part of life in this area, and issues may arise when selling a product between castes. Some higher castes will not purchase goods from the occupational castes, making distribution of a filtration product more challenging.

The conservatism in the region leads to some interesting issues. Many families in the Terai will not drink water that was fetched the previous day; they believe it is not fresh and unsuitable for consumption. This could be an issue with people letting water filter overnight. Also, when women are menstruating, they are considered impure, and anything they touch during this time is believed to be contaminated. Since women are typically the ones that get the water, if they were to accidentally touch the filter during this time, some households would throw the filter away. This is especially true of ceramic buckets, we believe due to their porous nature.

2.2.3 Practical Considerations.

There are numerous potters in the region, many of whom are stationed along the East-West Highway (an ideal shipping/receiving point). The weather in the Terai is very, very hot during the summer monsoon season. In this regard, ceramic buckets are quite valued, because they help to keep water cool throughout the day. Also, the flat terrain and comparatively well-developed road system make transportation less of an issue. It may be possible to effectively market ceramic buckets in this area of the country.

2.3 The Middle Hills

The Middle Hills were home to the majority of Nepal's population before the recent migration to the Terai. They currently hold 40% of the population. The terrain in the hills is very steep; the farming communities have developed a system of terraces that allow them to extract an impressive amount of crops from the land. However, growing families and subdivision of the land have left many areas unable to sustain themselves. Most of the population in the Hills is clumped in loose villages of ten to fifty households.

2.3.1 Water Characteristics.

Quantity is a major issue in the Hills, especially during the dry season. The majority of villages get their water from public taps, which are often spring-fed, and or directly from a spring or stream. The public taps that exist will sometimes go days without providing an adequate amount of water, and the springs and other sources flow at a much slower rate, if at all. Nearly all of the villagers that we talked to believed that the springs were clean; the water from them is "fresh" and uncontaminated. However, studies have shown that many of the springs do not meet WHO guidelines.

Domestic water usage by the Hill residents is less than in the Terai – generally 1-2L per person per day. The lower Hills also have an issue unique to their location: calcium buildup. Government installed pipes in the area have slowly filled with calcium, restricting flow. This could also be an issue with a point-of-use water filter; calcium buildup on a filter element could clog the pores, and be difficult or impossible to remove.

2.3.2 Social / Religious Considerations.

The Hills are less formal than the Terai. While the caste system still exists in some areas, its influence is slowly fading as the younger generation pays less heed to traditions and restrictions. From our field research, residents will use water from the previous day for non-consumption uses, such as for washing and animals. We think they would be willing to drink water that has been filtered overnight, if they are properly educated.

Many Hill residents do not have electricity, and use wood for cooking and boiling water. In some areas, wood gathering has been restricted, and it is always a burdensome task to obtain firewood. It is possible to use kerosene for cooking, as well, but this requires money, and many people in this region have very little.

There is also a fair amount of ethnic diversity in a small area. Many Hill tribes do not speak Nepali, and cannot even communicate with the people in the next valley. Also, education on health and sanitation is greatly dependent on proximity to a major town, and on NGO involvement in the community.

2.3.3 Practical Considerations.

The terrain is the determining factor of life in the Hills. Traveling to a town to sell wares or purchase supplies can involve an all-day walk or more, up and down very steep hills. For this reason, any product must be very light, durable, and as compact as possible. Family sizes are moderate, with five to seven members being the norm. The road system is also quite poor or nonexistent. Traveling to some villages to sell filters may prove difficult.

2.4 The Himalayas

As we had no opportunity for direct observation, we know comparatively little about the Himalayan people. They represent a small subset of the Nepali population, only 10% of the total, and are spread out over a wide area. They farm, but are incapable of producing enough food for sustenance. They also keep large herds of yaks and sheep, which graze on the high mountain plains during the summertime. They typically live above 3,000 meters, and can be found above 5,000 meters during the summer months.

2.4.1 Water Characteristics.

Again, we have not directly observed any of the water sources in the Himalayan region, but they would logically be cleaner than in the hills and the Terai, due to the geology of the region and a lesser animal presence. Supply could be a very big problem during the dry months, but in certain areas this problem could be averted by melting snow, if enough fuel was available.

2.4.2 Social / Religious Considerations.

In addition to being farmers and herders, the Himalayan people are also traders, and travel throughout the country, sometimes for months at a time. This can be just a single member of the family, or the entire family. Some families go to India to work in the fields during the winter months. This nomadic lifestyle would probably drive them to minimize their possessions (in other words, they might not want to carry a filter around as they travel throughout the country).

However, traders are also well versed in multiple cultures. They would likely be more receptive to new ideas and technologies than a typical conservative household. Also, the people in the Himalayan region are primarily Buddhist, and are less formal than people living in other parts of the country.

2.4.3 Practical Considerations.

The people of the Himalayan region are very difficult to get to. Roads are few and far between, and the population density of the region makes distribution of any sort of product very challenging. Also, the water quality is comparatively good, while education is poor. It is unlikely that focusing efforts here would yield much reward in the near-term.

3 Research Methods and Findings

3.1 Review of Ceramic Water Filter Technology

Ceramic water filters have been used in many places around the world as a means of treating drinking water at the household level particularly in developing countries. Some examples include the Potters for Peace Filtron (Nicaragua), the TERAFIL terracotta filter (India), and the candle filter (India, Nepal, Bangladesh, Brazil, etc).

Ceramic water filters can be categorized according to various key parameters:

1. Shape (e.g.: candle element, disk, pot)
2. Type of clay (e.g.: white kaolin, red terracotta, black clay…)
3. Combustible material (e.g.: sawdust, flour, risk husk…)

Ceramic water filters can also be described by their function(s):

1. Microbial removal (e.g.: Potters for Peace Filtron)
2. Chemical contaminate removal like arsenic and iron (e.g.: 3 Kalshi filter for arsenic)
3. Secondary contaminant removal like taste and odor (e.g.: Brita Filter)

Other key variables that influence the properties of ceramic water filters include:

1. Use of additional materials in production (e.g.: grog, sand, sawdust…)
2. Firing temperature
3. Mode of production (e.g.: hand mold, wheel, mechanical press)

The entire water filter unit is often defined in terms of two components: the filter *media* through which water passes and the filter *system* which houses the media, usually consisting of an upper and lower container for holding water. Some general strengths and weaknesses of ceramic water filters are listed below.

Strengths	**Weaknesses**
• Relatively cheap to manufacture and produce • The ceramics trade is well established in many countries • Materials (clay, sawdust, rice husk…) are often readily available • If constructed and <u>used</u> properly, can remove up to 100% of indicator organisms and reduce turbidity to below World Health Organization Guideline values.	• Very slow filtration rates. (typically ranging between 0.5 and 4 L/day) • Filter maintenance and reliability depends on the user – herein lies many non-technical social and cultural issues. • Breakage during distribution or use can be a problem since the filters are fragile. • Requires regular cleaning • The production process as implemented in countries such as Nicaragua and Nepal has tended to be relatively slow and it is difficult to maintain consistency (quality control is an issue).

A brief summary of the three most promising ceramic filter media shapes, Disk Filters, Pot Filters, and Candle Filters, is presented below

3.1.1 Disk Filters

Ceramic disk filter systems consist of an upper and lower chamber with a ceramic media disk inserted between the two chambers. Water is poured into the upper chamber and then allowed to filter through the disk into the lower collection chamber. A spigot is placed in the bottom chamber for dispensing the treated water.

An example of a disk filter system is the Indian TERAFIL filter (See Figure 2 below). The TERAFIL consists of two metal or terracotta containers and a ceramic disk fitted in between. The disk retails for approximately 25 Indian Rupees (INR 25) (USD $0.49)[a] and a complete set consisting of a disk and two ceramic containers (not metal as in the picture) retails for approximately INR 180 (USD $3.51).[6]

In January 2002, Civil engineering student Jason Low and Mr. Hari Govinda Prajapati experimented with different material compositions and production processes to produce a terracotta clay disk filter similar to the TERAFIL filter, but based on variations of the production process shared by Ron Rivera of Potters for Peace, Nicaragua (Section 3.1.2) (See Figure 3 below for a picture). They used local red terracotta clay from Thimi, a village outside Kathmandu, as the primary material for both the ceramic disk and the containers. The results from their work are published in Low's thesis.[7] Mr. Hari Govinda Prajapati's business, Madhyapur Clay Crafts, is now selling a modified version of this disk as an arsenic filter. The production cost for these terracotta filters is approximately NRs 78 (USD $1.02) for the disk and NRs 273 (USD $3.57) for the filter and two terracotta containers.[8]

Previous studies of the Indian TERAFIL disk filter show mixed results for filter performance in terms of microbial removal and flow rate. In his 2002 thesis, Low summarized a number of these studies, as well as conducted his own studies on the Indian TERAFIL and the Nepali disk filter that he and Hari Govinda had created.[9] Of concern in previous studies, including Low's, was the unsatisfactory microbial removal rates ranging from 93% to 99.99% (% total coliform removal).[10] Percent turbidity removal was reported to be quite good, typically approaching 99% removal and below the WHO Guideline of 5 NTU. Flow rates were another major issue, ranging from 1.0 to 11.0 L/hr with the average among all of the studies being around 3 L/hr. Most studies concluded that the ceramic filters should be used in conjunction with another form of disinfection such as chlorination or colloidal silver.

[a] 1 USD = 51.22 INR (Indian Rupees); 1USD = 76.5 NRs (Nepali Rupees) (8/11/2002)

Tests at MIT on the Nepali terracotta disk filters showed comparable microbial removal rates and turbidity reduction as the Indian TERAFIL filters; however, the flow rates were unacceptably low at 0.2-0.3 L/hr.[11] Considering this was the first attempt at making the terracotta disk filters at Madhyapur Clay Crafts, there is likely room for improving the production process to achieve acceptable flow rates comparable to the TERAFIL filter.[12]

Tests by Low on the TERAFIL filter unit at the Environment and Public Health Organization (ENPHO) laboratory in Kathmandu measured flow rates ranging from 5.9 L/hr to 6.9 L/hr[13] while similar tests performed a month earlier at MIT measured flow rates ranging from 1.1 L/hr to 1.9 L/hr. Despite the wide discrepancy in flow rates between the two seemingly identical TERAFIL units, the microbial removal rates of both units were comparable, ranging from 94% to 99.99%[14]. That a relatively high flow rate was achieved in a ceramic water filter without sacrificing microbial removal performance was of considerable interest and formed the basis for the next stage of studies.

Most studies also report that regular cleaning (scrubbing of the filter) is required to maintain filter performance primarily with respect to maintaining satisfactory flow rates.

3.1.2 Pot Filters

The Potters for Peace (PFP) Filtron system consists of a colloidal silver-impregnated ceramic pot perched inside a collection bucket (Figure 4). The flower-pot shaped filter unit is approximately 17 L (4.5 gallons) in capacity and the lower storage/collection unit ranges from 7.5 – 20 L (2 to 5 gallons)[15]. Unlike the disk filters based on the TERAFIL and Low/Govinda Thimi examples which consist of two materials (ceramic disk and plastic/terracotta/metal containers) combined together, the PFP filter unit is fired as one complete unit. This eliminates the potential for leakage, which can occur through the interface between two different materials such as a ceramic disk and a metal container. Typical flow rates for the PFP Filtron range from 1.0 – 1.75 L/hr[16].

An analysis of the PFP filters by Daniele S. Lantagne included these relevant conclusions[b17]:

- Analysis using a scanning electron microscope found pore sizes typically ranged between 0.6-3 microns. The PFP goal is to achieve 1.0-micron pore size to physically remove E. coli without the need for disinfection (pg 33).
- The majority of the water appears to filter through the *sides* of the filter and not directly through the bottom. Lantagne's recommendation was to ensure proper application of colloidal silver along the sides of the filter to

[b] http://www.potpaz.org/pfpexecsum.htm

ensure that water passing along the sidewalls comes in contact with colloidal silver (pg 39).
- A prior study of the PFP Filtron done in 1984 found the flow rate to decrease by ~50% over a one-year period. Lantagne confirmed that regular scrubbing of the filter should help to rejuvenate the diminished flow rate (pg 39).
- A summary of historical data showed that the PFP filter was effective at removing 98-100% of the indicator bacteria present in the source water in laboratory testing (pg 58), but gave poor indicator bacteria removal in actual household practice.
- Studies of two-to-seven year-old filters show that the filters are still effective at removing microbiological contaminants suggesting that the colloidal silver may remain effective over extended periods of time (pg 58) (how effective still remains unknown).

The flow rate for every filter produced is measured for quality control before it is sold. The flow rate must fall within a specified range: a minimum for practical purposes (likely 1 L/hr) and a maximum to ensure that the water is in contact with the colloidal silver long enough to achieve disinfection (likely 2-4 L/hr) Filters with abnormally high filter rates indicate that cracks are present and as such, they are discarded.

A preliminary cost analysis of the PFP filter shows the total cost of producing one complete unit is approximately USD $6.00 with a wholesale price of USD $9.00. The wholesale price will likely depend on the quantity purchased; being lower for large orders. The price of the filter is roughly equivalent to the price of a machete, which is one of the most important tools required for work in rural areas of Nicaragua[18].

As a point of interest, the PFP website also has a one-page graphical summary demonstrating how to use and maintain their filters (Figure 5).

3.1.3 Candle Filters

Imported Indian candle filters are the most common type of ceramic water filter used in Nepal.[19] Candle filter units consist of two chambers and one or multiple ceramic filter elements, shaped like a thick candle, which is screwed into the base of the upper chamber (Figure 6). Water is poured into the upper chamber and then allowed to filter through the ceramic filter element into the lower collection chamber.

Candle filters can have very low flow rates, and thus it is common to find filter systems with two or three candle filter units. Recent laboratory tests on five candle filters completed at ENPHO in January 2003 (see Section 3.4) showed flow rates ranging from 300 – 840 mL/hr/candle.

3.1.3.1 Indian Candle Filters

A number of Indian companies manufacture ceramic candle filters (e.g.: Puro, Himal, Kimal, Swagat, and Milton)[20]. Typical retail prices for these filters in Nepal range from 600 to 1600 NRs (USD $8.00 - $21)[21]. Some Nepalese families purchase plastic buckets at 170 NRs (USD $2.22) and the Indian candle filter unit separately in order to reduce the overall costs.[22] A hole is drilled in the bottom of the plastic bucket and the filter element is screwed into place. The candle filter elements are most often made with white kaolin clay.

3.1.3.2 Nepal Candle Filters

Very few candle filters appear to be manufactured within Nepal. One example; however, is a white clay candle manufactured at Madhyapur Clay Crafts in Thimi by Mr. Hari Govinda Prajapati. The white kaolin clay used by Mr. Govinda Prajapati in the production of his candle filters is imported from India (Figure 7). The upper and lower containers are made of red terracotta clay from Thimi, Nepal. Each container has a holding capacity of approximately 10 L. The candle filter element is roughly 17 cm high and 5 cm in diameter.[23] The complete unit sells for approximately 312 NRs (USD $4.07). Madhyapur Clay Crafts sells the complete unit in bulk quantity to retailers for 175 NRs (USD $2.29) (140 NRs (USD $1.83) for the containers and 35 NRs (USD $0.46) for the candle filter element). Typical replacement time for ceramic candle filters is six to twelve months[24]. The filters must be periodically cleaned with a brushed to remove surface buildup of particles.

3.1.3.3 Swiss Katadyn Drip Filters

The Katadyn Drip filter is a candle filter manufactured by a Swiss company called Katadyn (Figure 8). Two versions of this filter, the Gravidyn and Ceradyn, currently retail for US $160 and US $190, respectively.[25] The current market for these filters is for use in cabins and base camp expeditions. The following table summarizes the specifications of these two Swiss filters.[26]

	Katadyn Gravidyn	**Katadyn Ceradyn**
Technology	0.2-micron ceramic impregnated with fine silver powder plus activated granular carbon granulate	0.2-micron ceramic impregnated with fine silver powder
Microbial/Chemical Protection	Bacteria, protozoa, cysts and chemicals	Bacteria, protozoa, cysts
Flow rate	4 L/hr (3 candles)	4 L/hr (3 candles)
Service Life	6 months	150,000 L (2-3 years)
Weight	3 kg	3.3 kg
Retail Price (3 filter units and containers)	US $159	US $189

3.1.3.4 Hong Phuc Candle Filters

A company in Vietnam currently manufactures and sells a product called the Hong Phuc filter that is visually similar to those sold by Katadyn. The Hong Phuc filter, including two containers and three candle filter units, retails for US $5.00[27]. First Water and Oxfam GB are currently testing the Hong Phuc filter in Cambodia.

Figure 2: Indian TERAFIL Ceramic Disk Filter

Picture Source: Low. 2002[28].

Figure 3: Terracotta Ceramic Filters Manufactured at Madhyapur Clay Crafts (Nepal, January 2002)

Picture Source: Low. 2002[29]

Figure 4: Potters for Peace Filtron

Picture source: Potters for Peace website (www.potpaz.org)[30]

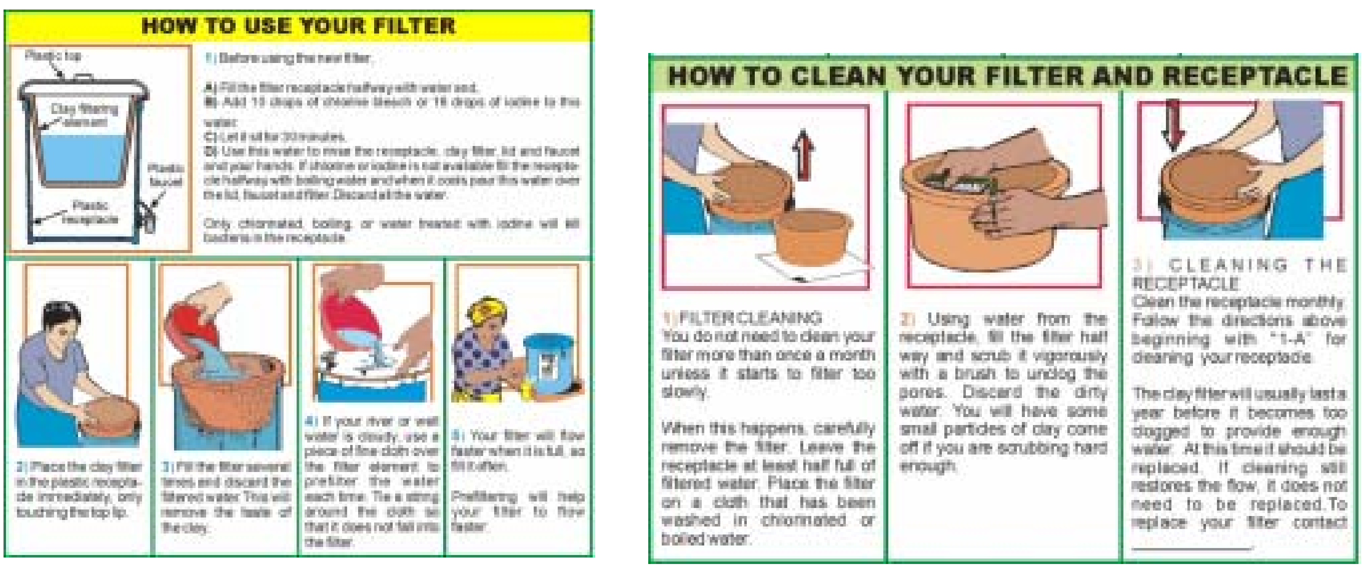

Figure 5: Potters for Peace Instructions for Use

Picture Source: Potters for Peace website (www.potpaz.org)

Figure 6: Indian Ceramic Candle Filter (BAJAJ)

Picture Source: Sagara. 2000[31].

Figure 7: Nepali Ceramic Candle Filter (Madhyapur Clay Crafts)

Picture source: Sagara. 2000

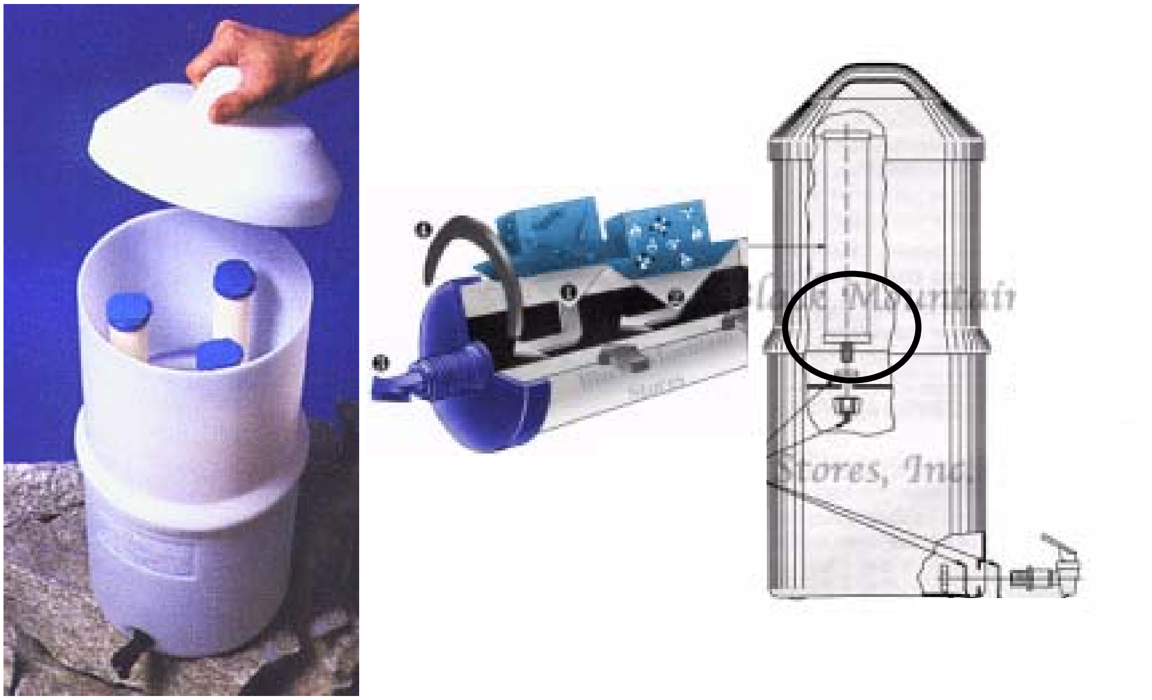

Figure 8: Katadyn Drip Filter

Picture source: Black Mountain Stores Website: http://www.katadyn.net/katadyn_drip.html

3.2 Expert Interviews

Our visit to Nepal was short, and this limited our ability to conduct thorough first-hand market research. Given more time, and better access to the Nepali countryside, CeraMIT would have conducted a complete market survey that elucidated current drinking water practices and desired product characteristics. However, this being impossible due to time and political constraints, the insights of several experts in the Nepali water situation and rural community characteristics were essential to our ability to quickly acquire as much information as possible. We are very grateful to these experts for sharing their time and knowledge.

3.2.1 Environmental and Public Health Organization (ENPHO)

ENPHO is a Nepali NGO with a fully equipped scientific laboratory that conducts environmental studies and training. ENPHO is the main partner organization to the MIT Nepal Water Project. ENPHO provided us with results of a prior study they conducted of ceramic filter users. ENPHO also provided laboratory facilities and support for our technical tests of ceramic filter media. ENPHO has played a central role in MIT Environmental Engineering's field studies in Nepal for several years, and provided CeraMIT with excellent support.

3.2.2 International Development Enterprises (IDE)

IDE is an international NGO that specializes in technology dissemination and business building. IDE Nepal has had success launching local entrepreneurs in the sale of human-powered irrigation pumps and a drip irrigation systems. IDE Nepal is the recipient of a $20,000 grant from the Development Support Foundation of New York via ceramics consultant Reid Harvey to study the feasibility of a low cost ceramic water filter project. The goals of this project overlap significantly with the goals of CeraMIT and ongoing ceramic filter research under the supervision of Susan Murcott. Consequently, IDE Nepal has been instrumental in CeraMIT's information gathering efforts during January 2003, and information has been shared freely between CeraMIT and IDE Nepal.

3.2.3 Nepal Red Cross Society and Japanese Red Cross Society

The International Red Cross is well known worldwide for its disaster relief and health education programs. The Nepal Red Cross works very closely with the Japanese Red Cross Society in providing these types of programs to the people of Nepal. We discussed our project with the Nepal Red Cross as potential customers (disaster relief) and as a potential promoter of our product through its health education efforts. They listed the following as desired product characteristics: light, durable, inexpensive, and easy to carry. The Nepal Red Cross Society would be willing to promote our product if it met with their approval.

3.2.4 Integrated Development Society (IDS)

Integrated Development Society (IDS) is a Nepali NGO, dedicated to improving the quality of life in Nepal by implementing sustainable community-based infrastructure development programs. IDS provided invaluable help in preparing our customer surveys and key suggestions for the overall marketing plan. IDS suggested that villagers will believe that saving money is more important than saving time, and suggested that we target schools and persons of status as potential early adopters of our product.

3.2.5 Gurkha Welfare Scheme (GWS)

The Gurkha Welfare Scheme (GWS) is a Nepali NGO that works to develop the home villages of retired Gurkha soldiers returning from careers in the British army Mrs. Bhim Kumari Aale, director of the GWS Water and Sanitation division, provided us with expert insight into conditions in rural villages surrounding Pokhara. She confirmed that the drinking water quality problem in the hills is severe, but for many villagers their first concern is quantity, especially in the dry season. She recommended that we partner with NGOs who do sanitation education. She also recommended that in marketing the product in rural areas, we contrast the filter with boiling as the filter will require less time and fuel, and therefore less money in the long run.

3.2.6 Mr. Poshan Nath Nepal

Mr. Poshan Nath Nepal is the former Secretary of the Ministry of Science and Technology. Mr. Nepal identified many key issues for our proposed filter. He believes that people will accept the product if it is inexpensive, easily transportable, and effective at microbial removal. He suggests that a disk shaped filter may be better due to a constant filtration surface area, and likely easier to transport. He estimates that at least 80% of villages are accessible by transportation. He also estimates the cost of boiling drinking water for the average Nepali family that uses electricity as a heat source is 600 NRs per year.

3.2.7 Department of Water and Sanitation Services (DWSS)

DWSS is the agency of the Nepali national government responsible for providing water and sanitation services to all of Nepal except for municipalities, which provide these services for their residents. Ram Mani Sharma informed us of a lime problem in the low hills, which would result in a hard scale that could clog our filtration media. Thakur Pandit directed us to a village called Naikap where filters had been distributed by the Conserve Nepal NGO a few years ago. We visited this village to evaluate their current situation.

3.2.8 Ms. Mangala Karanjit

Ms. Mangala Karanjit is the Chief of the Information Division of the Melamchi Water Supply Development Board. She is also a member of the board of the Federation of Business and Professional Women and one of two lead organizers of the 1998 2nd Women and Water Conference held in Kathmandu. Mangala identified one concern about the use of plastic; in traditional households during menstruation women are considered impure and everything they touch must be purified or discarded. Plastic could not be purified by flame; a metal container could. She also stressed the importance of ensuring that any gasket we use does not react with chlorine, as city water supplies are chlorinated.

3.2.9 Professor Subodh Sharma

Dr. Sharma is a professor in the Department of Biological and Environment Sciences at Kathmandu University. He has developed a portable lab kit, allowing him to analyze water samples for numerous parameters in the field. He has conducted sampling in many areas of Nepal and provided us with an excellent summary of the water quality problems facing Nepal. He will publish two papers on the subject in February, and estimates that of the rivers and streams he has sampled, that 85% are contaminated and that 70-75% of the springs he has sampled are contaminated. Another key comment he made is that sometimes villagers will not admit to breaking traditional practices (for example drinking collected rainwater), even though they do if they deem it necessary.

3.2.10 Lumanti

Lumanti is a Nepali NGO that is focused on housing and related concerns in Kathmandu. Lumanti made possible our survey of the Madhyanna Women's Group in Lalitpur Municipality #20, Kathmandu, a neighborhood group in a poor urban community.

3.3 *Field Research*

The January 2003 field research conducted was enlightening and played a significant role in leading us to the conclusions we ultimately reached. We are very grateful to IDE for arranging all of our rural field research, and to ENPHO and Lumanti for arranging our urban field research.

3.3.1 Kaun

Kaun is a village of approximately fifty households near a new India-built hospital in the hills outside Pokhara. We held a group discussion with nine women and two men, translated by Deepak Adhikari of IDE, and were accompanied by three members of IDE's Pokhara field office. Our discussion centered on current water use practices and related health issues. We received important first-hand information related to product design and marketing strategy.

Our discussion helped to identify and focus on some key product parameters. A typical 5 person family in Kaun uses 5-8 liters of drinking water each day, with a maximum of 10 liters in the hot season. At approximately 1-2 liters of drinking water per person per day, the filter may not need to be as large as we originally assumed (a 12 L size, as opposed to 20 L, may be sufficient to supply a family of five based on our observations of drinking habits). We also found that about 40% of the households in Kaun already had a filter, though only a quarter of those households (10% of total) used the filters. Complaints about the existing filters were that they had a low flow rate and were difficult to clean.

The villagers had several existing beliefs that will need to be addressed in any marketing effort. First, villagers do not like to drink "stale" water: water that has been left sitting in its container for too long. The definition of stale is hard to pin down, probably because it varies inversely with the scarcity of water. Villagers will use water collected the previous day, if it is kept outside overnight, but not for drinking. They usually keep drinking water in a covered container, but will leave it uncovered if using it soon.

This village claims to not have much difficulty with waterborne illnesses. One man estimated that he spent 40-50 NRs (USD $0.52-$0.65) per month on treatment of such diseases. Since these villagers do not have a significant problem with waterborne illnesses, they are unlikely to purchase a filter, but if they did have a problem, they say they would spend whatever was necessary to correct the problem. Also, they do already differentiate between water for drinking and water for other uses, which we were warned they may not. But, in more remote areas, this may not be the case, as Kaun has participated in some Red Cross educational efforts.

3.3.2 Retailer Interviews

While in Pokhara, we interviewed two storekeepers who sell existing ceramic filters. We were able to look at the range of available products and discuss with the storekeepers current sales information and customer behavior. Most of the storekeepers' customers are from the town of Pokhara rather than rural villages, but understanding the current market was helpful in planning for our larger target market.

In both stores, sales exhibit a strong seasonal pattern. Sales are 2-4 units per day during the rain season, when water sources have visible turbidity. During the remainder of the year, very few units are sold; one storekeeper estimated 2-3 per month in the cold season. The best selling units are between 13 and 21 liters in size. The aluminum filters are the lowest priced filters, between 360 and 580 NRs (USD $4.70 - $7.58) depending on size and number of candles. Stainless steel and copper filters are more expensive, ranging from 700 to 1800 NRs (USD $9.15 - $23.53). Each storekeeper prices the filters to earn 15-20% margin, as they may have to lower the price by 10% during haggling.

Both storekeepers would be willing to sell a plastic model. They said that it would have to be good quality plastic, and that the tap must not drip. One of the storekeepers actually improvised a plastic filter for some visiting foreigners, who preferred plastic to metal. One of the storekeepers expressed that Nepalis prefer metal because it is more durable, and also because they believe that plastic containers cause water to smell. The storekeepers also thought they could sell a disk shaped filter, provided that the seal was good and available as a spare part. One also thought the disk had good potential because the candles often break. She sells 20-30 replacement candles each month.

Current customers for ceramic filters often purchase the filters as wedding gifts. They tend to ask questions about the overall quality of the product, but very few ask about the effectiveness of microbial removal. Some customers will ask how to use and clean the filter. As a preemptive measure against product returns , one of the storekeepers teaches all customers how to use and clean the filter unless the customer claims to know already. People do not ask about the filtration rate, but many people we spoke with cite low flow rate as the reason they stop using the filters.

3.3.3 Begnas

Begnas is a lakeside village of 100 households in the hills of Kafki district, near Pokhara. We held a group discussion with two women and four men, translated by Deepak Adhikari of IDE, and were accompanied by one member of IDE's Pokhara field office. Our discussion centered on current water use practices and related health issues. This village had recently received a public water supply system, so we were able to contrast past and present practices.

Our discussion confirmed some ideas about product parameters. Villagers said that filter capacity should be 15-20 liters. They also expressed some concerns about plastic containers. Villagers currently use metal containers, and believe that plastic would be less effective at keeping water cool in the hot season. They joked that cool water is important, because Nepalis like spicy food.

Our discussion was useful in identifying important components of any potential marketing campaign. This village does have some trouble with waterborne illnesses among children and spends up to 2,000 NRs (USD $26.14) per household on medicine each year. They expressed that they would be willing to spend up to 500 NRs (USD $6.54) on an effective filter. When they are sick, they boil their water, and they do not like the taste of boiled water. One party to the discussion did have a filter and used it actively. He cleaned the filter weekly, without removing the candle, and has broken the candle twice.

3.3.4 Naikap

Naikap is a village of over 100 households in the hills at the western periphery of the Kathmandu valley. An NGO (Conserve Nepal), with the support of Susan Murcott, distributed 24 aluminum candle filters over a two year period (12 in 1999, 12 in 2000). We held a group discussion with 16 women and 3 men, all but 2 of which were participants in the filter program. This discussion provided an interesting perspective about longer-term use of ceramic filters.

Of the 24 households who received filters in the study, 14 were represented in our discussion. Two of these households were still using filters, though these were not the original filters. They purchased stainless steel filters to replace the aluminum ones. Approximately 75% of the filters stopped functioning properly during normal use. The women cited three modes of failure: broken candles, leaking taps, and aluminum corrosion. Three of the families bought new candles or new taps, which worked for a while but broke again; the families then stopped using the filters. Two families upgraded to the stainless steel filters, and continue to use them and are pleased with their performance. These two families observed health benefits from the original filter and decided it was worth spending the money on a better filter.

Like others we interviewed, the villagers at Naikap expressed concerns about the durability of plastic, and that water would smell if stored in plastic. They did say they would consider it if the product is consequently less expensive. Since they have experienced corrosion of the aluminum filters, the corrosion-free nature of plastic might be used as a selling point with them, and possibly as an example with others. We discussed with them the concern with women's "impurity" during menstruation raised by Ms. Mangala Karanjit and they felt that it did not apply to plastics, only to ceramics.

A new water source was developed a few years ago and since that time, villagers have noticed a significant improvement in the quality of their water supply. Five water samples were taken January 20th 2003 for testing:

- Two hitigah or dhungedhara wells[c]: Passl Tol Ward #8 and Jholaytol Ward # 9
- Upper and lower container of one ceramic candle filter unit
- Water source used to supply the majority of the village including the woman who owned the ceramic candle filter that was tested.

The results showed high microbial concentrations in the two wells:

Passl Tol Ward #8
- Total Coliform: 2130 cfu/100 mL
- E Coli: 74 cfu/100 mL

Jholaytol Ward # 9
- Total Coliform: 1660 cfu/100 mL
- E Coli: 5 cfu/100 mL

Negligible microbial concentrations in the ceramic water filtration unit:

Ganga Thapa's Water Filter – Upper Container
- Total Coliform: 1 cfu/100 mL
- E Coli: 0 cfu/100 mL

Ganga Thapa's Water Filter – Lower Container
- Total Coliform: 7 cfu/100 mL
- E Coli: 0 cfu/100 mL

And some contamination of the source water prior to treatment:

- Total Coliform: 127 cfu/100 mL
- E Coli: 2 cfu/100 mL

The water elevation in the 2 traditional walk-in wells was relatively low at the time of sampling since the women had already collected water in the morning. Apparently, the water level rises back up to the upper steps overnight. It is possible that the microbial contamination changes throughout the day as the water elevation fluctuates. Apparently 50 households use Passl Tol Ward # 8 well for drinking and 8-10 households use Jholaytol Ward # 9 well for drinking. Additional households use Jholaytol Ward # 9 when water is scarce elsewhere.

Five people live in Ganga's house where the ceramic water filter was located. The filter unit is approximately 1.5 years old. The filter was given to Ganga by Thakur Parsad Pandit, a drinking water engineer with the Department of Water & Sanitation who is also one of the founders of the small NGO Conserve Nepal.

[c] "walk-in" wells with stone steps leading into the well.

Ganga cleans the filter with boiling water and some salt once per week. She cleans the container with soap and water.

3.3.5 Madhyanna Women's Group

Madhyanna Women's Group is a group of 16 women responsible for households in Lalitpur Municipality #20 Nayag. We felt it was important to meet with a group of urban poor and incorporate their concerns into the filter design, as it was being considered as a secondary market for IDE's water filter project. Also, multiple experts identified Kathmandu water as the worst in the country, so this group may be the most in need of a low-cost water filter.

There were a few important differences between the members of this group and the villagers we interviewed. First, they have no concerns about using plastic to store water. Second, they seem to be much more price sensitive, quoting target filter prices of 100-200 NRs (USD $1.31 - $2.61), with a maximum at 300 NRs (USD $3.92). Third, they are the only group that expressed concerns about having enough space for the filter. Finally, they have significantly larger families; the smallest was the same as a typical village family (6 persons), and the largest was 18 persons. From these discussions, we see the importance of vigilance regarding keeping costs low, and a greater need for high filtration rate than we originally thought.

3.4 Laboratory Research

Three disk filters and five candle filters were tested by CeraMIT team engineer Rob Dies at ENPHO for microbial removal efficiency and flow rate. The tests were performed over a seven-day period starting January 12, 2003. All of the disk filters had the same dimensions, while the candle filters varied in shape. For different sets of filters, one or two of a given set of two or four respectively were coated with colloidal silver to test the effectiveness of colloidal silver as a biocide to reduce microbial contamination. The results of these tests are summarized below.

3.4.1 Ceramic Filters Tested

The following three types of disk filters were tested:

1. White Clay Disk Filter: Hari Govinda Prajapati
   - Made from white kaolin clay imported from India.
   - Two disks were not coated with colloidal silver and two were coated with colloidal silver.
2. Red Clay Disk Filter: Reid Harvey
   - Made from Thimi red clay grog and Thimi red clay.
   - Two disks were not coated with colloidal silver and two were coated with colloidal silver.
3. Black Clay Disk Filter: Reid Harvey
   - Made from Thimi red clay grog and Bhaktapur black clay.
   - Two disks were not coated with colloidal silver and two were coated with colloidal silver.

The following five types of candle filters were tested:

1. Swiss Katadyn Ceradyn Filter
2. Swiss Katadyn Gravidyn Filter
3. White Clay Filter without colloidal silver coating: Hari Govinda Prajapati
4. White Clay Filter with colloidal silver coating: Hari Govinda Prajapati
5. Vietnamese Hong Phuc filter

3.4.2 Material Setup

Uniform plastic buckets and taps were obtained from local shops for housing the disk and candle filters. The bottoms of the upper containers were cut to fit the filters. Candle filters required an approximately 15-mm (½-inch) diameter hole and were screwed into place with a plastic nut. The 152-mm (six-inch) disk filters required an approximately 108-mm (4 ¼-inch) diameter hole and were glued to the bottom of the buckets using silicone. Plastic lids were used to cover the upper containers. A layer of tape was put around the interface between the upper and lower buckets to ensure that the inside of the lower container was free of external contamination during testing.

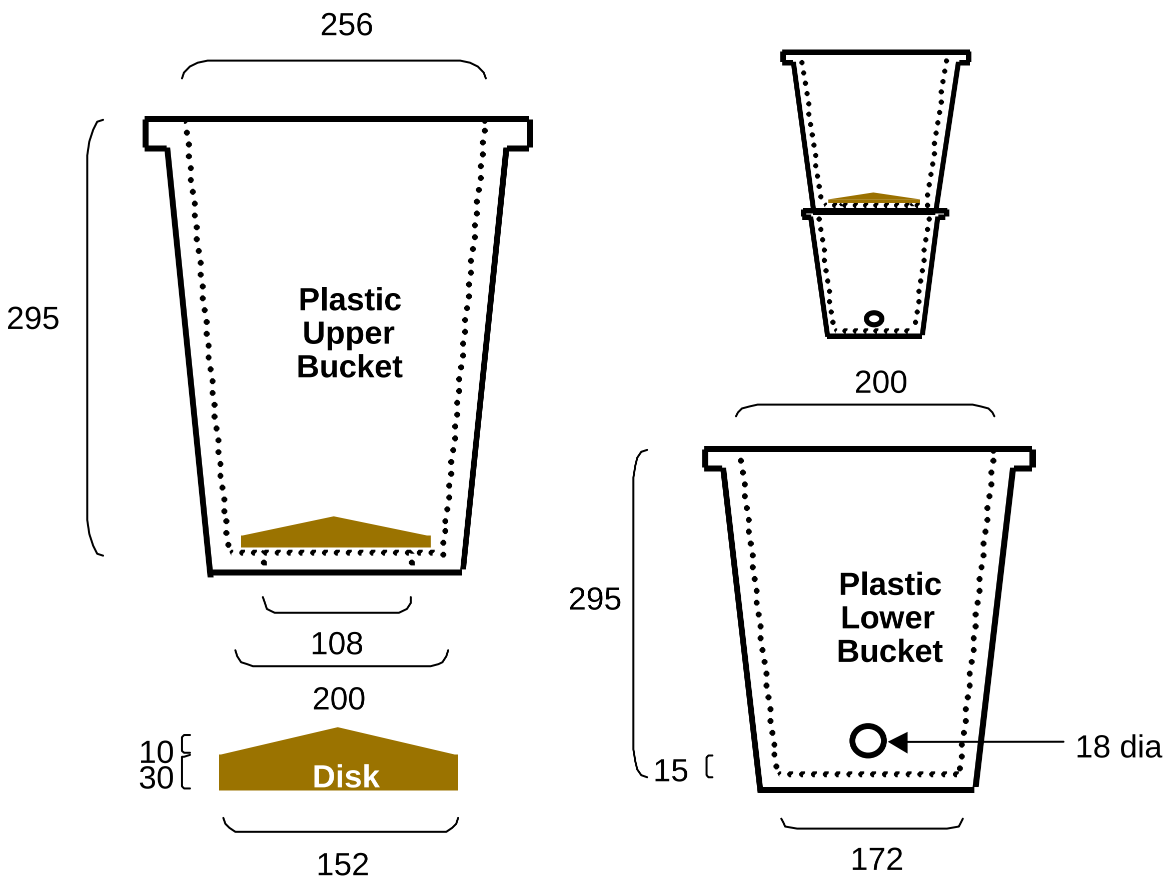

Figure 9. Schematic of bucket system used to house the ceramic disk filters during laboratory testing

3.4.3 Raw Water Preparation

ENPHO often uses water from the nearby Dhobi Khola River next to the bridge in New Baneswor to generate its raw water for water quality testing in their laboratory. For the SODIS project, ENPHO uses approximately 200 mL of Dhobi Khola River water per 20 L of tap water collected from the tap on the roof to create a microbial concentration of approximately 4,000 – 5,000 colony forming units (cfu)/100 mL.[32] The roof-top tap water originates from the municipal water supply.

The roof-top tap water was tested twice for the presence of coliform bacteria:

- January 12, 2003
  - total coliform = 3 cfu/100 mL
  - E Coli = 0 cfu/100 mL
- January 15, 2003
  - total coliform = 1,550 cfu/100 mL
  - E Coli = 0 cfu/100 mL

The large discrepancy in total coliform concentrations is likely due to the refilling of the rooftop reservoir, which occurred sometime between the first and second tests. It is possible that refilling the tank either brought in contaminated water or mixed the contents of the tank (the tank may contain sediments/organic material that is contaminated and settles over time) causing a spike in the concentration of total coliform.

The raw water for the two experiments with the disk filters was produced by mixing approximately 4 mL of river water (Dhobi Khola River) with 2 L of tap water to achieve total coliform concentrations on the order of 1,000-2,000 cfu/100 mL. The candle filter test had a lower raw-water concentration on the order of 100 cfu/100 mL due to a different mixing ratio of river water to tap water. The raw water was well-mixed in an 80-L plastic garbage pail for each experiment.

3.4.4 Testing Procedure

The filters were soaked overnight with tap water to ensure they would be saturated at the beginning of the test. In the morning, the buckets, taps, and lids were cleaned with soap and water (water from the roof tap) and allowed to dry completely in the sun for one to two hours. The filters were cleaned by lightly brushing an abrasive scrub brush over them. A sample from the Dhobi Khola River was collected and mixed with tap water in the 80 L garbage pail to get the desired raw water coliform concentrations. A raw water sample was then collected from the garbage pale. The upper bucket containers were then filled with the raw water to a height of ~240-mm for the candle filters and 170-mm for the disk filters. The time was noted.

A water sample was taken from each of the lower buckets after allowing the filters to operate for approximately three hours. The volume of water in the lower containers was measured every two hours using a 1,000 mL graduated cylinder. The residual water beneath the tap inlet was measured at the end of the test and added to the first flow rate measurement. Similarly, samples collected at the three-hour point were added to the appropriate volumetric measurements to ensure proper flow rate calculations. The average flow rate was then calculated by averaging the results over a four to six hour period depending on the test.

3.4.5 Microbial Testing Procedures

Standard methods were employed using a Millipore Membrane Filtration unit and Millipore mColi Blue broth to measure both total coliform and E Coli in terms of colony forming units (cfu) per 100 mL. The raw water samples were diluted approximately four times giving five plates in total (one blank and four plates representing four dilutions). The plate with the appropriate number of colony units (i.e.: 20-80) was used to calculate the final microbial concentrations. The remaining plates including the blank were used as checks (for example, the 10^3 dilution should have 10 times as many colonies as the 10^4 dilution).

The filtered-water samples were usually diluted one time giving three plates per sample (blank, 1:1 dilution, and 1:10 dilution). Typically, the 1:1 dilution plate count was used since the resulting microbial concentrations tended to be low (less than 100 cfu/100 mL).

3.4.6 Testing Results

The test results are presented on the next page. Graphs of the results are located in Appendix 2, Figures 12 through 17.

Disk Filter Test Results

Filter Name	Producer	Average Hourly Flow Rate	Total Coliform Bacteria Removal Efficiency	E Coli Removal Efficiency
White Clay Disk without colloidal silver	Hari Govinda Prajapati	377 mL/hr	99.2% (given raw water: 2,861 cfu/100mL)	99.3% (given raw water: 1550 cfu/100mL)
White Clay Disk with colloidal silver	Hari Govinda Prajapati	353 mL/hr	>=100.0% (given raw water: 2,861 cfu/100mL)	100.0 % (given raw water: 1550 cfu/100mL)
Red Clay Filter without colloidal silver	Reid Harvey	850 mL/hr	80.2% (given raw water: 2,500 cfu/100mL)	79.5% (given raw water: 1561 cfu/100mL)
Red Clay Filter with colloidal silver	Reid Harvey	756 mL/hr	99.8% (given raw water: 2,500 cfu/100mL)	99.9% (given raw water: 1561 cfu/100mL)
Black Clay Filter without colloidal silver	Reid Harvey	412 mL/hr	99.6% (given raw water: 2,500 cfu/100mL)	99.8% (given raw water: 1561 cfu/100mL)
Black Clay Filter with colloidal silver	Reid Harvey	341 mL/hr	99.1% (given raw water: 2,500 cfu/100mL)	99.4% (given raw water: 1561 cfu/100mL)

Candle Filter Test Results

Filter Name	Producer	Average Hourly Flow Rate	Total Coliform Bacteria Removal Efficiency	E Coli Removal Efficiency
Ceradyn Filter	Swiss Katadyn	641 mL/hr	100% (given raw water: 89 cfu/100mL)	100% (given raw water: 56 cfu/100mL)
Gravidyn Filter	Swiss Katadyn	844 mL/hr	100% (given raw water: 89 cfu/100mL)	100% (given raw water: 56 cfu/100mL)
White Clay Filter without silver colloidal	Hari Govinda Prajapati	742 mL/hr	84.3% (given raw water: 89 cfu/100mL)	99.7% (given raw water: 56 cfu/100mL)
White Clay Filter with silver colloidal	Hari Govinda Prajapati	678 mL/hr	100% (given raw water: 89 cfu/100mL)	100% (given raw water: 56 cfu/100mL)
Hong Phuc	Vietnamese Company	300 mL/hr	85.4% (given raw water: 89 cfu/100mL)	100% (given raw water: 56 cfu/100mL)

Note. The raw water concentration was < 100 cfu/100 mL, which is an order of magnitude lower than that used in the tests performed on the disks filters.

3.4.7 Discussion and Limitations

The results support the hypothesis that colloidal silver acts as a biocide and aids in the inactivation of indicator microorganisms such as total coliform and E Coli bacteria. As an example, the red clay disks painted with colloidal silver showed 99.8% removal of total coliform and 99.9% removal of E.Coli compared to ~80% removal of those two organisms for the same filter without colloidal silver. The significance of colloidal silver is that its use means that a higher flow-rate media can potentially be used (e.g.: a more porous disk filter) without sacrificing the filter's ability to remove microbial contamination.

The flow rates for the candles, except for the Hong Phuc filter, were comparable to the flow rates for the red clay disk filters ranging from ~650 to 800 mL/hr. The remaining disk filters (Black Clay Disks and White Clay Disks) and the Hong Phuc candle filter had relatively low flow rates: typically below 400 mL/hr. The low flow rate of the disk is due to the low porosity of the disks as well as its thickness. The thickness was approximately 40-mm which was originally thought to be rather thick. More experiments on varying disk thickness may provide insight into the effects of thickness on microbial removal efficiency and answer the question: "Does a thick porous disk perform better than a thin less-porous disk?"

It should be noted that the test results are limited to a 24-hour period within which they were performed. The results do not give any information on filter performance over an extended period of time beyond 24 hours. In order to evaluate filter performance over time, further testing both in the field and laboratory is absolutely necessary. In particular, long-term testing (weeks to months) is required to evaluate filter performance in terms of microbial removal efficiency and flow rate. Field testing is also necessary to evaluate performance under non-laboratory conditions.

4 Hari Govinda Prajapati

Hari Govinda Prajapati is a small-scale entrepreneur who lives and works in Thimi, a pottery community about 30 minutes outside of Kathmandu. He is the owner and managing director of Madhyapur Clay Crafts, a pottery shop on the Arniko Highway near Bhaktapur. He is also the chairman of the Nepal Ceramics Cooperative Society, a seven-year-old co-op that serves potters in the Kathmandu Valley and Janakpur in the Terai.

Hari shows an impressive knowledge of his craft, and an equally impressive understanding of the markets in which he operates. He is very intelligent and disciplined, and possesses solid business acumen. He understands the cost structure of his business very well, and has the experience and drive to grow his business in several areas.

He has also been working on water filters since before 1999 when the first MIT Nepal water project team made contact with him. He is the only ceramicist in Nepal, to our knowledge, with a ceramic water filter product. He has been indispensable in the study and experimentation required to find a good filter design. His experience and curiosity will continue to benefit this effort.

4.1 Madhyapur Clay Crafts

The majority of Hari's business comes from stoneware ceramics. His filter business is a relatively small portion of his total business. Annually, he sells 3,000-4,000 filter candles, and another 500-600 ceramic filter bucket systems. The vast majority of these are sold through original-equipment filter system manufacturers – the businesses that make the ceramic, aluminum, and stainless steel bucket systems. Hari's candle is popular with these manufacturers because it is cheaper than the imported Indian filters, but performs better than most. For instance, a cheap Indian import might sell for 40 to 55 NRs (USD $0.52-$0.72), while Hari sells his candle for 35 NRs (USD $.46). A Puro-brand candle sells for 60-85 NRs (USD $0.78-$1.11). In a test performed by a German lab, Hari's candle performed much better than the cheap candle, but slightly worse than the Puro.

Hari has sold a few candles as replacement parts through retailers in Kathmandu, but has not had a lot of success. These retailers have been marking his candles up to 55 NRs (USD $0.72) to improve their margins, and requests from Hari to lower the price have been ignored. He would like to grow this area of his business in the future.

Hari's current capacity is adequate for any short-term needs. With his media, he can manufacture up to 150 candles per day. With Reid Harvey's Pottery Purification Media (PPM), he can manufacture 100 candles per day, assuming he can solve some production issues. If Hari makes disk-shaped filters, however, he can make up to 200 units per day. Bottlenecks in his production process are mixing and drying. The drying issue is easy to solve, but to increase his mixing capacity would require either a larger or an additional mixer. If the market exists, he is willing to make this investment.

If his customers want a 6-inch disk that is not coated in colloidal silver (CS), he can supply disks made with his media for about 30 NRs (USD $0.39), and those made with Reid Harvey's media for about 42 NRs (USD $0.55). Adding the CS will add cost, but the additional cost would be identical regardless of media chosen.

Hari would like to be a national distributor of filter systems. He believes that he can build and maintain relationships with potters and retailers outside of the Kathmandu Valley, and he also has the ability to build up the capacity of his business to virtually any size necessary, as long as the market exists. He would also like to be the assembler/distributor of any product that is ultimately made. He thinks he has the distribution network to perform well in this role.

4.2 Nepal Ceramics Cooperative Society, Ltd.

In his role as a founding member and Chairman of the NCCS, Hari has built a solid cooperative society that serves its members in a variety of ways. It was started in 1995 with 25 members, and has since grown to 39 members. Initially, it provided its members with working capital and purchasing power, but it has grown in scope as well as size.

The co-op currently provides its members with several benefits. First, each member is required to invest in the cooperative every month. This amount is pooled and loaned to members at a prescribed interest rate. Thus, the members have access to a line of credit to use in running their business. The co-op also purchases supplies on behalf of the members in large quantities, thus getting them cheaper. Twice per year, 2 members go to India to purchase supplies and any machinery that members need. The supplies are stored in the co-op's building, and sold to members at slightly over cost.

The organization also provides training for its members. New skills, such as glazing, are taught to members so that they can provide wider product lines that compete with new materials such as plastics. The co-op also provides administration expertise. There are 3 full-time employees that assist members with business that they conduct outside the Kathmandu Valley – especially in cross-border transactions.

The scale of the co-op also provides access to materials that would otherwise not be available. They can, for instance, keep a stock of glazes or chemicals that would be inefficient for an individual potter. Or they can purchase a machine for the use of members that would otherwise not be affordable. As the co-op grows, these benefits will only increase (provided that it does not grow beyond their ability to manage it efficiently).

5 Recommendations

Our field research was too limited to provide statistically significant data; however, it has given us enough background and insight into our customers' opinions that we feel comfortable making a number of recommendations, which fall into four major categories:

(1) **Filter Design**, where we discuss two design ideas and their pros and cons;
(2) **Business Organization**, where we discuss how the product should be produced, assembled, and distributed;
(3) **Marketing Methods**, where we offer suggestions on how to prepare the population of Nepal for this product, and how to present it to them when it is ready for sale; and
(4) **Recommendations for Future Work**, where we explore the further work that needs to be done to ready this filter product for market, as well as more research that must be done to make the design more efficient and robust.

It should be noted that these recommendations are being made based on preliminary scientific research and three weeks of field research. More study is warranted on most points, and these recommendations should be considered preliminary, and contingent on further scientific research.

5.1 Filter Design

In general, we have come up with several attributes that any filter design should incorporate. These attributes are:

Media	System
• Low cost • High flow rate (2L/hr minimum) • Disk filter unit, 9" diameter • A candle filter unit for legacy systems • Durable – particularly when cleaning with a semi-abrasive brush/cloth. • Easy to maintain & clean • Complete seal between the media and the system.	• Low cost • 20 L capacity or more • Bucket material should not affect taste or smell of water • Light and durable • Easy to carry • High-quality tap (no leaks) • Compact for transport & storage (one bucket should fit in the other) • Lid to cover the top bucket • Optional stand • Easy to maintain & clean

5.1.1 Primary Filter Design.

Given these general design parameters, we have devised, aided by the staff at IDE, a primary filter design **(see diagram)**

[Diagram to be inserted here]

Figure 10: Primary Filter Design

This design incorporates a 9" disk filter element sandwiched between two plastic buckets of 10L capacity each.

The filter element itself should be made out of whichever medium proves most effective in subsequent testing (see Section 3.4 on Laboratory Testing). Our initial testing data shows that the colloidal silver has performed well, and that its use could allow for a more porous filter element that could increase flow rate substantially. Therefore, it is our recommendation that the disk be soaked in a CS solution of a strength to be determined through further testing and refinement. Of primary importance is finding the proper mix between pottery medium, CS concentration, and flow rate (Section 3.4).

The filter element is surrounded by a tire-shaped gasket that covers the entire outside edge of the disk. This gasket should be made of a soft, compressible, and waterproof rubber. The seal between the buckets and the filter element is formed by squeezing the two buckets together and compressing the gasket on the top and bottom of the element. The type of rubber chosen should not react harmfully with chlorine, or affect the taste or smell of the water. Also, this gasket should be available as a spare part, along with replacement filter disks.

The buckets would be best if made out of a transparent plastic, ideally #7 (PET), that is thick, durable, and does not affect the taste or smell of the water. The areas that provide support for the filter element should be of sufficient strength to handle the compression load as well as the weight of 10L of water in the upper chamber. If #7 plastic proves cost prohibitive, then our next preference would be a translucent high density poly ethylene (HDPE) plastic similar to that used by Katadyn. A last resort would be a thick but opaque plastic, white in color. Durability, as well as taste and smell attributes of the filter are key, however, and should not be compromised.

The lid should be made of the same material as the buckets, and fit snugly over the top bucket, but should be loose enough to be easily removed with one hand.

The four clips on the side can be of various designs. One option would be to use a spring clip that will flex and provide the proper clamping strength. Another would be to use a ski-boot-style cable system. Still another could incorporate a latch similar to the spring clip, but instead use a rubber shock cord to attach to the upper bucket. These should be evaluated based on clamping strength, durability, and cost.

The tap should, above all else, be durable. Several of the people we interviewed complained of leaking taps, and replacement is expensive and frustrating. Either metal or plastic designs would work, but a flip-style would probably be preferable to a spinning ‘faucet-style’ handle. If a faucet style is deemed best, the handle should not rotate more than 90 degrees from opened to closed and, if possible, keep the tap short enough to fit into a square cardboard box for packaging purposes.

This design is relatively simple from the user’s standpoint. We feel that the typical Nepali would be able to operate the system with minimal instructions, and with a low incidence of failure. Also, this design makes it very easy to clean the filter; one simply removes the element by flipping up the 4 spring clips and removing the top bucket, and then scrubbing the element in a bucket of clean water. It would be very simple and cheap to replace the filter and/or gasket, as well; no need to replace any part that is still in working order. In addition, the rubber gasket will help to protect the disc from chipping and breaking during handling.

Cost Analysis. This filter design is probably too expensive for our target market. However, since we had literally nothing in the way of supplier cost estimates, we decided to keep it as our primary design alternative until definitive cost information is available. That said, we attempted to estimate, based on our limited knowledge of the Nepali manufacturing industry, what it would cost to produce and distribute. *Note: these numbers are very preliminary.*

Part	Est. Cost (NRs)	Est Cost (USD)
Top bucket	80	1.05
Bottom bucket	90	1.18
Lid	25	0.33
Gasket	40	0.52
Filter disc (9”), incl. CS	70	0.92
4 spring clips or equivalent (15 ea)	60	0.78
Tap	35	0.48
Material Cost	400 NRs	5.23 USD
Assembly	15	0.20
Shipping (representative)	30	0.39
Packing (no box)	5	0.07
Cost to Retailer	450 NRs	5.88 USD
Retailer markup (15%)	68	0.89

Cost to Customer	518 NRs	6.77 USD

If this cost analysis is reasonably accurate, some modifications will have to be made in the design to make it affordable to our target market.

Cost Reduction Suggestions. We have several suggestions for getting the cost of this product down to a more reasonable level. Several are fairly easy, and maintain the same design.

Using a cheaper bucket material (either translucent or opaque) as discussed above could save 20-50 NRs (USD $0.26-0.65) per filter. Also, if testing proved this viable, reducing the number of clips from 4 to 3 could yield a 15 NRs (USD $0.20) savings. Designing a cheaper lid with thinner and/or cheaper plastic and a simpler design could also yield up to 15 NRs. Perhaps a cheaper material could be found for the gasket, as well, saving up to 10 NRs (USD $0.13). Also, slightly more drastic, we could eliminate the tap and replace it with a 10-cm rubber hose and a clamp, saving as much as 25 NRs (USD $0.33).

Implementing all of these changes could potentially yield 115 NRs (USD $1.50) in savings, bringing the final cost to the customer down to 385 NRs (USD $5.03). However, the functionality of the design would be significantly degraded, most notably through the absence of a tap. For this reason, we have another design idea that we believe is more appropriate.

5.1.2 Secondary Filter Design.

This design eliminates the compression-type fitting for the filter element, replacing it with a screw-type design. As shown in Figure 17 below, this design eliminates the gasket and the spring clips, replacing it with a new plastic part.

[Secondary design diagram to be inserted here]

Figure 11: Secondary Filter Design

The same 9" filter element is permanently fixed to the new plastic part with white cement. This part is screwed onto the bottom of the upper bucket, creating a tight, waterproof seal. The upper bucket/filter assembly is then placed on top of the lower bucket. When cleaning the disk, one removes the top bucket, unscrews the plastic assembly, and scrubs the disk in a bucket of clean water (alternatively, you can scrub it without removing from the top bucket, as well). To replace the disk, one removes the disk/plastic assembly and discards, and purchases another from a local store. It may eventually be possible to reuse the plastic part to which the filter is attached.

Eliminating the gasket and spring clips will eliminate about 100 NRs (USD $ 1.31) in cost, but the new plastic part will probably add about 40 NRs (USD $0.52), for a net savings of 60 NRs (USD $0.78). However, when used in combination with some of the other cost reductions above, we think a product with a retail price of 350-400 NRs (USD $4.58-$5.23) is well within reach. We would only eliminate the tap as a last resort.

The final bucket design should be chosen based on its technical performance, durability, ease-of-use, cost, acceptability to the target market, transportability, social acceptability and overall sustainability.

5.2 Business Organization

Distributing a product in Nepal is no small task. Geography, lack of infrastructure, and certain cultural phenomena all work to make commerce difficult. We have approached a production and distribution plan for this water filter in two phases. Phase 1 is designed to get relatively small volumes of the product produced and sold in easily-accessible locations throughout the country. Phase 2 is designed to handle larger volumes and get them to villages farther away from major cities.

5.2.1 Phase I.

Initially, we should tool up, train, and monitor one supplier for each part of the filter product. The obvious choice for filter production is Mr. Hari Govinda Prajapati. As mentioned in Section 4, Hari is the most experienced filter manufacturer in Nepal, and has worked extensively with MIT since January 2000 to develop this product. Suppliers for the plastic and rubber parts have not yet been located, but producers of those parts should have no trouble meeting any volume requirements that we may have.

Once suppliers for the parts are lined up, we will need an assembler/distributor for the filter kits. Hari has expressed an interest in performing this role, and we see no reason to send that function elsewhere. Hari has the business acumen and experience to handle this new responsibility, and if he assembles the final kit, it would minimize the handling of the filter disks, the only fragile part of the kit. In exchange for this service, Hari will charge a handling and assembly fee. It is the opinion of our team that this fee not exceed 15 NRs (USD $0.20) per filter, and perhaps be significantly less. Assembly should take no more than 2 or 3 minutes per filter, so a single worker should be able to assemble up to 200 in a day.

Packing is the next concern. A box large enough to hold this filter, complete with label, would cost between 30 and 50 NRs (USD $0.39 – $0.65). For this reason, we think we should forgo a box, and ship without a container. We have designed the filters such that the buckets can be placed inside one another, and in them we can ship the tap, a cleaning brush, and any literature we want to include. The packer would then place the lid on top and tie the bundle in such a way that the buckets would not separate, and the lid would not come off. You could then place several of these in a large sack, and ship to dealers throughout the country.

Shipping is also a major cost issue. Selling systems in the Kathmandu Valley will not be terribly difficult, but getting filters to the Terai, Pokhara, or smaller villages in far-away areas of the country can be prohibitively expensive. Creative methods for shipping must be found, such as sending on a grain truck that is returning to the Terai after dropping off a load, or shipping on the top of a public bus.

Whatever product design is shipped, we have to have a retailer or distributor to receive at the other end. During Phase 1, it seems to make the most sense to use potters to sell the filters in distant parts of the country. While the volume is still low, potters should be able to either sell through their own shops, or pass on to local retailers to sell. This is another area where Hari's position as distributor will be valuable. In his capacity as director of the Nepal Ceramics Cooperative Society, he can get potential retailers to join NCCS, and in that way, he can both provide them with capital to fund inventory, as well as keep a solid financial relationship with them (in other words, he'll have leverage to make sure they pay). These potters would then have access to all the benefits that NCCS provides its members, as well.

In the Kathmandu Valley, Hari can probably handle the shipping and distribution without going through NCCS. He can expand his network of retailers in Kathmandu and the surrounding areas as he sees fit. He can also, of course, sell through his shop, as well. Hari is already well-known and respected in the area for his filters; he seems to be the best person to introduce a new technology to the local market.

This business arrangement will probably work well for a least a year, perhaps much more. But as the volumes grow larger and the customers get farther away, it may be time to go to Phase 2.

5.2.2 Phase 2.

This phase begins with training another ceramicist to manufacture the filter discs and possibly filter candles. It will probably make sense to have a second expert trained and producing filters, just in case Hari decides to exit the business. Also, if we had a manufacturer in another part of the country (say, the western Terai), we could probably reduce shipping and handling costs somewhat.

If the filter is a big success in a particular area, it may be necessary to further develop the distribution network in that area. For instance, it might be necessary to stop working through the local potter, and hire a full-time distributor to manage the product demand at all the retailers in the region. Ultimately, our goal is to create a competitive market for these filters that keeps the price low enough for all to afford them.

It will also eventually be necessary to begin aggressively selling in the Hills and other rural areas of the Terai and Himalayas. These areas will be much more difficult to efficiently sell to, and a new distribution network will have to be created that targets low-population-density areas of the country. As this is a long way off, we won't address the specifics at this point.

5.3 Marketing Methods and Tips

Developing a detailed marketing plan is premature at this point because we don't yet have a final product design, and we have yet to test any prototypes in the field. However, in our discussions with various NGOs and potential customers, we did pick up several pieces of advice that we would like to pass on:

Plastic Construction. Be sure to inform the customer of all the benefits of plastic construction. The average Nepali has a negative impression of plastic containers in general; they think plastic is flimsy, high-maintenance, and makes the water smell and taste bad. It is important that they understand that a high-quality plastic has none of these traits; it lasts for years, it won't taint the water, and it is easier to clean than aluminum or stainless steel. Not to mention lighter to carry. During our field research, we found that a useful illustration tool is bottled water; those bottles keep water safe and untainted for months at a time.

Filtration Advantages. Also, it will be useful to explain the virtues of having a filter in general: saving money, saving time, protecting health, and reducing turbidity. First, using a filter *saves money.* Most Nepalis spend much more on unnecessary doctor bills, medicine, and fuel to boil water in a year than it would cost to purchase a filter. Second, it *saves time.* If your household is boiling water, the filter is a fantastic way to reduce your workload. Third, it reduces incidence of several types of waterborne illnesses, including diarrheal disease and eye infections. Fourth, they filter out turbidity in the water.

Spring Water Quality. It was surprising to us how many people thought their springs were clean. Tests have shown that about 75% of the springs in the country are contaminated[33]. People think that because they can't see contamination, the water is safe to drink. This isn't the case, and they need to be taught that.

Filter Quality. When people are shopping for a filter, they don't even *ask* about flow rates, microbe removal, or filter life. Their main concern is cost. They need to know that our filter is better in those areas of providing high quality and safe drinking water. Along those same lines, very few people realize that the filters available on the market are not filtering out all of microbial contamination. They need to be told that these candle filters are not 100% effective, and that our product is superior.

Cleaning Misconceptions. Also, some get the impression that when a filter looks dirty, it is no longer cleaning the water (so people drink raw water instead). This misconception needs to be corrected. People also carry the opinion that all filters have slow flow rates, and they're difficult to clean. They should be informed of the improvements we have made in those areas.

Branding and Status. In terms of general marketing information, we think it is important to have a strong brand name associated with this product, and to protect it at all costs. Coca-Cola's bottled water product in Nepal has "100% Trust" printed on the bottle. That's the type of reputation this new filter brand should strive to earn. Several people we spoke to thought we should initially position the filter as a status product; sell to people who are respected for their position and intellect first. Then concentrate on schools and schoolteachers.

Role of NGOs and Women. It would be useful if we could get several NGOs to help promote the product and build up trust in the brand. Not only will they get more filters out to customers, but their recommendations will help to bolster the brand name. Also, we should approach the Red Cross to see if they would be willing to officially endorse the product, provided that we have all the scientific and testing data to back up our claims. In addition, we should investigate the use of a presence/absence test as a sales tool. Given that the vast majority of the users of these filters are women, it's important that any advertising or recruiting efforts are tailored to women.

These observations should give a feel for the types of issues that will arise when attempting to sell these filters. One thing is clear: education is going to be a very large part of any campaign to sell this product. The customers have to understand first why they need a filter at all, and then why ours is superior to the others on the market.

5.4 Recommendations for Future Work

It is the opinion of CeraMIT that the water quality problem in Nepal is an acute problem, and must be addressed with urgency, while ensuring that the solution is correct and complete in terms of technical performance and social acceptability.

The following recommendations encompass future work that we believe must be done by any organization(s) that may attempt to promote a ceramic filter as a point of use drinking water treatment solution.

Collaboration: CeraMIT is aware of four organizations committed to working towards ceramics based point of use water treatment solutions in Nepal.

- The MIT Nepal Water Project has four years of experience studying the drinking water quality problem in Nepal, and the viability of a ceramic filter as a point of use water treatment solution.
- ENPHO has been a partner to the MIT Nepal water project for three years and has more than ten years of experience working with water issues in Nepal.
- IDE Nepal has recently begun a project to develop a low cost ceramic water filter to be marketed in the hills of Nepal. IDE Nepal has considerable experience marketing appropriate technologies.
- Madhyapur Clay Crafts (Mr. Hari Govinda Prajapati) is, to our knowledge, the only ceramics cooperative actively manufacturing ceramic water filters within Nepal.

CeraMIT sees these four organizations as sharing the goal of providing the people of Nepal with clean drinking water in a sustainable manner using ceramic technology. CeraMIT also believes that these organizations have complementary skills and resources, and consequently, that a well-structured collaboration among these organizations would lead to the best product becoming widely adopted in Nepal, and perhaps beyond.

CeraMIT also believes that more detailed understanding of water quality issues in Nepal could be obtained by exploring joint studies between MIT and Dr. Subodh Sharma of Kathmandu University.

Prototype Testing: Thorough testing must be done of several prototypes before the first field pilot test. This should include systematic testing for durability, seal effectiveness, effectiveness of microbial removal, flow rate, ease of use, and social acceptability. Such testing will ensure that the product for the initial field pilot test has the best chance of performing as desired and being marketable. This testing must be complete enough to provide statistically significant data about variability of the filter media, and long enough in duration to provide information about changes in filter (and if included, colloidal silver) performance over time. An organization with substantial laboratory facilities such as ENPHO or MIT would be best suited to conduct this testing.

Field Testing: In addition to marketability testing, field testing should include monitoring of the filter's microbial removal effectiveness, turbidity, flow rate, and presence of colloidal silver (if applicable). Field testing should encompass both the rainy and dry seasons.

Colloidal Silver: If colloidal silver is used in the product, the production of colloidal silver should be done using a controlled and easily reproducible process. This may be done best in a laboratory environment by an organization such as ENPHO, or by the dilution of the Microdyn product, as is done in the manufacture of the Potters for Peace filter in Nicaragua.

The MIT Nepal Water Project team began investigations of colloidal silver in 1999 and 3 studies have been carried out at MIT to date (Sagara, J. 2000, Lantagne, D, 2001, R. Hwang, 2003). Further studies by an MIT Chemistry or Chemical Engineering student could prove quite useful in understanding its manufacture and its role in microbial inactivation.

Design Improvement: Throughout the testing process and early marketing of the product, research should continue into materials and refining the initial design to reduce costs and improve performance. Specifically, finding the optimal combination of which clay is used, filter element thickness, porosity, diameter, firing temperature, and CS concentration will ensure that the product provides the best flow rate with the appropriate level of microbial removal.

Product Line Expansion: There are several opportunities for product line expansion that should be investigated in the future.

- Investigate the possibility of using ceramic buckets for the Terai. Though ceramics are more variable and difficult to transport, they may prove to be more marketable because of lower cost and insulating properties. This investigation might alternatively be included in a market study conducted by a team of MIT Sloan students.
- Very conservative households would like a metal bucket so that it can be purified by flame if it is touched by a woman who is menstruating. A metal bucket may also be preferred by wealthier households and offer greater profit opportunities.
- Larger families might prefer a larger capacity, especially if we get the flow rate up to 3.0L/hr.
- As mentioned above, we need to have a candle product to sell to people who already own candle filters (taking Hari's current candle and coating with CS may be sufficient).
- We should continue to look into an ultra-low-cost filter (150 NR or less).

Women's Involvement: Our field studies indicate that the primary users of the product will overwhelmingly be women. It is likely that women will also be the primary decision makers in purchasing the product, given its function and low cost. Women's input must systematically be incorporated throughout management development and marketing of the product.

Further Ceramics Study: The MIT Nepal Water Project team has done 4 years of study on the effectiveness of ceramic filters. However, a study on the ceramic formation process by an MIT Materials Science student is needed.

Project Gantt Chart: We have attached a Gantt chart in Appendix 4 to help provide some guidance on achieving important project objectives over the next few years. The chart is divided into four sections: prototype design and construction, field testing, production design finalization, and marketing/ distribution. Field testing is to be carried out throughout the life of the project and into the future to ensure the design is continuously improved. It is envisioned that a production-ready design will be finalized by early April 2004 and production will begin later that month.

6 Conclusion

We believe that the water quality problem in Nepal, and throughout many regions in the world, is an urgent one. Having access to safe drinking water is a basic human need that goes unfulfilled for much of the world's population. Our purpose with this study was to try to develop a solution in Nepal that could be replicated in other areas of the world, one that meets our criteria of low cost, effective microbial removal, and social acceptability. Given the short nature of this project, CeraMIT cannot participate in the implementation of these recommendations. However, we believe that action needs to be taken to address this problem quickly, without compromising the quality of the solution.

With this report, we have studied this problem and outlined what we think are some appropriate actions to take to reach an effective solution. There are many constituents currently involved in this project, and each has its own areas of competence and experience. We hope that all of the organizations with interest in solving this problem will recognize their own strengths and weaknesses, and the resulting opportunities to complement each other, and work together effectively in reaching and disseminating the best solution as quickly as possible.

Appendix1 : Contact Information

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Appendix 2: Disk Filter Testing Results

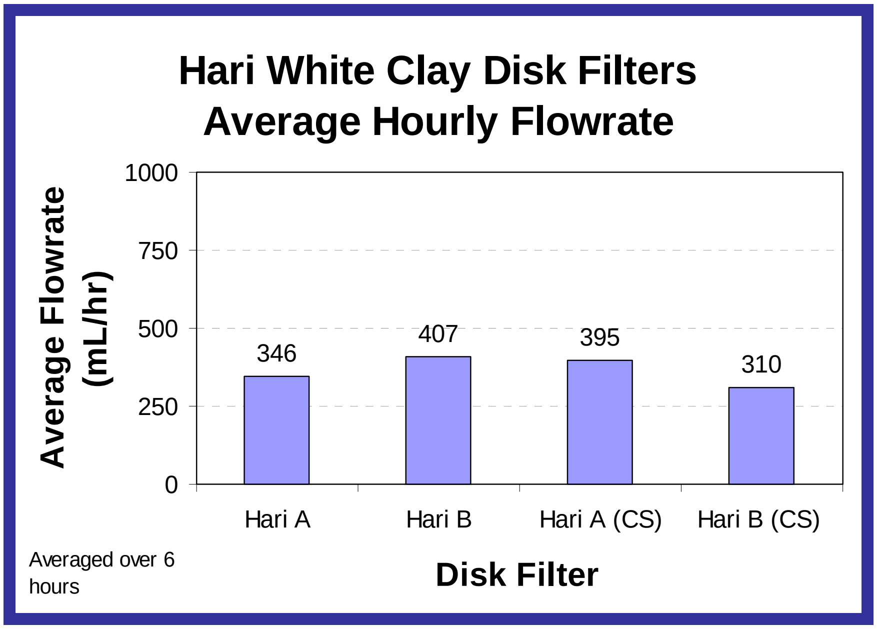


Figure 12: Average Hourly Flow rate - Hari Govinda Prajapati White Clay Disk Filters

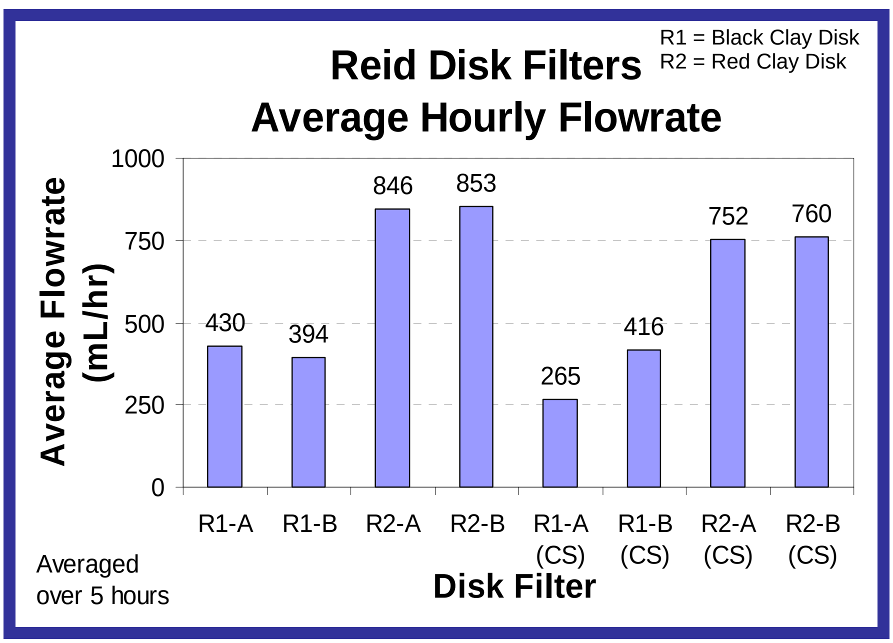


Figure 13: Average Hourly Flow rate - Reid Harvey Disk Filters

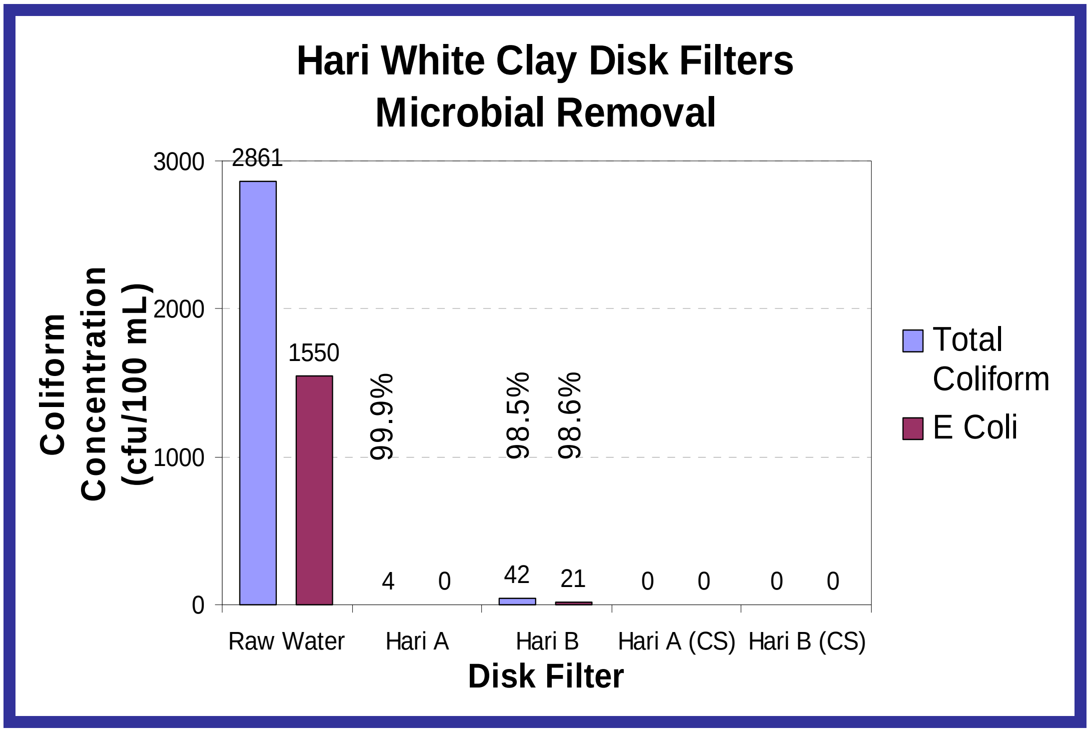


Figure 14: Microbial Removal Efficiency – Hari Govinda Prajapati White Clay Disk Filters

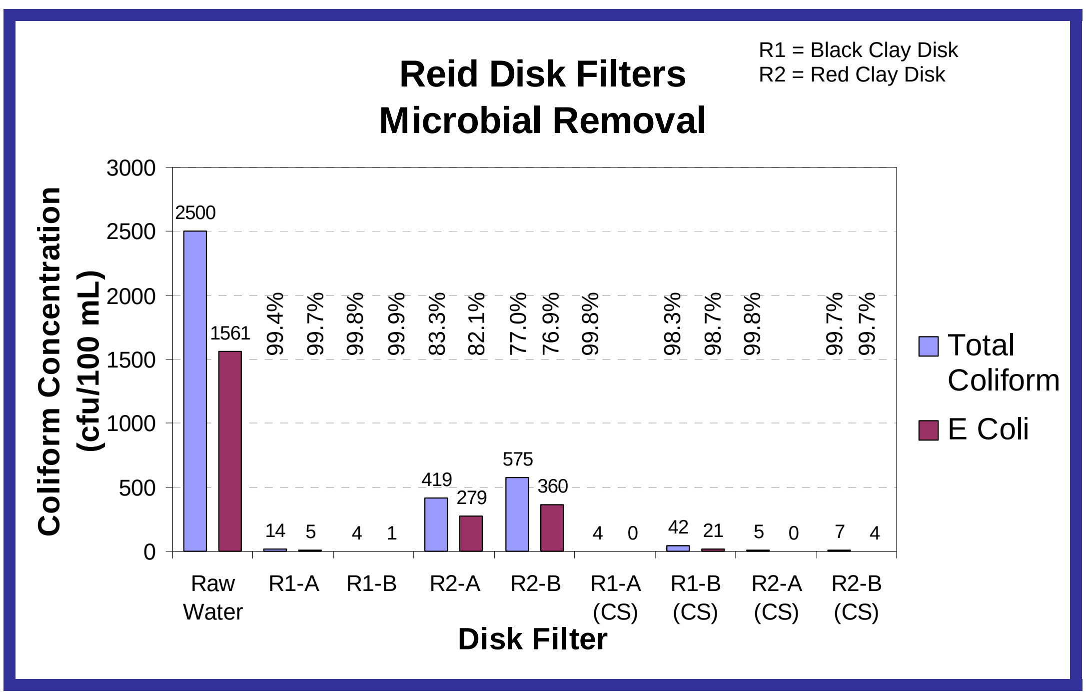


Figure 15: Microbial Removal Efficiency - Reid Harvey Disk Filters

Appendix 3: Candle Filter Testing Results

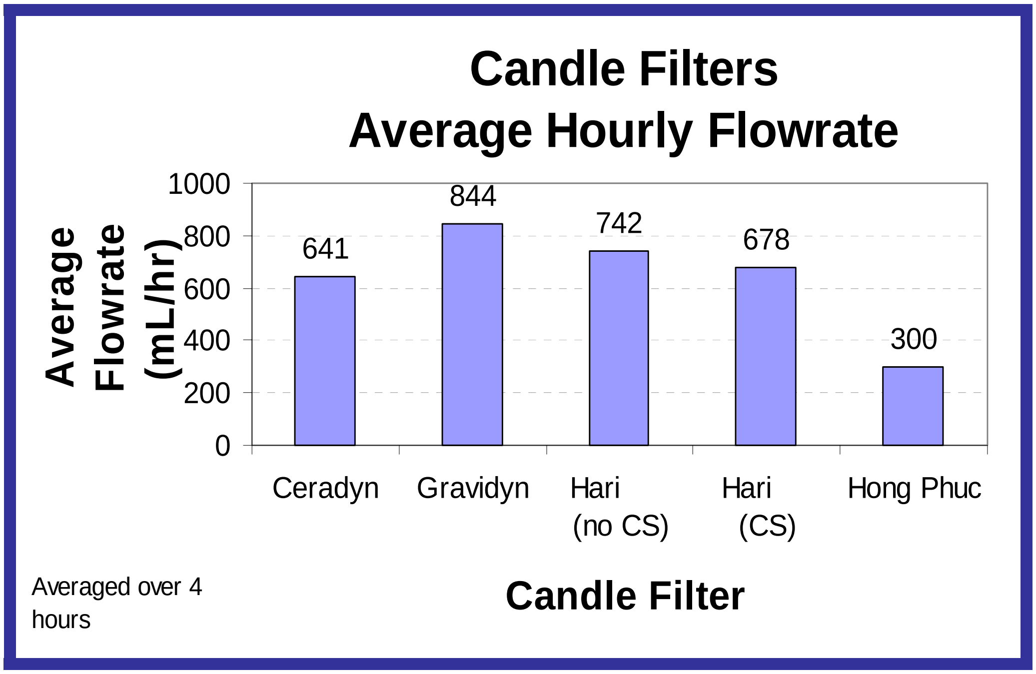


Figure 16: Average Hourly Flow rate - Candle Filters

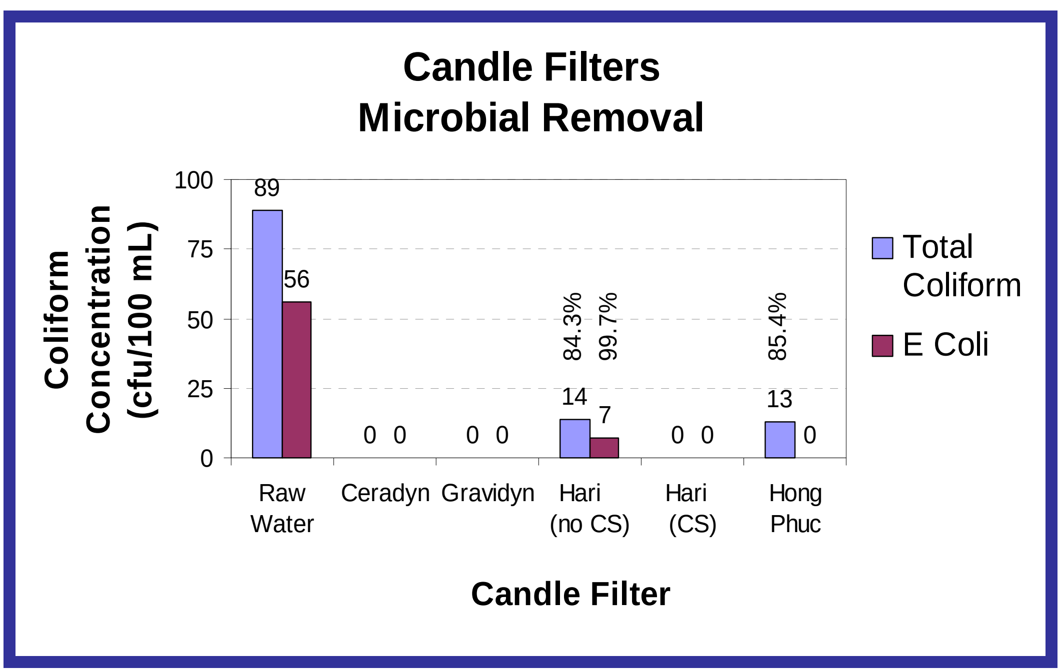
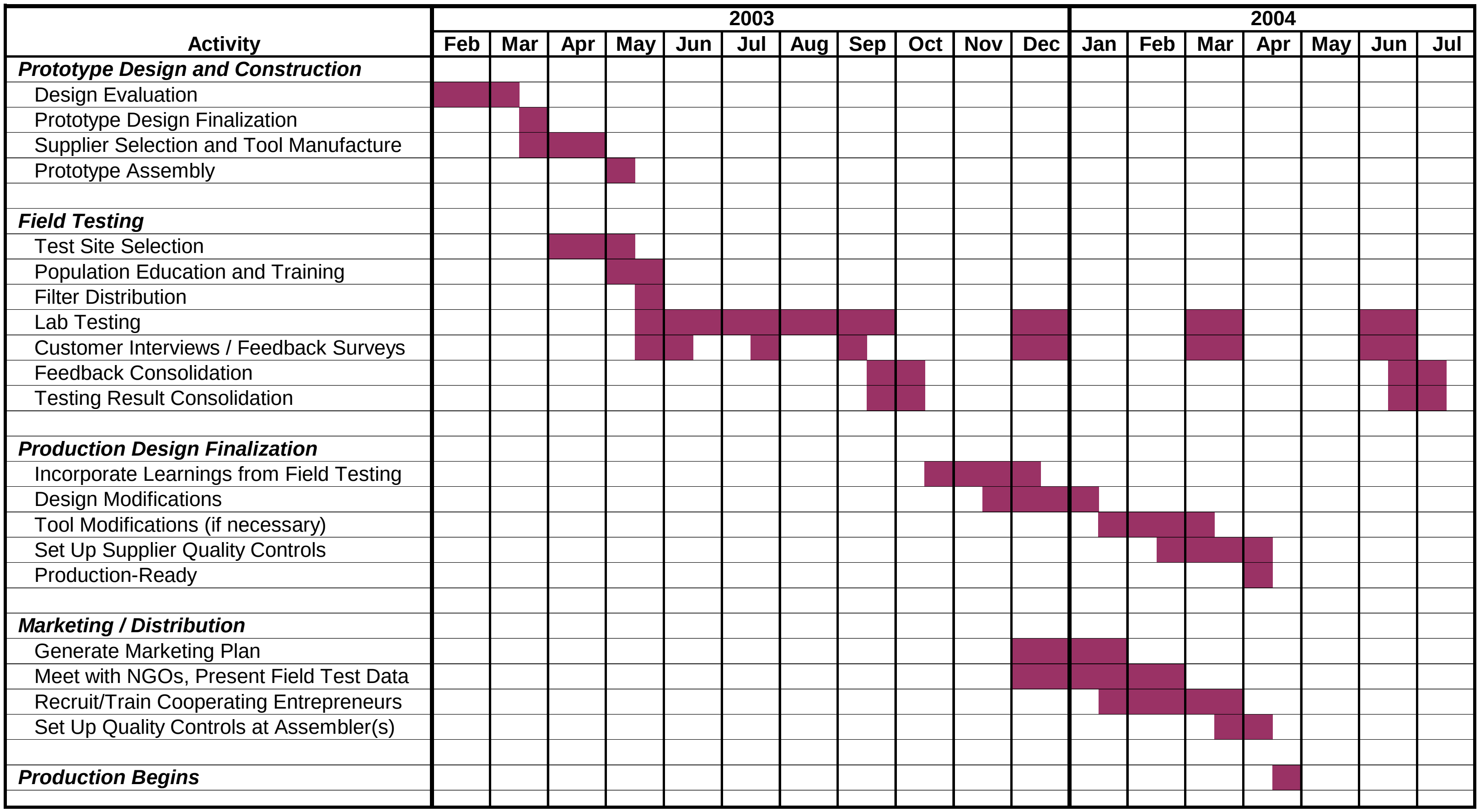


Figure 17: Microbial Removal Efficiency - Candle Filters

Appendix 4: Project Gantt Chart

Low-Cost Ceramic Water Filter Project

High-Level Project Gantt Chart



Endnotes

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