BIOSAND HOUSEHOLD WATER FILTER PROJECT IN NEPAL

By

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Abstract

This purpose of this study was to investigate the effectiveness and the performance of the BioSand filter in Nepal. To achieve this, the author undertook a field trip to Nepal in January, 2001. The trip was made possible with generous support provided by the Department of Civil and Environmental Engineering of MIT. The author spent 3 weeks in Nepal - 4 days in the vicinity of Tansen in the central Palpa region and 9 days in the Nawalparasi district in the Terai collecting water samples. Turbidity measurements were taken and presence/absence tests for total coliform, *E.coli* and H_2S producing bacteria were carried out. At MIT, membrane filtration tests were also carried out. This study found that while filtered water from the BSFs in Nepal has low turbidity and flows at a sufficiently high rate, only 9 out of 12 properly functioning BSFs removed total coliform and 10 out of 12 properly functioning BSFs removed *E. coli*. Membrane filtration tests carried out in MIT indicate that the BSF technology is effective at removal of total coliform with an average removal of 99.5% of total coliform in the source water. Based on the effectiveness of the BSF in removing microbial contamination, the author recommends the BSF technology to be adopted on a large scale in Nepal, but only if it is coupled with a monitoring plan to ensure correct construction, operation and maintenance procedures are followed. A monitoring plan is necessary to reduce the fraction of BioSand filters that were not working properly.

Supervised by: Susan E. Murcott
Title: Lecturer of Civil and Environmental Engineering

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This thesis is dedicated to the many kind people Nat and I met in Nepal, including the young boy who sat in our jeep as we went around Tansen in search for the next BioSand filter. I sincerely hope that this thesis will, in some way, contribute to the betterment of their lives.

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1 INTRODUCTION

The BioSand Filter (BSF) is a household-scale slow sand filter developed by Dr. David Manz of the University of Calgary, Canada. This filter has been tested by several government, research and health institutions as well as NGO agencies in Canada, Vietnam, Brazil, Nicaragua, and Bangladesh. A Nepali NGO, Hope For The Nation, has been promoting the filter in the central foothill region of Palpa and the southern flatland region of Nawalparasi.

The filter was formerly called the Canadian Water Filter (CWF). The new legal and registered name of is “The BioSand Filter Using the Award-Winning CWF Design” or its short form, “BioSand Filter” (Ritenour, 1998). The filter was also given other names describing its intermittent process such as “Intermittent Operated Slow Sand Filter” (IOSSF) and “Manz Intermittent Slow Sand Filter” (MISSF) (Palmeteer et al., 1997). The filter was also called the “BioSand Water Filter” (BWF) in Cambodia and “Guras Water Filter” in Nepal after the national flower (Chettri, 2001b). Other names based on its physical appearance include “Barrel Filter” and “Cement Filter” (IDRC Module 5, 1998). In this thesis, the term “BioSand Filter” or BSF will be used.

Figure 1: Arjun G.C. of Hope For the Nation (left), BioSand Filter (middle) and a technician (right) in Nepal.

1.1 PURPOSE OF STUDY

This purpose of this study was to investigate the effectiveness and the performance of the BioSand Filter in Nepal. To achieve this, the author undertook a field trip to Nepal in January, 2001. The trip was made possible with generous support provided by the Department of Civil and Environmental Engineering of MIT.

The author spent 3 weeks in Nepal, 4 days in the vicinity of Tansen in the central Palpa region and 9 days in the Nawalparasi district in the Terai investigating the BSF pilot project in Nepal. The remainder of the time was spent in Kathmandu. The Palpa region is in the foothills of the Himalayas and is a highly mountainous terrain. The pilot project was started in these 2 locations in Nepal about 2 years ago by a local NGO; Hope for the Nations (HFTN), Nepal.

Currently, there are a total of 15 such filters in Tansen (Chettri, 2001a) and more than 100 in Nawalparasi (Magar, 2001) and the numbers are increasing.

1.2 A BRIEF HISTORY OF SLOW SAND FILTERS

Slow sand filters have filtration rates of 0.1m/h as opposed to rapid sand filters that have filtration rates of 10m/h (Haarhoff and Cleasby, 1991). Slow sand filters have been used to deliver potable water to the public since the early nineteenth century. The first recognized use of slow sand filtration for water supply was in Paisley, Scotland in 1804 when John Gibbs set up an experimental slow sand filter to supply his bleachery and sold excess treated water to the townspeople (Baker, 1981). By 1852 the health advantages of filtered water were so evident that the Metropolis Water Act required all Thames River water to be filtered before use by Londoners. The 1854 Broad Street cholera outbreak further reinforced the need to filter public supply. Since then slow sand filters have been adopted by many major European cities including London, Amsterdam and Zurich for potable water treatment and are still in use today as a secondary filtration step (Baker, 1981).

The development of slow sand filtration in the United States, in contrast with the European experience, was slow (Logsdon and Fox, 1988). The year 1832 saw the first slow sand filtration plant in the United States built in Richmond, Va. In 1833, the plant had 295 water subscribers. The next US plant to open was in Elizabeth, N.J., in 1855. Slow sand filters were introduced in Massachusetts in the mid-1870s. Sand filters and other treatments were primarily designed to improve the aesthetic quality of water. It took major developments in bacteriology during the 1870s and 1880s to demonstrate that microorganisms that exist in water supplies can cause human and animal diseases. This led to the realization that water treatment could help prevent disease. Robert Koch, the German physician and microbiologist who postulated the germ

theory of disease, and the Scottish surgeon Joseph Lister were major players in this work. By the 1890s filtration was gaining recognition for not only straining out undesirable particles, but also removing deadly germs. Towns and cities along the Hudson River in New York State that used filtration for water purification had fewer outbreaks and incidences of typhoid than communities that did not filter the Hudson River water.

Installation of both slow rate and rapid rate filtration plants took place in the 1890's and 1900's, but shortly thereafter, rapid filters gained popularity. By 1940, the United States had about 100 slow sand filtration plants, whereas nearly 2300 rapid rate plants had been constructed (Baker, 1981). A number of factors may have been involved in this shift in interest. River water that was muddied by runoff from clay soils could be treated successfully with properly designed and operated rapid rate filtration plants. Such waters, on the other hand, clogged slow sand filters. Additional advantages for medium-sized and large water utilities were the reduced land requirements in populated areas and the lower labor requirements in operations and maintenance for rapid filters compared to slow filters (Logsdon, 1991).

In the late 1970's and early 1980's, the potential for application of slow sand filtration in the United States was reconsidered. Increase in outbreaks of waterborne giardiasis in the USA throughout the 1970's played an important role in the renewed interest in slow filters. Most giardiasis outbreaks had occurred in places where the raw water was of low turbidity and therefore appeared suitable for treatment by slow sand filtration. Although there was plenty of evidence that slow sand filters remove bacterial and viral contaminants, there was no data to verify that slow filters remove *Giardia* cysts. As a result, the U.S. EPA sponsored several

research projects in the early 1980's to determine the capabilities of slow sand filtration, which includes controlling *Giardia* cysts in surface waters (Graham, 1988).

The success of these projects led to a program of research in slow sand filtration at institutions such as Iowa State University, Ames; Colorado State University, Fort Collins; Syracuse University, Syracuse; Utah State University, Logan; University of Washington, Seattle; and University of New Hampshire, Durham (Weber-Shirk and Dick, 1997). There was also evaluation of slow filters in the state of New York, and the province of British Columbia in Canada. Limitations for use by large water utilities were recognized, but the process was considered for use by small systems, where requirements for land and labor would not be a serious drawback.

In 1980, the United Nations declared the beginning of the International Drinking Water Supply and Sanitation Decade. Provided that water demands were not too high and that sufficient land was available, the only water treatment considered reliable and recommended for developing nations was slow sand filtration (Graham, 1988).

In 1985, the Surface Water Treatment Rule (SWTR) was passed in the United States; this regulation requires filtration and disinfection as minimum treatment for surface water. Although only about 50 slow sand filtration plants were in operation in the United States in 1991 (Schuler et al., 1991), more plants may be built as small communities (as well as places like campgrounds, adult and youth camps, and rural conference centers) comply with the SWTR. Slow sand filters in the United States are found primarily in smaller communities with fewer than 10,000 people, 45% of which serve fewer than 1,000 people (Sims and Slezak, 1991).

Slow sand filtration has also been found to be a highly efficient means of removing the protozoan parasite, Cryptosporidium parvum, from water (Timms et al., 1994). In recent years, this parasite has been recognized as a significant threat to potable supplies. The resistant stage – an oocyst – is relatively untouched by chlorine disinfection. In experiments performed by Thames Water Utilities, United Kingdom, slow sand filters reduced concentrations of Cryptosporidium oocysts by 99.997% from 4000/L to 0/8L (Timms et al., 1994). Another study in British Columbia by Fogel contradicts the aforementioned study (Fogel et al., 1993). Fogel found removal efficiencies of 48%; this figure is significantly different from the 100% removals from previous literature. However, a point to note concerning the British Columbia filters is that they were operating well out of the range of the recommended design limits for the uniformity coefficient[1] at 3.5 (Fogel et al., 1993). Furthermore, temperature can adversely affect the performance of a slow sand filter; the British Columbia filters were operating at extremely low temperatures of less than 1°C (Fogel et al., 1993). Overall, the literature supports data that strongly suggests slow sand filtration is a viable option for *Cryptosporidia* removals.

Although slow sand filtration often has been replaced by faster and more advanced high-rate filtration methods, its low cost, ease of operation, minimal maintenance requirements, and success in removing pathogenic microorganisms make slow sand filtration an attractive option for rural communities and developing nations (Collins et al., 1992). The following table shows the typical treatment performance of conventional slow sand filters.

[1] For a discussion of uniformity coefficient, see section 3.3.1.

Table 1: Typical treatment performance of conventional slow sand filters (Collins, 1998)

Parameters	*Values*
Turbidity	<1.0 NTU
Coliforms	1-3 log units
Enteric Viruses	2-4 log units
Giardia Cysts	2-4+ log units
Cryptosporidium Oocysts	>4 log units
Dissolved Organic Carbon	<15-25%
Biodegradable Dissolved Organic Carbon	<50%
Trihalomethane Precursors	<20-30%
Zn, Cu, Cd, Pb	>95-99%
Fe, Mn	>67%
As	<47%

1.3 HISTORY OF THE BIOSAND FILTER

In 1987, when Dr. Manz flew to the Zulu homeland in South Africa as part of an international development project, he found himself in a world of perpetual illness, high infant mortality and rampant fatalism (Pearce-McLeay, 1996). International aid organizations had come and gone, leaving in their wake scattered springs, bored holes and instructions to boil or chlorinate the community water supply (University Technologies International, 1998). Driven by the desire to help the developing world find a better way, Manz spent the next few years developing a simple, cheap and effective filtration system (Legge, 1996). The filter design was

based on a new form of slow sand filtration, replacing the continuous process used since the late 19th century.

The first prototype was out in 1988. In initial tests run by the Public Health Laboratories at Calgary's Foothill Hospital in the fall of 1988, the filter eliminated 99 per cent of fecal coliform (University of Calgary, 1994).

In the fall of 1991, research into what was initially called "the Canadian Water Filter" was initiated in the Department of Civil Engineering of the University of Calgary. Initial positive results convinced the Pan American Health Organization (PAHO), through the Centro Latinoamericano de Perinatologia y Dessarollo Humano (Latin American Center for Perinatology and Human Development) or CLAP, to invest USD$10,000 from one of its projects known as Proyecto de Desarollo de la Salud Perinatal (Development of Perinatal Health Project) or DESAPER into a pilot Canadian Water Filter evaluation project in Nicaragua. DESAPER is a program to develop maternal, perinatal and child health in selected areas of Bolivia, Honduras, Nicaragua, and Peru (University of Calgary, 1994). It is funded by the Canadian International Development Agency (CIDA) and is co-administered by the Division of International Development of the University of Calgary and CLAP. Subsequent to the successful initiation of the pilot project, an additional USD$8,000 was provided to expedite and continue research into technology (University of Calgary, 1994). Based on the success of the pilot project, Health Canada provided an additional USD$60,000 to the University of Calgary for a Phase Two of the water filter project in Nicaragua and a second pilot project in Honduras. This was because Health Canada saw significant potential application for the water filter technology not only in Central America but also in the more remote regions of Northern Canada (Uniworld, 1995).

The filter has attracted the attention of a number of humanitarian organizations and service clubs who have supported the installation of the systems worldwide. One such organization is Samaritan's Purse, an international Christian relief agency active in about 60 countries. Samaritan's Purse first heard about the filter after reading an article in the Calgary Herald (Lowey, 1993). With activities in Central America, they were able to visit a Nicaraguan village, Valle Menier, where the filter was tested. When Samaritan's Purse visited the village, no one had been in touch with villagers since the filters were field deployed 2 years previously. The filters were still working efficiently, and diarrhea and cholera, common to the area, had disappeared (Lowey, 1993).

Samaritan's Purse has since funded the initiation of water filter projects in various countries including the Kandaal Province in Cambodia (1999), the village of Santarem in Brazil (1998), Vietnam (1998), and Nepal (1998). Samaritan's Purse looks for partnerships with local NGOs to develop the water filter project.

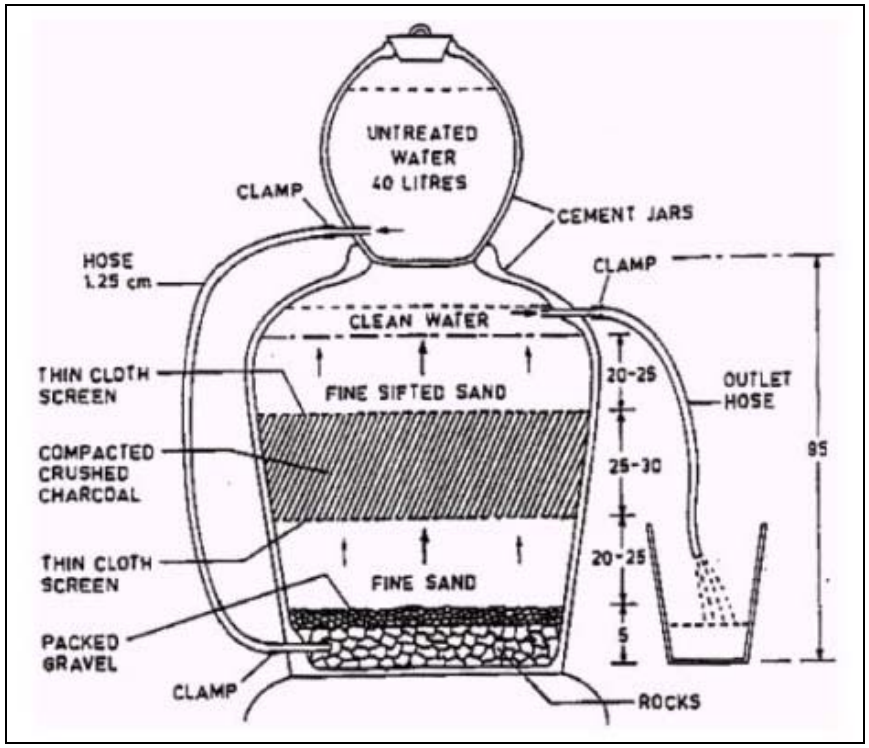
Without the time or resources to properly introduce the filter to developing countries, Dr. Manz has relinquished the responsibility to undertake these humanitarian efforts to Samaritan's Purse and the International Development Research Center (IDRC), which is a public corporation created by the Canadian government to help communities in the developing world find solutions to social, economic, and environmental problems through research. Through a licensing arrangement with University Technologies International (UTI) Inc., Dr. Manz has started his own company, Davnor Water Treatment Technologies Ltd., to commercially market the filter for use on farms, acreages, and recreational property. In 1996, Dr. Manz was awarded a Summit Project Achievement Award by the Association of

Professional Engineers Geologists and Geophysicists of Alberta (University Technologies International, 1998).

The filter is currently in use in Canada, the U.S., Mexico, Nicaragua, El Salvador, Costa Rica, Brazil, Ecuador, Haiti, Indonesia, Bangladesh, Laos, Vietnam, China, the Philippines, Ethiopia, Kenya, Nigeria, Gabon, Nepal and the list continues to grow (University Technologies International, 1998).

The BSF is by no means the only kind of household slow sand filter. Many indigenous designs have been used, ranging from simple pots filled with sand through which water is poured to complex designs incorporating upward flow, several ceramic layers, and multiple sand and charcoal layers (Burch and Thomas, 1998). An example, the UNICEF filter, is shown in Figure 2. Hydraulic head is provided by an upper jar that feeds the lower filtration jar. The unit incorporates two sand layers separated from a charcoal layer by thin cloth screens, and a gravel layer and a rock layer at the inlet for rough filtering.

Figure 2: A schematic of the UNICEF filter, an upflow household slow sand filter (from [Gupta and Chaudhuri, 1992])



2 THEORY

2.1 CONTRAST BETWEEN SLOW SAND FILTER AND RAPID SAND FILTER

Slow sand filters operate at very low filtration rates, use very fine sand, and usually function without pre-chlorination. The low filtration rate results in long detention times in the water above the filter sand, and within the bed of the sand. The long detention time results in substantial biological life in the slow sand filtration process.

Rapid filters have short detention times and are often operated with pre-disinfection so that no significant biological life is sustainable. Hence, rapid filters use physical straining to trap solids in the pores between sand particles. While rapid filtration can only remove particles larger than the void space between the sand particles, slow sand filters can remove particles smaller than the space between sand particles.

Also, slow filtration particle removal occurs mainly at the surface of the sand bed with minor removal within the bed. Rapid filtration particle removal occurs mainly within the bed over a substantial depth.

In addition, rapid filters are cleaned every day or two when terminal head loss is reached. To clean the filter, flow is reversed through the filter bed at a high rate that fluidizes the bed, actually expanding the spaces between sand particles and flushing trapped material to waste. Backwashing a slow sand filter using the same method as in a rapid sand filter would create havoc with the biological layer because fluidizing of the bed would damage the biofilm and disrupt the intricate interrelationships of sand and microscopic life. Slow sand filters usually are returned to operational status by scraping and removing the top layer of sand because that is

where the clogging takes place. Compared to rapid sand filtration, there is a net savings of water as large quantities of backwash water are not required.

Rapid filters are suitable for large urban centers where land scarcity is an issue. Slow sand filters are suitable for developing countries and small rural systems, where sufficient land is available.

Slow sand filtration is simpler to operate than rapid filtration, as frequent backwashing is not required. Therefore, in terms of level of operation and maintenance, rapid filtration requires a technically qualified operator whereas operating a slow filter requires little technical skills. Furthermore, rapid filtration typically requires the addition of coagulant chemicals whereas slow filtration does not.

Table 2: Typical differences between slow sand filter and rapid sand filter (Haarhoff and Cleasby, 1991)

	Slow Filters	*Rapid Filters*
Filtration rate	0.1m/h	10m/h
Water above top of sand	1.5m	1.5m
Sand depth	0.8m	0.8m
Retention time above sand	15 hr	9 min
Retention time in sand bed	3.2 hr	2 min
Cycle length	1-6 month	1-4 day
Sand effective Size	0.15-0.35mm	0.35-1mm
Sand coefficient of uniformity	1.5-3	1.2-1.7

2.2 CONTRAST BETWEEN BIOSAND FILTER AND SLOW SAND FILTER

The BSF is a household-scale slow sand filter but with some differences. A typical square concrete BSF is 0.9m tall, and measures 0.30m along its inner edge. A slow sand filter usually has a height ranging from 3-5m and a width of 4-15m (Haarhoff and Cleasby, 1991). The BSF also has a higher flow rate than a typical slow sand filter.

The BSF is also different from a slow sand filter with respect to its design to sustain the biofilm during intermittent flow. Two elements of the design contribute to the preservation of the biofilm. First, the filter is designed to hold 5cm of water above the top surface of the sand column while at rest. The 5cm resting water level is based on research performed to determine at what head height the biology receives the maximum oxygen while still being protected from incoming water. A constant aquatic environment is necessary for the organisms present in the layer to survive. However, the water layer cannot be too deep or oxygen will not diffuse and the microorganisms will suffocate. Second, a diffuser plate/basin (see Section 3: Elements of a BioSand filter) blocks input water from disturbing the top layer of sand. (Ritenour, 1998)

Table 3: Differences between BSF and slow sand filter

	BioSand Filter[a]	*Slow Filters*[b]
Filtration rate	0.6m/h	0.1m/h
Resting water above top of sand	0.05m	1.5m
Sand depth	0.46m	0.8m
Size	Height: 0.9m Width: 0.3m	Height: 3-5m Width: 4-15m
Raw Water Quality	Max. Turbidity: > 100 NTU[c]	Max. Turbidity: < 20 NTU

a For a typical square-based, concrete BSF

b Haarhoff and Cleasby, 1991

c Davnor Water Treatment Technologies Ltd.

2.3 THE SCHMUTZDECKE

Imprecise terminology has contributed to the confusion surrounding proposed particle removal mechanisms in slow sand filters. Particle removal in slow sand filters has been attributed to the *schmutzdecke*, but the *schmutzdecke* has been defined in several different ways, including (1) a layer of particles deposited on top of the filter bed (2) biological growth on top of the filter bed (3) biologically active zone within the filter bed. Weber-Shirk and Dick (1997b) proposes using "filter cake" to denote the first two definitions and "biologically active zone" for the third definition so as to avoid confusion. In this thesis, the author uses the terminology consistent with that of Weber-Shirk and Dick.

2.4 BIOLOGICAL REMOVAL MECHANISMS

Biological activity in the sand bed is not well understood. Scientists have a vague idea of the possible processes involved, but specific interactions are still unknown. Suggested biological

removal mechanisms of harmful microorganisms are metabolic breakdown, predation, scavenging, natural death and inactivation (Haarhoff and Cleasby, 1991).

2.4.1 Metabolic breakdown

For many years, the biodegradation of organic matter was thought to be an important biological mechanism in slow sand filter. Huisman and Wood (1974) describe the process as follows:

> "Deposited organic matter is being used as food. The bacteria oxidize part of the food to provide the energy they need for their metabolism (dissimilation), and they convert part of it into cell material for their growth (assimilation). The dissimilation products are carried away by water to be used again at greater depth by other organisms. The assimilation is accompanied by an equivalent dying off. This in turn liberates organic matter, which becomes available to bacteria at lower depths. In this way, the whole of the degradable organic matter present in the raw water is gradually broken down and converted into water, carbon dioxide, and inorganic salts such as sulfates, phosphates, and nitrates to be discharged in the filter effluent."

Experimental studies (Fox et al., 1984) indicated that metabolic breakdown plays only a minor role in the removal of bacteria in slow sand filtration because only a small percentage of the organic carbon is biodegradable. What matters is bacterivory as discussed in the next section.

2.4.2 Bacterivory

Bacterivory is the consumption of bacteria by predators such as protozoa and rotifers. Protozoa are unicellular organisms that ingest their food. Examples of protozoa include

rhizopods (*Rhizopoda*) and ciliates (*Ciliaphora*). Rotifers (*Rotatoria*) are a group of invertebrates that are distinguished by a crown of moving cilia that draws a vortex of water into the mouth. Two proposed mechanisms by which predators such as protozoa and rotifers may assist in the filtration are (1) predators graze on bacteria and detritus attached to sand grains and (2) predators remove suspended particles as the particles flow through the filter. Predators that graze on attached bacteria potentially free up sites for future bacteria attachment while suspension feeding predators directly remove particles from the mobile phase (Weber-Shirk and Dick, 1998). Recent studies and experiments conclude that while bacterivory is a significant cause of bacterial removal in slow sand filters (Weber-Shirk and Dick, 1997a), it is not the mechanism for removal of larger (>2µm) pathogenic protozoa such as Giardia lamblia and Cryptosporidium oocysts (Weber-Shirk and Dick, 1998).

2.5 PHYSICAL REMOVAL MECHANISMS

Two proposed physical removal mechanisms in a slow sand filter are surface straining and interparticle attraction (or attachment). An experimental-based research to study the physical-chemical mechanisms responsible for particle removal in slow sand filters was recently conducted in Cornell University (Weber-Shirk and Dick, 1997b). Results of the study suggest that straining is the "dominant mechanism of particle removal in slow sand filter cakes where the pore sizes are the smallest", while "inter-particle attraction is primarily responsible for particle removal within the slow sand filter beds".

2.5.1 Surface straining

Surface straining is the "most obvious capture mechanism for particles too large to pass through the interstices between the grains" (Haarhoff and Cleasby, 1991). A tightly packed bed of spherical grains could capture particles about 15% of the grain diameter (Huisman and

Wood, 1974). A clean sand of 200µm effective size is expected to capture particles of about 30µm in size by surface straining. This is substantially larger than many particles to be removed from surface water such as cysts (1-20µm), bacteria (0.1 to 10µm), viruses (0.01 to 0.1µm), and colloidal particles (0.001 to 1µm) (Haarhoff and Cleasby, 1991). However, larger particles (such as algae and vegetative debris) can be captured by surface straining. As these particles are captured at the surface, the surface pore openings become smaller and surface straining is enhanced, allowing capture of much smaller particles as the filter cake develops. The filter cake, composed of living organisms and other debris from the water, ultimately becomes an effective filtering medium (Cleasby et al., 1984). The filter cake has been described as an extension of the filter bed containing the smallest interstices to achieve the most effective straining (Weber-Shirk and Dick, 1997b). Surface straining was also described as a "sieve effect which is amplified by deposit on the filters' surface of a layer made up of clay, organic matter, algae, and macro- and microorganisms" (Barbier, 1992).

2.5.2 Inter-particle Attraction

Particle attachment to previously removed particles resulting from interparticle attraction can occur in both the filter cake and in the underlying filter bed. Prior to attachment, the particles are transported along flow streamlines unless they are captured by interception or transported across the streamlines causing them to reach a grain surface. If the conditions at the grain surface provide favorable particle-to-grain interaction, attachment will occur.

The efficiency of particle attachment is related to the net attractive force between the medium (consisting of sand and previously removed particles) and suspended particles. Viscous forces hinder attachment or cause detachment by shearing particles from the medium. Shearing forces are expected to be the highest in the filter cake, because shearing forces increase as the

pore size of the medium decreases. Thus, net attachment of particles to previously removed particles because of interparticle attraction may be less efficient in the filter cake than in the underlying filter bed (Weber-Shirk and Dick, 1997).

2.6 FILTER RIPENING

Slow sand filters require a long ripening period at the beginning of each filter run. This is to allow the biology in the sand layer to mature. Filter ripening is a complex process that involves both biological and physical mechanisms. As filtration progresses, biological growth consisting of algae, bacteria, and zooplankton occurs within the sand bed and gravel layer (Bellamy et al., 1985; Graham 1988). During the ripening period, the filter does not effectively remove bacteria. Bellamy et al. (1985) concluded that a new sand bed will remove 85% of the coliform bacteria in the influent. As the sand bed matures biologically, the percent removal improves to more than 99% for coliform bacteria.

The ripening period for the BSF is usually one to two weeks. However, for slow sand filters, the ripening process can be accelerated by using synthetic polymers (Jellison et al., 2000) to agglomerate particles in the raw water and hasten their removal at the filter surface so as to quickly develop the filter cake. However, the addition of chemicals to the BSF would complicate the originally simple filtration process.

2.7 PREVIOUS BIOSAND FILTER RESULTS

According to the Davnor website, the BSF is effective in removing iron, manganese, sulfur, low concentrations of gases, bacteria, viruses, waterborne parasites, algae, silt and clay (Davnor Water Treatment Technologies Ltd.). The BSF has successfully treated water ranging in temperature from 1^{o} to 45^{o}C. Table 4 summarizes the contaminant removal performance of the BioSand Filter in other countries.

Table 4: Contaminant Removal Efficiency of BioSand Filter

Country	*Organization*	*Date*	*Contaminant*	*Reported Removal (%)*
Nicaragua	Instituto Nicaraguense de Acueductos y Alcantarillados	7/1993	Coliform Bacteria	99.1-99.6
Canada	University of Calgary	11/1995	Fecal Coliform	99.1-99.7
			Turbidity	94.1-96.1
Canada	National Water Research Institute	11/1996	Heterotrophic Bacteria	65 – 90+ (1)
			Giardia Cysts	99.99
			Organic and Inorganic Toxicants	50-99.99
			Total Suspended Solids	100
			Total Organic Carbon	14-18
			Chemical Oxygen Demand	100
Vietnam	Samaritan's Purse	11/1998	E.coli Bacteria	95.8 (2)
Brazil	Samaritan's Purse	11/1998	Fecal Coliform	99.7 (3)
Bangladesh	Proshika Manobik Unnayan Kendra	8/1999	Total Coliforms (river water)	99.8 (4)
			Fecal Coliforms (river water)	99.8 (4)
			Total Coliform (three households)	60-100 (4)
			Fecal Coliforms (three households)	74.3-100 (4)
Canada	Montana Native Reserve	Date not available	Iron	91.5
			Turbidity	85.7

(1) Damage of 10 to 15 % of schmutzdecke discovered at the end of test period
(2) Average of 32 households
(3) Average of 21 households
(4) Raw and treated water not tested on the same days.
All samples show zero levels of fecal coliform and minimal levels of total coliform on day of final test
(Source: Davnor Water Treatment Technologies Ltd.)

3 ELEMENTS OF A BIOSAND FILTER

Cross-section of a concrete BioSand Filter is shown in Figure 3. A BSF has several main components:- body/shell, diffuser plate, sand/gravel, and lid. Each of these components will be described in detail in this section.

Figure 3: Cross-section of a concrete BioSand Filter

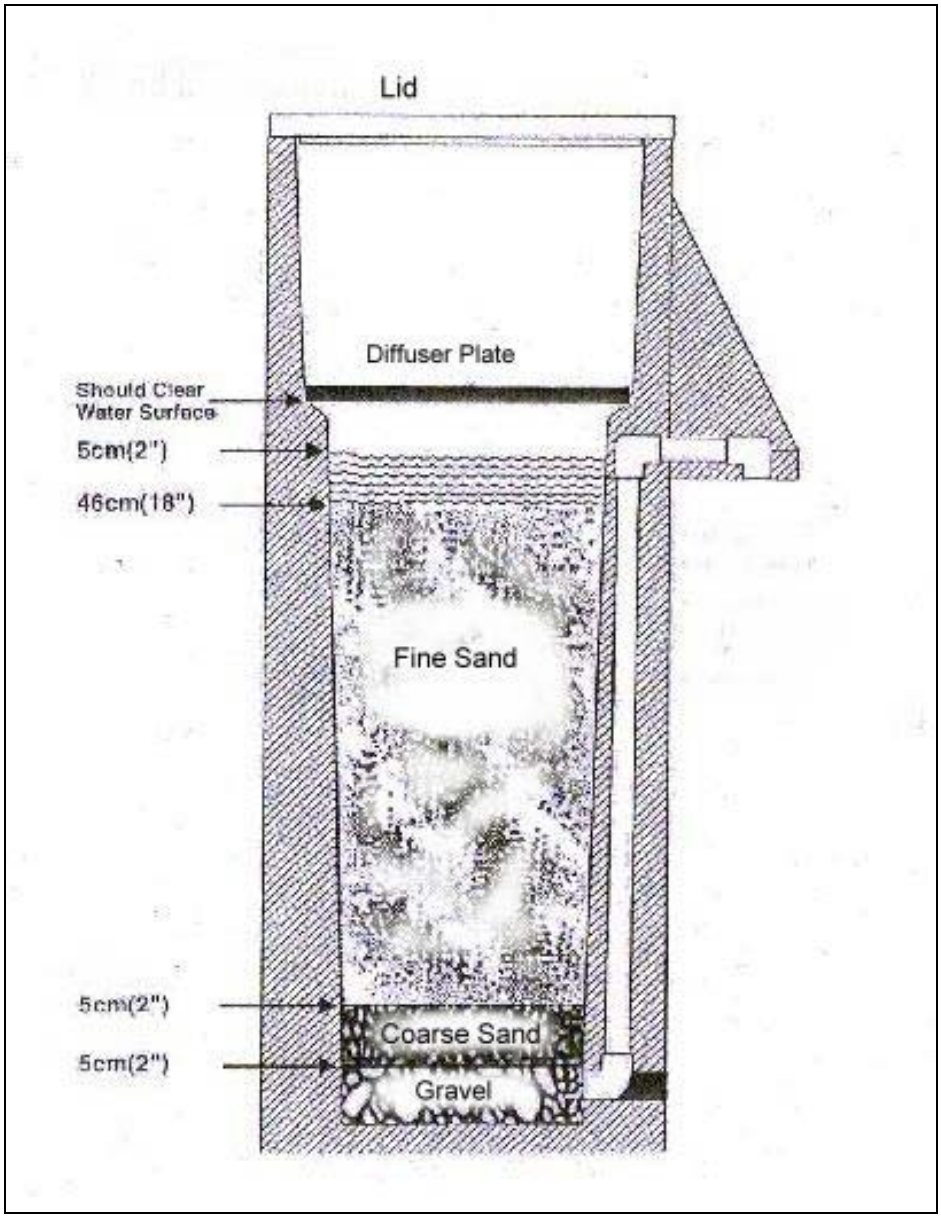


Table 5: BSF Design Parameters

Design Parameter	*Value*
Fine Sand Size	<1mm
Coarse Sand Size	1mm – 6mm
Underdrain Gravel Size	6mm – 15mm
Surface Area of Sand	540m^2
Initial Flow Rate	1L/min ± 30%
BSF Size	30cm x 30 cm x 90cm

3.1 CONCRETE BODY/SHELL

The BSF shell can be made of plastic or concrete. The plastic BSF shown in Figure 4 costs \$125[2] from Davnor Water Treatment Technologies Ltd., which is about four times the cost of a locally made concrete filter as shown in Figure 5 (\$32[3]). Therefore a concrete filter is far more affordable for an average Nepali household.

The concrete shell is cast in a steel mold. Casting is carried out on site because transportation over long distances with bumpy road conditions to some of the less accessible places in Nepal might cause damages to the BSF shell (Chettri, 2001a). The concrete BSF can have a square or round base (Figure 6 and Figure 7).

[2] Invoice from Davnor Water Treatment Technologies Ltd for a plastic BSF bought by Lee Hersh, a retired chemist from Cornell University and donated to MIT in Fall 2000.

[3] BSF unit price quoted by Hope For The Nation to MIT in March 2001

Figure 4: Plastic BSF from Davnor Water Treatment Technologies Ltd.

Figure 5: Concrete BSF made from shop drawings provided by Davnor Water Treatment Technologies Ltd.

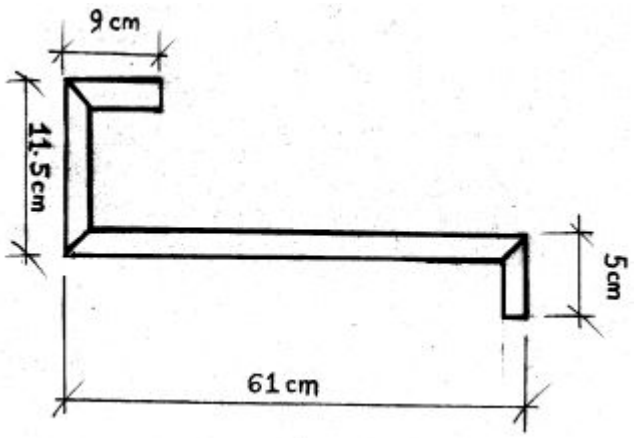
Figure 6: Concrete BSF with square base.

Figure 7: Concrete BSF with round base.

3.1.1 Riser pipe assembly

Cut the PVC pipe into four sections (Chettri, 2001c) and saw off the edges forming a 45° angle as shown below:

Figure 8: PVC pipe dimensions (not to scale)



Join the various sections together with glue (IDRC Module 5, 1998). Alternatively, heat join using a flat heating plate.

3.1.2 Preparation of mold

Detailed technical drawings for the steel molds of the concrete version of the BSF are available through Samaritan's Purse or IDRC (IDRC Module 5, 1998). Figure 9 shows the cross section of the steel mold.

Figure 9: Cross section of inner and outer molds (Ritenour, 1998)

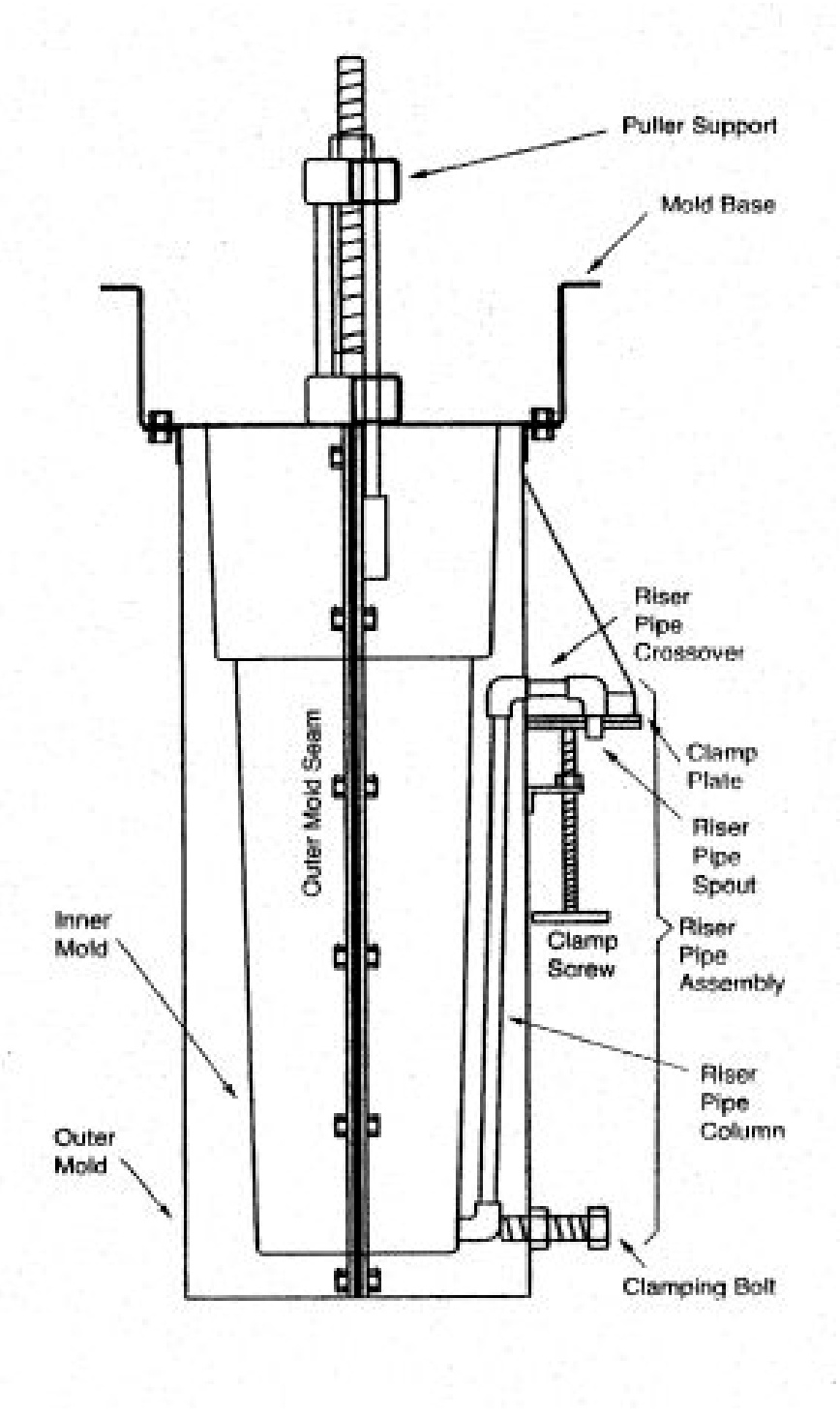


Figure 10: Unassembled steel mold – inner mold (left) and outer mold (right).

Figure 11: Steel mold for concrete BSF shell (assembled)

Stand the fully assembled mold upright, base down. Install the riser pipe that was assembled previously inside the outer mold section. Coat the inside of the molds and the clamping bolt with edible oil or lard. This is to prevent the concrete from sticking to the molds.

3.1.3 Mixing concrete

Materials required for concrete body:

1. 36 L of cement
2. 36 L of sand
3. 36 L of gravel
4. Water
5. Bucket

6. Shovel
7. Mixing tray/slab or wheel barrow
8. Steel or wood rod
9. Piece of wood (to use as a trowel)

Concrete is mixed in equal proportion (by volume) in a wheel barrow or on any clean surface. Water is added a little at a time until concrete reaches the proper consistency. The amount of water needed depends on the initial moisture level of the sand and gravel. As a rough guide, take a handful of the final mixture and squeeze it hard. If the consistency is right, it will just be possible to squeeze a few drops of liquid out of the handful.

Figure 12: Concrete Mixing I

Figure 13: Concrete Mixing II

3.1.4 Concrete Pour

The concrete pour should not be carried out in direct sunlight because the concrete must cure in the shade. These are the procedures for pouring:

Pour one third of the concrete into the steel mold. Thrust a steel or wooded rod in and out of the concrete and pound the outside of the mold with a rubber mallet to ensure that the concrete fills all sections of the mold and to release any air bubbles. Repeat this procedure twice more, each time pouring a third of the concrete. Prior to completely filling the mold, oil the top portion of the inner mold as some oil will have worn off in the pouring process.

Figure 14: Tamping the concrete mixture with a wooden rod

Level the top of the concrete surface using a short piece of wood. Adjust the clamping bolt which holds the riser pipe against the inner mold so that there is enough pressure to hold the rise pipe in place without causing the outside mold to deflect on that side. This will leave a hole in the filter wall that will have to be patched later. About fifteen minutes after the concrete is poured, release the concrete clamping bolt.

3.1.5 De-molding

Materials required:

1. Mold wrenches
2. About 200g of concrete
3. Pliers
4. Hammer
5. Scrap wood

Carefully turn the mold right side up (inner mold legs up). Since the mold, now charged with concrete, has an enhanced capacity to smash fingers, set a piece of wood down to avoid setting the mold flat on the ground. Remove the riser pipe clamping-bolt using a wrench. Clean this bolt and its threading nut with a wire brush after each casting.

Place the puller-support in its slots and screw in the threaded rod. The rod only needs to be threaded the depth of the base nut. Once in place, hand tighten the floating nut against the puller-support crossbar. Remove base bolts. Using a wrench, continue to tighten the floating nut against the crossbar to break the inner mold free. Raise it about 5cm. At this point, the inner mold should be sufficiently loose for two people to lift it out by hand. If the inner mold sticks, tap the outer mold with a rubber mallet while tightening the nut. Set the inner mold aside. Remove the nuts and bolts connecting the two sections of the outer mold. Remove the riser pipe spout using a pair of pliers. Remove the pour spout clamp plate and gasket.

Starting with the rear outer mold section, use both hands to slowly pull back on the mold base and remove this section. Pull gently and evenly, avoiding jerking motion. If the mold does not budge, tap the connection edge (where the halves bolt together) using a piece of wood and a hammer, alternating from one side to another. Be careful not to strike the concrete with the hammer and always use a piece of wood. One person should be pulling on the mold while another is tapping. Remove the front section of the mold.

Using some concrete, patch the hole created by the clamping bolt, any cracks that appear, and any other significant imperfections in the concrete. Scrape the rough edges off the filter. These usually occur at the top of the filter and along the two sides where the seam of the outer mold section was. Scraping should be done while the concrete is still curing.

Keep the filter wet and out of the sun for 2 to 3 days to allow the concrete to cure properly. Water can be poured in to keep the filter body wet. If it cures too quickly due to sun exposure or a warm, dry wind, cracking may occur. Clean the mold and all its parts. If an even, debris-free layer of lard or oil remains on the mold, it may be left for the next casting.

3.2 DIFFUSER PLATE

The diffuser plate is a thin plate with 3mm perforations spaced 2cm apart in a square grid. The plate rests on the inner ledge above the resting water level. (see Figure 17). The main function of the diffuser plate/basin is to distribute the fall of the water over the whole filtering surface to avoid damage to the upper sand layer and the destruction of the biological layer (Module 5, 1998). The diffuser plate/basin also serves to sieve the larger impurities carried by the water, such as leaves, branches and larger insects.

3.2.1 Materials

The diffuser plate can be made of various common materials such as metal, wood, or plastic. This flexibility in the choice of materials allows the tailoring of the diffuser plate according to which material is locally available and therefore the lowest cost. In Nepal, most diffuser plates are made of galvanized zinc or plastic. A main criterion for the choice of metal is non-corrosiveness. Figure 15 shows a typical galvanized zinc diffuser plate in Nepal.

Most plastic diffuser plates in Nepal are made of low density polyethylene (LDPE) cutting boards, which are widely available in Nepal and locally known as “Korea plastic” (Magar, 2001) (see Figure 16). The design of the Nepali LDPE diffuser plate owes to the ingenuity of one of the local technicians, Durga Bahadur Ale Magar. He found that the breadth of the cutting board is about the same as the inner edge of the filter. This simplifies the steps to make a diffuser plate to just sawing off the length of the cutting board to make a square. To save

materials, two sawed-off portions are fastened together (with staples or dowel pins) to form another diffuser plate.

Although wood is another recommended material for diffuser plates (Ritenour, 1998), wooden diffuser plates were not found in Nepal. The wood to be used must not leach color, shrink, swell, or warp in water. If color runs out of the wood, it will pass through the filter and discolor the filtered water. If the wood shrinks or warps, it will not fit tightly against the filter body and water will skirt its edge, disrupting the top layer of sand.

Figure 15: A typical metal diffuser plate with handle in Nepal

Figure 16: Low Density Polyethylene Plastic (LDPE) diffuser plate in Nepal

3.2.2 Design

There are several designs for a diffuser plate. These include basin, pan, and plate. A basin rests on the top ledge of the concrete body (see Figure 17 and

Figure 18). A basin for a square filter is usually made from three sheets of metal. To increase rigidity, the top edge of the diffuser basin is folded back. For a round filter, aluminum pots have been used as the diffuser basins. If the size of the pot is slightly too small for the concrete, it can hammered to form a bigger one (see Figure 19). Holes are drilled at the base of the diffuser basin.

A pan is like a shallow basin. It rests on the inner ledge of the concrete body. It is made from two sheets of metal- one for the sides and one for the base. To join the metal sheets in both the basin and the pan models, the edges of the metal sheets cannot be soldered since most solders contain lead and other heavy metals, and using lead-free solder is more expensive.

Also, galvanized sheet metal, if used, cannot be welded because of the coating. Therefore, a way to join these sheets is folding the edges back so that the sheets interlock and cannot slide apart.

Diffuser plates are more common than basins or pans since it requires less material. The plates rest on the inner ledge of the concrete body. The dimensions of the plates must be such that the sheet fits tightly against the inner wall of the filter. For the standard concrete BSF in Nepal, the dimensions of a diffuser plate is approximately 30cm x 30cm x 0.5 – 2.5cm. The diffuser plate should be held down by a piece of rock (that covers as few holes as possible), or two pieces of wood to wedge along the edges of the plate. This will prevent the diffuser plate from dislodging when water is poured in. There should be a handle (see Figure 15) on the diffuser plate for lifting it out of the filter. Again, as few holes as possible should be blocked. A screw in the center as shown in Figure 20 or some wires looped through two of the holes in the opposite corners could be possible alternatives.

Figure 17: Metal diffuser basin I

Figure 18: Metal diffuser basin II

Figure 19: A metal pot used as a diffuser basin in a round BSF

Figure 20: A screw to aid lifting the diffuser plate out of the BSF

3.3 SAND AND GRAVEL

Sand porosity is an important factor relative to the formation of the filter cake and the biologically active zone. Sand porosity depends on the size and shape of the grains. It increases with the size of the grains and with the homogeneity of grain size and shape.

High porosity leads to high flow rate and low probabilities of collisions between particles in water and the sand grains. Low porosity will bring about low flow rate and clogging. Therefore, a moderate porosity is required for optimal operation of the BSF. The porosity is small enough to trap particles in the water and large enough to let the water through and allow some room for biological growth.

3.3.1 Requirements

The following are requirements for the type of sand appropriate for use in a slow sand filter:

1. Hard, durable, angular grains free from loam, clay and organic matter. Angular grains decrease porosity and increase resistance to flowing water.

2. An effective diameter (d_{10}) range of 0.15-0.35mm.

3. A uniformity coefficient (C_u) of less than 3. Uniformity coefficient is a ratio calculated as the size opening that will just pass 60 percent (by weight) of a representative sample of the filter material divided by the size opening that will just pass 10 percent (by weight) of the same sample (Sims and Slezak, 1991). This implies a fairly narrow range of grain sizes with an almost even distribution between the smallest 10% and the largest 10% and with most of the grains being a size in the middle. This distribution of sizes decreases the porosity of the sand, increasing the surface area per volume and the likelihood of collisions in the top portions of the sand.

3.3.2 Preparation

There are several steps to the preparation of the sand and gravel.

Locating source of gravel and sand

Sand from a crushing operation is pure, clean and relatively uniform in size and shape. It requires the least preparation and is the best possible sand source. In the absence of a manufactured source, it is necessary to locate a natural hillside sand deposit. If there are no other choices, one could use riverbed sand. This is not highly recommended because riverbed sand could be contaminated from animal wastes. In addition, riverbed sand grains are more rounded and smooth (as opposed to angular) in their shape, which decreases the effectiveness in trapping contaminants. Sand from high on a riverbank where there is no visible contamination should be used in preference to river bottom sand.

Biological quality testing

Each sand source needs to be tested for its biological quality. A sand source that is regularly used should be tested every 6 months. The following is the recommended procedure (Ritenour, 1998):

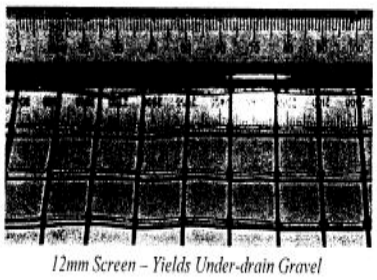
1. Boil about 1 liter of the cleanest and purest water available (not distilled, mineral, or chlorinated water) for about 5 minutes.
2. Let the water cool to room temperature
3. Test a sample of this water for microbial contamination. This is used as a control.
4. Add 5g of sand to 100ml of water. Stir to mix, cover and let sit indoors or in the shade for 12 hours.
5. Decant the water into a clean container.
6. Test a sample of this water for microbial contamination.

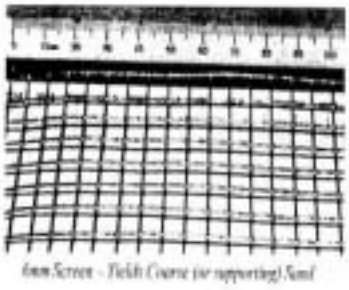
The boiled water should show negative results. If it does not, there has been a sampling error or the water was not boiled long enough. Positive results in the water with sand sample means the contamination is coming from the sand. Sand from this sand source is not suitable for use in the filter; however it could be used for the construction of the concrete body. More sand sources should be sought out and tested for biological quality as outlined above until a clean source is found (Ritenour, 1998). Alternatively, the sand could be disinfected by boiling or spread out in the sun (Murcott, 2001).

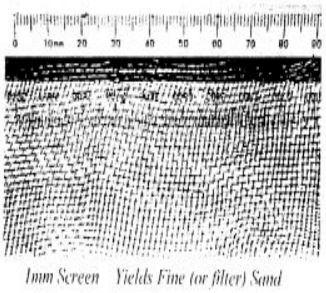
Sifting

Sifting is required to separate coarse and fine sands from underdrain gravel and larger rocks. A total of three different size screens are needed: 12mm screen for under-drain gravel, 6mm screen for the coarse (or supporting) sand, and 1mm screen for the fine (or filter) sand.

Figure 21: Sieves for Sand and Gravel







Cleaning and Flow Rate Test

The sand must be free of dirt, clay fines, and organic matter. Slow sand filters are not backwashed so after the sand is placed in the filter beds, it cannot be cleaned quickly or easily. Therefore, sand must be washed and impurities removed before placement in the filter.

Installing

Gravel and sand are then put into the shell according to the layer heights specified in Figure 3.

3.4 LID

A lid is essential to prevent debris, insects and dirty hands from entering and contaminating the filter. The lid should cover the filter at all times, except when adding water or performing maintenance. The lid may be made out of any material, but it must be clean, must not contain gaps that insects might pass through and should be secure and heavy enough so young children cannot disturb it.

4 EVALUATION METHODOLOGY OF BIOSAND FILTER

As stated earlier in Section 1, the purpose of this study was to investigate the effectiveness and the performance of the BioSand Filter in Nepal. The effectiveness and the performance of the BSF can be evaluated by various means. The ones used by the author included microbial tests, turbidity, flow rate and physical observation.

4.1 MICROBIAL TESTS

The microbial tests used in this study evaluated the effectiveness of the BSF in removing indicator organisms. The concept of indicator organisms was introduced in 1892 and is the basis for most microbiological quality standards in water today (Hach, 2000). Pathogens in water are usually few in number and difficult to isolate (Metcalf and Eddy, 1991). Instead of determining the actual concentrations of pathogens, indicator organism concentrations are often measured to determine the level of contamination in water. Indicator organisms are typically microbes that do not cause diseases themselves, but are found in conjunction and in higher concentrations than waterborne pathogens. Coliforms are one of the most common indicator organisms because they are so numerous in fecal matter. A problem arises when trying to determine the origin of coliform because they may come from benign sources, such as soil, as well as from harmful fecal sources (Metcalf and Eddy, 1991). One coliform entirely of fecal origin, *Escherichia coli*, is considered direct evidence of fecal contamination from warm-blooded animals (Meyers and Sylvester, 1997).

The WHO guidelines for microbial contamination in drinking water is set at zero CFU/100mL for total coliform and zero CFU/100mL for *E.coli*. Broadly speaking, there are two types of

microbial testing methods: qualitative or Presence/Absence (P/A) tests and quantitative/enumeration techniques.

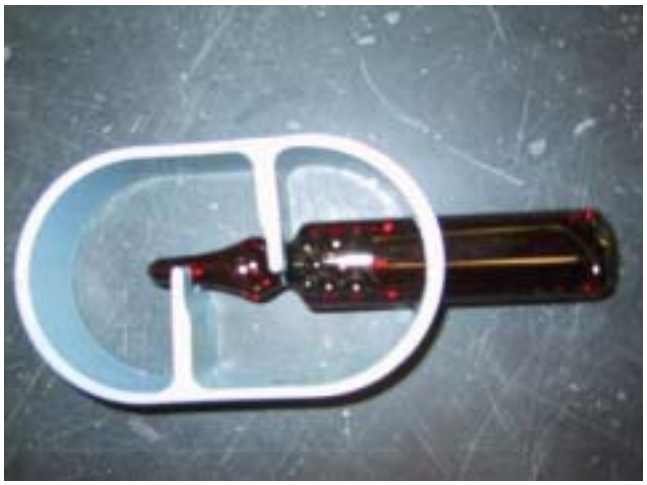
Presence/absence (P/A) tests give a simple yes or no answer to whether certain bacteria are in a water sample, but does not indicate its quantity in the water. The advantage of these tests is that they are simple, inexpensive and sensitive.

During the field work in Nepal, we used two tests from Hach Company. The first, the Presence/Absence (P/A) test is an U.S. EPA-equivalent[4] testing method; it gives a positive or negative response to total coliform as well as *E.coli* (Hach, 2001). This test is easy to perform: it only requires that the reactive medium (P-A Broth - see Figure 22) be combined with 100 mL of sample and incubated for 24 to 48 hours at 35°C. The culture medium acts as the food source for the bacteria present in the water sample. During the incubation period, these bacteria, if present, reproduce in large numbers, resulting in a color change (from purple to yellow) of the liquid mixture, thus making their presence apparent. The analysis is modified to test for *E.coli* by using a 4-methylumbelliferyl-β-D-glucuronide (MUG) reagent that fluoresces under long-wave ultraviolet light when *E.coli* are present.[5]

[4] Method is accepted for presence/absence testing of drinking water in Code of Federal Regulations 40 CFR, Part 141.21 subpart (F)(3) and Standard Methods for the Examination of Water and Wastewater 908A, 19th edition (Hach, 2001).

[5] MUG produces a fluorogenic product when hydrolyzed by glucuronidase, an enzyme specific to *E.coli*. (Products for Analysis, 2001).

Figure 22: P/A Broth in Glass Ampule.



Another P/A test from HACH used during the trip was the PathoScreen™ Medium Pillows for 20-mL sample bottles (see Figure 23). This test detects the presence of H_2S-producing bacteria including *Salmonella, Citrobacter, Proteus, Edwardsiella* and some species of *Klebsiella* (Hach, 2001) with a color change from yellow to black to indicate H_2S bacteria presence.

Figure 23: PathoScreen™ Medium pillows.

Other P/A tests include using the EBPI[6] WaterCheck™ test kit (also known as ColiBag) and International Development Research Center (IDRC) hydrogen sulfide paper strip test.

Figure 24: WaterCheck™ test kit

WaterCheck™ (see Figure 24) detects fecal coliform bacteria (fcb) and it is recommended by Samaritan's Purse for water quality testing of BSF (Ritenour, 1998). The test-kit comes in a sterilized plastic bag. Water sample collection, mixing, incubation, and observation are all done in the same bag. If the water sample is contaminated with a single colony forming unit (CFU) per 100mL of water, there will be a color change from yellow to bluish-green. Currently, WaterCheck™ is more costly than the HACH P/A test.[7]

The IDRC hydrogen sulfide test uses a paper strip that is treated with a medium prepared from dissolving peptone, dipotassium hydrogen phosphate, ferric ammonium citrate, sodium thiosulfate and teepol (detergent) in water. The treated paper strip is incubated with the water sample. If bacteria are present in the sample, they produce hydrogen sulfide, which turns the

[6] Environmental Biodetection Products Incorporated. See company website: http://www.ebpi-kits.com/

[7] One WaterCheck™ test kit costs CAD$4.00 (US$2.70) (http://www.ebpi-kits.com) and one HACH P/A test costs $1.50 (Products For Analysis, 2001). Shipping not included.

paper black. This method was developed through a project funded by IDRC (Manja et al., 1982) and it was first tested during an epidemic of hepatitis A infection in Gwalior, India. The IDRC H_2S test is low-cost, easy-to-use, and could be carried out by a local person after being trained (Pillai et al., 1997). The cost of one test is $0.13 (Murcott, 2001).

We planned to carry out microbial testing using the H_2S method. For that purpose, about 100 homemade test kits were brought to Nepal. However, these test kits were not used, after a discovery that our method of preparation was erroneous due to a typographical mistake in the IDRC instructions (Murcott, 2001).

Quantitative tests measure the amount of fecal coliform bacteria in CFU per 100mL water. One such method is the membrane filtration technique. This method requires filtering a sample of appropriate volume through a membrane filter of sufficiently small pore size to retain the organism(s) sought. Then the filter is placed on an appropriate agar medium, or pad saturated with an appropriate broth medium, and incubated. If the organisms sought are present, colonies will grow on the membrane filter. Colonies are examined and identified by size, color, shape and sheen. Typical colonies are counted and the number is reported as the number of colony forming units per 100 mL of sample. This technique is sensitive enough to detect 1 CFU/100mL. However, this method was not used in the field because it was expensive and it was too difficult to conduct under field conditions encountered in Nepal.

In April and May 2001, membrane filtration tests were carried out on water samples prior to and after filtration through a plastic BSF in a laboratory at MIT, Cambridge, Massachusetts. Test results are presented in section 6.

4.2 TURBIDITY

Turbidity is a water quality parameter that quantifies the degree to which light traveling through a water column is scattered by suspended organic and inorganic particles. The scattering of light increases with the increased suspended load. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), but may also be measured in Jackson Turbidity Units (JTU) (Metcalf and Eddy, 1991).

Excessive turbidity, or cloudiness, in drinking water is aesthetically unappealing, and may also represent a health concern. Turbidity can provide food and shelter for pathogens. If not removed, turbidity can promote regrowth of pathogens in the distribution system, leading to waterborne disease outbreaks, which have caused significant cases of gastroenteritis throughout the United States and the world. Although turbidity is not a direct indicator of health risk, numerous studies show a strong relationship between removal of turbidity and removal of protozoa (U.S. EPA, 1999). The WHO guideline for the non-microbial turbidity level in drinking water is set at 5 NTU. In Nepal, the inflow water from the Sundarigat water treatment plant was found to have turbidity levels varying between 8 and 15 NTU (Sagara, 2000).

Figure 25: HACH Pocket Turbidimeter

Turbidity was measured in the field using a HACH Pocket Turbidimeter™ Analysis System (see Figure 25). The Pocket Turbidimeter™ Analysis System[8] measures turbidity in the range from 0.1 to 400 NTU. It operates on the nephelometric principle of measurement, monitoring light scattered by the sample at 90° to the incident beam. The optical system includes an infrared LED (880 nm wavelength) and scattered-light detector (Pocket Turbidity Analysis System, 1997).

4.3 FLOW RATE

Flow rate measurement is useful at both the sand selection stage and the operations stage. At the sand selection stage, it indicates whether the sand in the filter is of an appropriate size. At the operations stage, it indicates if the filter requires maintenance.

[8] The system meets ISO 7027 Turbidimetric Measurement Standards. (Pocket Turbidity Analysis System, 1997)

The flow rate of a filter is determined by the effective size and uniform coefficient of the sand grains. The recommended initial flow rate (for the purpose of sand selection) is 10 ± 3L per square meter per minute (Ritenour, 1998).

The flow rates of the BSFs were found from measuring the time it takes to fill up a container of known volume (see Figure 26). In the field, 250mL sample bottles were used together with a wristwatch with a timer function. Only single measurements were taken.

Figure 26: Measuring flow rate

The flow rate depends on the head of the water. High flow rate would result if there is a high head gradient. To eliminate variations in flow rate due to the head gradient, flow rate measurements were started when the water level was about midway from the diffuser plate and the top of the filter (Ritenour, 1998). This ensured that comparison can be carried out uniformly across all the filters based only on the combined resistance to flow due to the sand, gravel and clogging of the filters.

As the biological layer thickens and as fine silts deposit on the topmost layer of sand, the flow rate of the filter will decrease. As the filter clogs, its output decreases but its effectiveness in

purifying water does not. In fact, the effectiveness is expected to increase, since slower flow rate allows longer contact time between the biofilm and the raw water.

However, low output may not be sufficient to meet the needs of the family. If the water is coming out at a slight trickle, it is time to service the filter.

The frequency of clogging is directly related to the quality of the water being treated. Very turbid waters, as in the case of surface water sources in Nepal during the monsoon seasons, contain a large amount of fine silts, which are trapped in the uppermost layer of sand and biology. The higher the content of fine silts, the more quickly the filter will clog. Also, if the water contains a large population of biology, the biofilm that feeds on this content will rapidly grow or thicken. This will also result in clogging at the top of the filter.

4.4 PHYSICAL OBSERVATIONS

There are several observations that can be made regarding different aspects of the filter. These observations are important in detecting possible operating problems with the filters. The different aspects of the filter are spouts attachment, diffuser plates, sand layers and cracks in the concrete body.

4.4.1 Spouts Attachment

There should not be any types of attachment to the spout. This is because the flow in a BioSand filter should be continuous and not stopped. Stopping the flow for extended periods of time (especially when water has just been poured in) is not favorable to the growth or sustenance of the biology in the filter since oxygen diffusion is reduced.

4.4.2 Diffuser Plate

The diffuser plate must be kept in good condition to keep the force of pouring water from disturbing the layer. If the biological layer is disturbed, the effectiveness of the filter will be compromised and more significant numbers of harmful organisms may pass through the filter.

4.4.3 Sand Layer

The sand in the BSF is crucial to the filtration process of the BSF. If this layer is disturbed or damaged, the effectiveness of the filter will be compromised and more significant numbers of harmful organisms may pass through the filter. If the top layer of sand is uneven, it is a sign that there is water is skirting the edge of the diffuser plate and scouring the surface.

The resting water level must be below the diffuser plate for the biofilm to receive enough oxygen, and it must be 5cm above the sand level to buffer the sand from incoming water. Also, the biological layer cannot take high loads of toxic chemicals, such as bleach.

4.4.4 Cracks in the Concrete Body

The filter has to be checked for cracks below the resting water level. If there are such cracks, the filter could be leaking and the flow rate would decrease. This is because the cracks create paths of less resistance for the water. Correspondingly, there will be less filtration.

5 RESULTS AND DISCUSSION

The author spent four days in the district of Palpa and nine days in the district of Nawalparasi performing sample collection and testing. A total of 39 sets of samples were tested. Each set of samples consisted of two individual samples; one sample of water before filtration and one after filtration by the BSF. All 78 samples were tested for H_2S-producing bacteria and turbidity. Due to a constraint of resources, not all samples were tested for total coliform and E.coli. Table 6 summarizes the number and type of the test performed at each location.

Table 6: Number of samples analyzed

	Turbidity	*H_2S*	*Total Coliform*	*E. coli.*
Tansen	12	12	2	2
Nawalparasi	66	66	36	36
Total	78	78	38	38

5.1 MICROBIAL TESTS RESULTS

Of the 39 BSFs that were studied in Nepal, 14 of them do not show favorable results in one or more of the microbial tests performed. Of the subset that did not work, 9 of the BSF were found to have problems either with the diffuser plate, the resting water level or the maturity of the biofilm (Figure 28). Since these filters may not be representative of the microbial removal efficiency of the BSF operating under "good" conditions, we separated the data into 2 categories in order to observe the performance of only the filters that were working properly. The results of the analyses – for all filters and only the filters that were working properly - are shown in Figure 27.

Figure 27: BSF microbial results

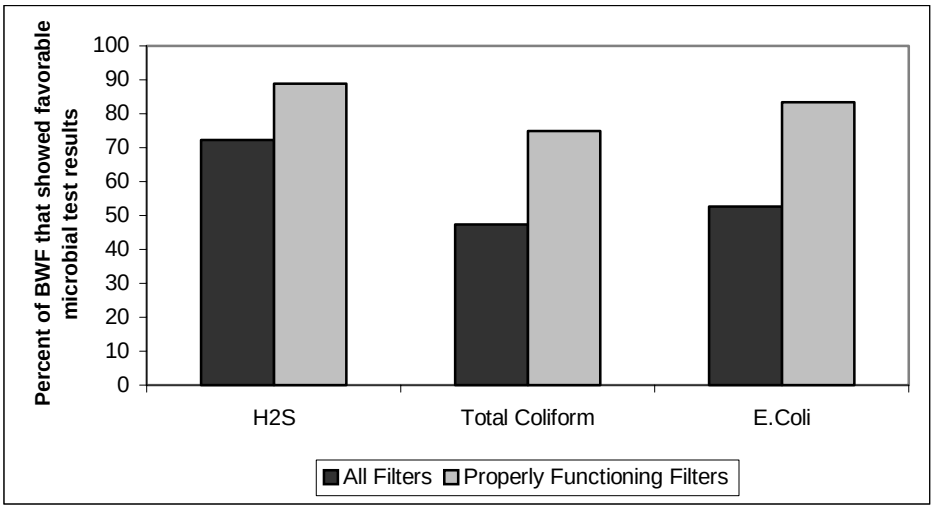
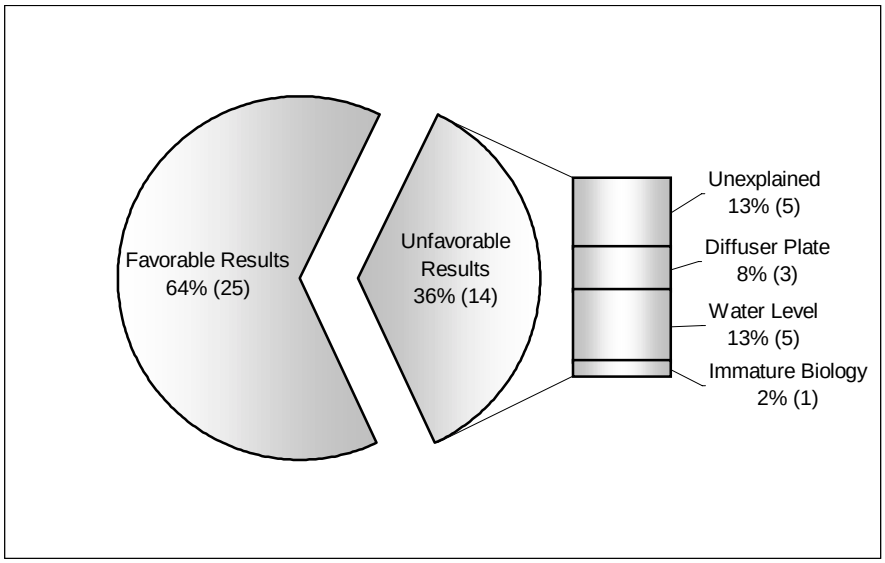


Figure 28: Distribution of observed problems with the BSF



From Figure 27, if we include all the BSFs that were tested, only 47% managed to remove total coliform, 53% removed *E. coli* and 72% removed hydrogen sulfide producing bacteria. If we consider only the 25 filters that were working properly, percentages that removed total

coliform, *E. coli* and hydrogen sulfide producing organisms increased to 75%, 83% and 89% respectively.

As shown in Appendix C, only 12 properly functioning were tested for total coliform and *E.coli*.. Of these 12 BSFs, 9 meet the WHO guidelines for drinking water of zero CFU/100mL for total coliform, and 10 meet the WHO guidelines for drinking water of zero CFU/100mL for *E. coli*. This is a significant improvement in the drinking water quality as compared to the Indian and Nepali ceramic candle filters and the Haitian Gift of the Water Filter that were tested in Nepal by the previous MIT M.Eng group, none of which removed total coliform and only the Indian filter removed *E. coli* (Sagara, 2000). The Haitian Gift of Water Filter, which includes a chlorination step was successful at bacterial disinfection. However, it also suggests that the BSF is not a perfect technology since about 30% of the BSFs did not meet the WHO guidelines, for subset of BSF that were identified to be working properly.

5.2 TURBIDITY RESULTS

The average turbidity of the influent water is 10NTU for all BSFs and 13NTU for BSFs that were working properly. Both are below the maximum recommended turbidity limit of 100 NTU (Davnor Water Treatment Technology Ltd.). This suggests that the BSF could be suitable for use in Palpa and Nawalparasi during non-monsoon season. In the monsoon season, it may be necessary to pretreat the source water simply by letting the water settle before pouring it into the BSF. Otherwise, it becomes necessary to clean the filter more frequently since more clogging is expected to occur with higher levels of source water turbidity. If the frequency of maintenance is so high that the there is not enough time for the biology to mature, then the effectiveness of the BSF is reduced.

The turbidity of water coming out of a BSF is 0.9 NTU if averaged over all the filters and 0.8 NTU if averaged over only the ones that were observed to be functioning properly. Both values are lower than 5 NTU, which is the WHO guideline for maximum allowable turbidity in drinking water.

Turbidity removal averaged 75% for all the BSFs that were tested. Excluding the filters with problems, on average, 84% of the turbidity of the influent water was removed (Figure 29). Figure 30 describes the distribution of percentage turbidity removal. The mode of the distribution lies in the range of 90-100% turbidity removal.

Figure 29: Turbidity removal results.

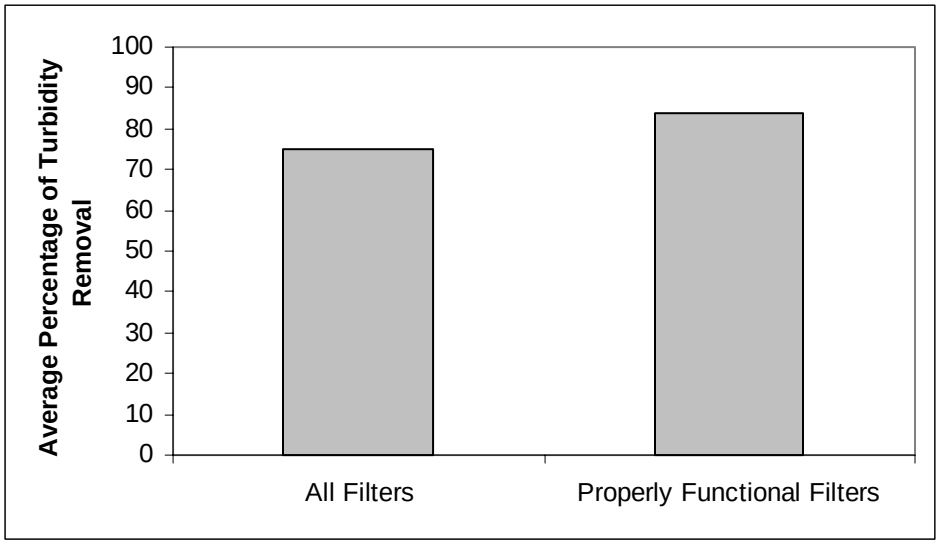
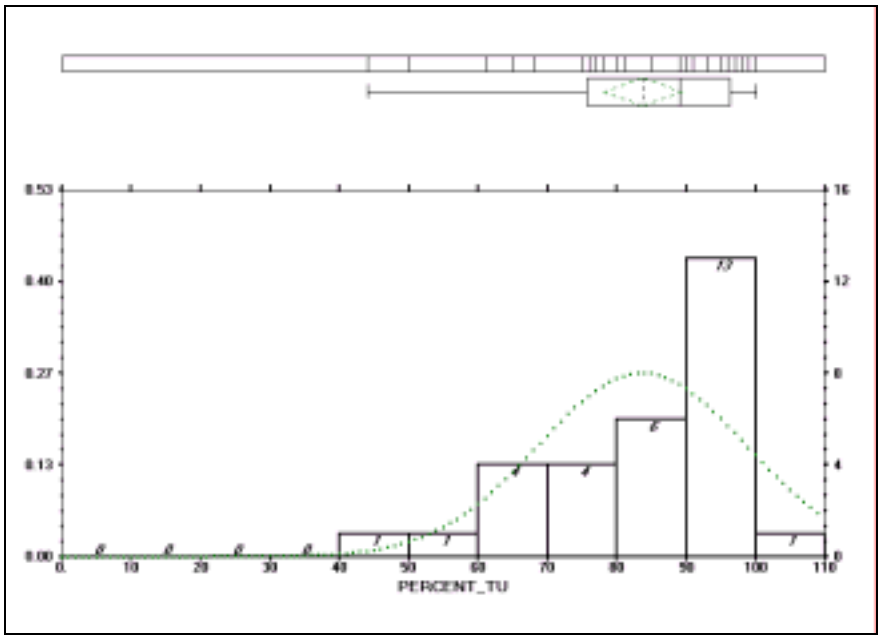


Figure 30: Distribution of percentage turbidity removal for filters that were working properly.

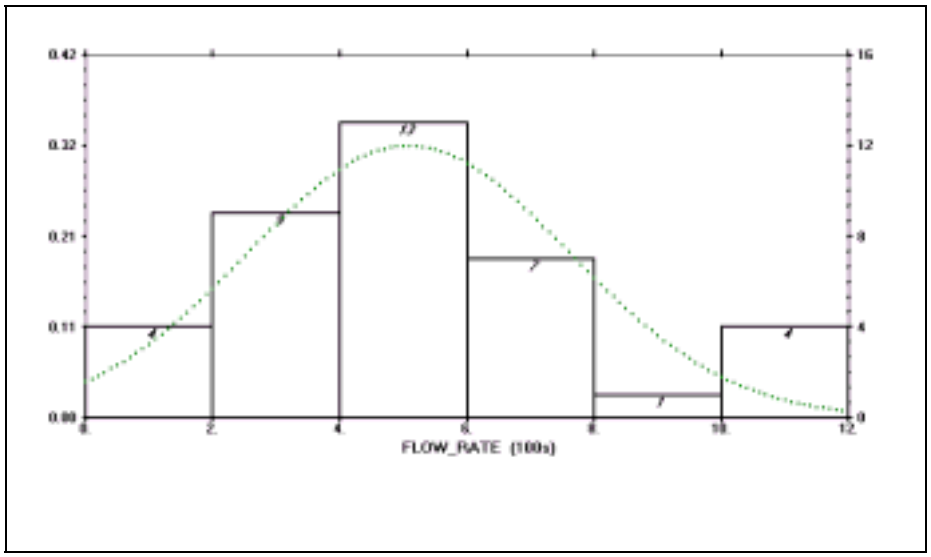


5.3 FLOW RATE RESULTS

The flow rates of the filters ranged from about 3L/hr to 60L/hr and averaged 30L/hr. This is significantly higher than the flow rates of the Indian and Nepali ceramic candle filters and the Haitian Gift of the Water purifier that were tested in Nepal by the previous MIT M.Eng group which ranged from 0.01-0.5L/hr and averaged 0.25L/hr (Sagara, 2000). The flow rate results suggests that the BSF is capable of providing sufficient amounts of drinking water to Nepali households if the filter runs for only two to three hours a day (recommended amount of drinking water is 7L per capita per day [Spruijt, 2000]).

The measured average flow rate of BSF in Palpa and Nawalparasi of 30L/hr is within the suggested initial range of flow rate of 36±10L/hr (Ritenour, 1998) for the typical square concrete filter with area of 0.0625 square meters. The distribution of BSF flow rates from the field trip in Nepal is shown in Figure 31.

Figure 31: Distribution of flow rate



5.4 PHYSICAL OBSERVATION RESULTS

5.4.1 Spouts Attachment

Of the thirty-nine BSFs that were investigated, twenty had spigots or wooden/metal plugs attached to the spout, thirteen had no such attachments and for six, observations on spouts were not made. Presence of a spigot does not mean blocked flow, it merely gives the user the option to stop the flow of water. Stopping the flow for extended periods of time (especially when water has just been poured in) is not favorable to the growth or sustenance of the biology in the filter since oxygen diffusion is reduced. On the other hand, users of the filters like the flexibility afforded by a tap; they do not have to constantly attend to the filter or worry that water might overflow and flood their homes. To solve this conflict of interest, some have come up with the idea of an intermediate, storage container as shown in Figure 32. The spout leads directly into the intermediate storage container which has a tap allowing the users to dispense water when needed. This solution removes the need to plug the spout (Figure 33) and

the need to constantly attend to the filter. However contamination could occur during storage, particularly if the containers are not cleaned hygienically (Cave and Kolsky, 1999).

Figure 32: Intermediate storage container for filtered water

Figure 33: Spout is not plugged, allowing continuous flow.

5.4.2 Diffuser Plate

Of the 39 BSFs that were investigated, 34 had diffuser plates and the remaining had diffuser basins. There were no diffuser pans. Of the 34 diffuser plates, 25 were made of LDPE and 9 were made of metal. The diffuser basins were mostly made of metal; only one was made of plastic. Of the plastic diffuser plates, 5 were found to float when water was poured in, as shown in Figure 34. This is an undesirable condition because a floating diffuser plate is not supported by the inner ledge of the BSF and thus has the additional degrees of freedom on the horizontal plane. Thus, when more water was poured in at one side of the filter, the diffuser plate would be free to tilt downwards in response to the force derived from the weight of the water. This allows the water to scour the sand layer, disturb the filter cake and reduce the effectiveness of the BSF.

Figure 34: A floating LDPE diffuser plate.

5.4.3 Sand Layer

Of the 39 BSFs that were investigated, 10 had a disturbed top sand layer (see Figure 35). This is easily observable when This is another undesirable condition because. The disturbed sand could be a result of hydraulic scouring of the sand or human hands. Two BSFs were observed to have resting water level that was below the sand layer (see Figure 36). There was only 1 case where the resting water level was higher than the prescribed 5cm (see Figure 37).

Figure 35: Disturbed top layer of fine sand.

Figure 36: Water level at rest below top layer of fine sand.

Figure 37: Water level at rest more than 5cm above the topmost sand level.

5.4.4 Cracks in Concrete Body

Of the thirty-nine BSFs that were investigated, only 2 had cracks in the concrete shell. One was mended using cement paste (see Figure 38), the other was not mended.

Figure 38: A cracked BSF that was mended by a technician

5.5 CORRELATIONS

A summary of the correlations between various pairs of parameters is presented in Table 7. There is little correlation between turbidity removal and flow rate. Correlations between the microbial tests are moderately strong to strong.

Table 7: Summary of Correlations

Parameter 1	*Parameter 2*	*Correlation, ρ (correlation sample size)*	
		All BSFs	*Functioning BSFs*
Turbidity Removal	Flow Rate	-0.23 (38)	-0.11 (24)
H_2S Test	Total Coliform Test	0.64 (19)	0.52 (12)
H_2S Test	*E. coli* Test	0.72 (19)	0.67 (12)
Total Coliform Test	*E. coli* Test	0.9 (19)	0.78 (12)

5.6 DRAWBACKS

The first major drawback of the BSF is that it does not appear to be a 100% effective technology. About 30% of the filters that were working properly did not manage to meet WHO's standards for drinking water of zero CFU/100mL for total coliforms and *E. coli.*

The second drawback is that although the BSF is a simple technology, there are many ways for errors to occur that will compromise the effectiveness of the technology. Mistakes can occur at the construction stage, operations stage and maintenance stage. At the construction stage, an improperly cast concrete body would leak. A faulty diffuser plate would reduce its protective function. Selection of an inappropriate sand source will cause the flow rate of the filter to deviate from the recommended range. Installing too much or too little of the sand or gravel could cause the standing water to be too low or too high. At the operations stage, if the user plugs the spout for extended periods of time while there is still considerable standing water,

the biology in the filter might not get sufficient oxygen. In the maintenance stage, the user might not know the proper procedures to clean the filter and therefore decide not to clean it.

The third drawback of the filter is that it takes time for the biology to fully mature. During this ripening period, which is estimated to be 2 weeks, the filter is less effective in removing contamination.

The fourth drawback is that the efficiency of the filter is limited by the turbidity of the source water. In the monsoon season, the performance of the filter will be compromised. Pretreatment steps may be necessary to reduce the turbidity of the influent water to the filter.

6 EXPERIMENTS CARRIED OUT AT MIT

Microbial results from the Nepal field trip were less satisfactory than that reported by previous studies on the BSF (see Table 4). Also, we did not carry out any quantitative (enumeration) tests in Nepal. There was a need to further evaluate the effectiveness of the BSF technology in removing microbial contamination if we wanted to recommend it for adoption.

At MIT, the author conducted membrane filtration tests and pH tests on a plastic BSF (Figure 4). The experiment started on March 13 and ended on May 7, 2001. During the test period, about 20L of water from the Charles River was collected every day (except weekends) and passed through the filter. The BSF was allowed 45 days to mature. Membrane filtration tests were then carried out. The pH was also measured, in response to a comment made at the presentation given by this year's MIT Masters of Engineering Program at the headquarters of the Federation of Business and Professional Women - Nepal.

6.1 MEMBRANE FILTRATION

A total of five trials were carried out. Each trial consists of two 100mL of water samples: one before and one after the passing through the filter. Dilution was required for the influent water sample because the total coliform bacteria were too numerous to count (TNTC) in the original water sample. Dilution of 1/10 made the counts fall in the recommended range of 20 to 80 (American Public Health Association, 1992). The medium used was the m-Endo broth manufactured by Millipore, which tests for total coliform. The results of the membrane filtration tests are shown in Table 8. Average percentage removal of total coliforms is 99.5%. This result confirms the results reported in Table 4. This indicates that the BSF is a fairly effective technology at removing total coliforms.

It is also important to remember that these tests were carried out under controlled conditions. First of all, there were no problems with the construction of the filter. The plastic BSF shell used in the experiment was manufactured by Davnor Water Treatment Technologies and there were no cracks or leaks; the sand and gravel were also from a crushing operation; the diffuser basin is manufactured and fits perfectly. Secondly, the operation of the filter followed the rules of use. The filter was continuously fed with water everyday except on weekends; the filter was not moved; and the sand was not disturbed for the duration of the experiment. These factors could explain the difference in the performance of the plastic BSF in the laboratory and the concrete BSF in the field. Other possible factors include the quality of source water.

Table 8: Membrane filtration total coliform results

Trial Number	*Date*	*Influent (CFU/100mL)*	*Effluent (CFU/100mL)*	*% Removal*
1	April 28	560	3	99.46
2	April 29	610	5	99.18
3	May 1	680	3	99.58
4	May 2	590	2	99.66
5	May 5	730	2	99.72
Average		630	3	99.52

Figure 39: Membrane filtration total coliform results - Charles River water before filtration (left); after filtration (right)

6.2 pH

pH was measured using a pH-probe. A total of four trials were carried out on the May 7th. There is no significant change in the pH before and after filtration, as shown in Table 9. This indicates that the sand and gravel from Davnor is inert.

Table 9: pH values of water before and after filtration

Trial Number	*Influent pH*	*Effluent pH*
1	6.3	6.5
2	6.2	6.7
3	6.0	6.3
4	6.5	6.4

7 SUMMARY AND CONCLUSIONS

From the field survey in Nepal, the author found some design implementation problems with concrete BSFs in Nepal that resulted in the filters to perform less satisfactorily. These problems, as noted in section 5.4, ranged from cracks in the BSF resulting from poor construction to inability of the diffuser plate to protect the filter cake. Of the thirty-nine filters that were investigated, nine of the filters had these problems, leading to poor filter performance.

From turbidity measurements of the influent and effluent of the BSF, the author found that the turbidity removal in a BSF averaged 75% for all the BSFs that were tested. Among the filters which were working properly, on average, 84% of the turbidity of the influent water was removed. The average effluent turbidity was less than 5 NTU, which is the WHO maximum standards for drinking water.

From presence/absence tests, the author found that only 9 out of 12 properly functioning BSFs removed total coliform, 10 out of 12 properly functioning BSFs removed *E. coli.*, and 24 out of 27 properly functioning filters removed hydrogen-sulfide producing bacteria. As these results were not indicative of the effectiveness of the BSF at removing bacteria, further tests were carried out on a plastic BSF at MIT to evaluate the effectiveness of the filter. Membrane filtration results showed that the BSF removed an average of 99.5% of total coliform after being in operation for 45 days. This verified that the BSF is a fairly effectives technology for the removal of total coliforms in water.

Flow rate measurements of the effluent water from the BSFs in Nepal yields an average of 30L/hr, which means that the BSF could provide an adequate supply of drinking water for a typical Nepali household.

Based on the result of the study, namely, effective removal of total coliforms, reduction of turbidity and high flow rate, the author recommends the BSF technology to be adopted on a large scale in Nepal. However, this needs to go hand-in-hand with a monitoring plan to ensure correct construction, operation and maintenance procedures are followed. The monitoring plan is necessary to reduce the fraction of BioSand filters that were not working properly. The author also recommends further studies on developing such a monitoring plan.

Other drawbacks to the system, as mentioned in section 5.6, should also be addressed. For example, pretreatment of higher turbidity water in the monsoon season is necessary to reduce the silt/clay loading which would clog up the filter. For further discussion on how pretreatment may be carried out, the reader is recommended to refer to Paynter (2001).

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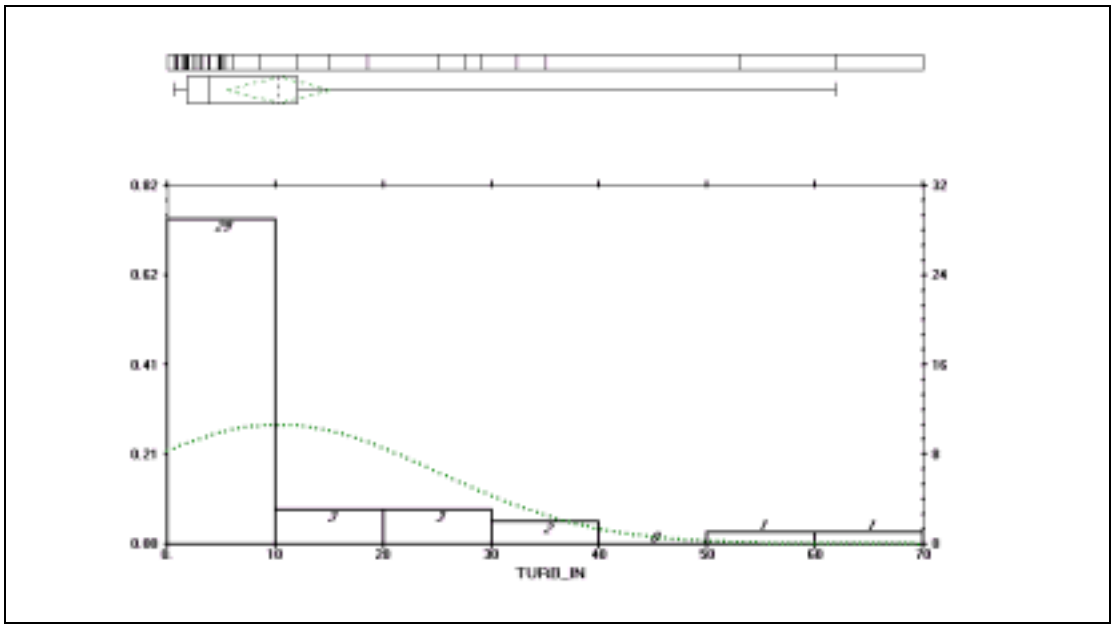
APPENDIX A: LIST OF EQUIPMENT USED DURING FIELD TRIP IN NEPAL

1. Hach Pocket Turbidimeter x 1
2. P/A Ampules with MUG Reagent x 40
3. Hach PathoScreen Medium x 100
4. 100mL Bottles x 12
5. 20ml Bottles x 50
6. Fluorescent Light with Spare Tube x 1
7. Toenail clipper x 1
8. Rubbing Alcohol x 1
9. Candle and Matches x 1
10. Ampule breaker x 1
11. Incubator equipment: 20mL x 2, 100mL x 2
12. Plastic Sample Bottle x 12

APPENDIX B: TURBIDITY MEASUREMENT STATISTICS

Influent Turbidity

All Filters



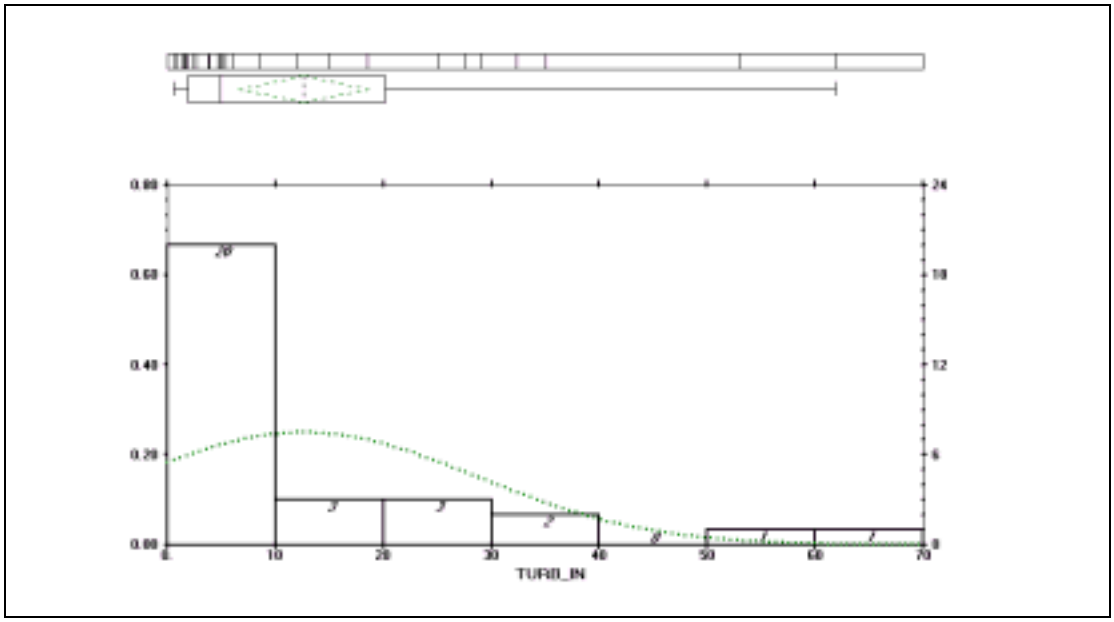
Descriptive Statistics

Variable Name is TURB_IN

N = 39

Mean = 10.28718	St. Dev (n-1) = 14.63157
Median = 3.90	St. Dev (n) = 14.44276
Minimum = 0.60	S.E.M. = 2.34293
Maximum = 61.90	Variance = 214.08273
Sum = 401.20	Coef. Var. = 1.42231

Filters that were working properly



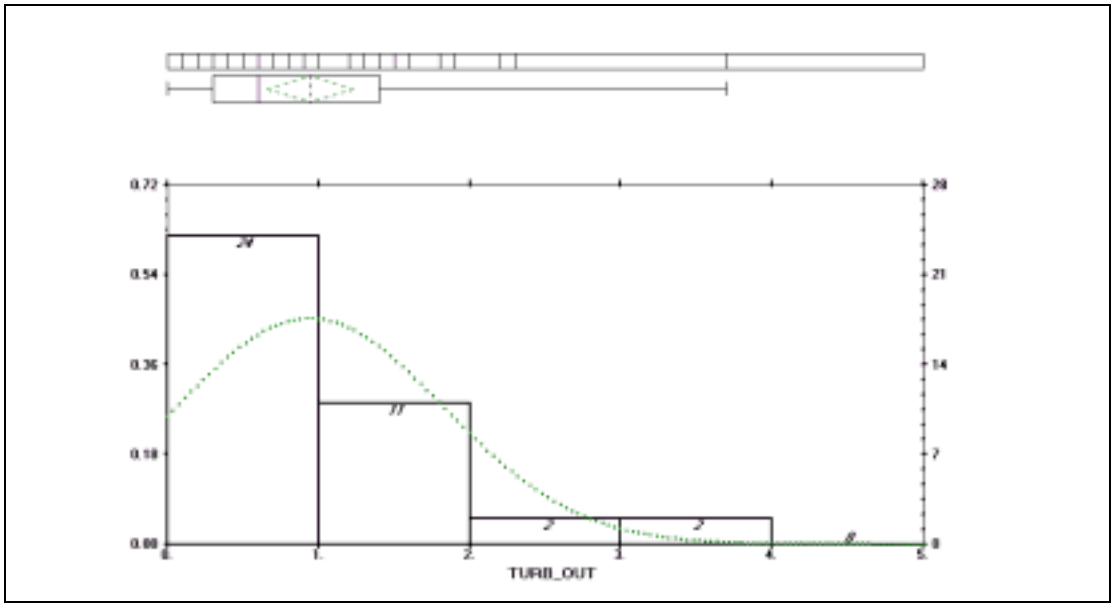
Descriptive Statistics

Variable Name is TURB_IN

N	= 30		
Mean	= 12.64667	St. Dev (n-1)	= 15.97059
Median	= 4.95	St. Dev (n)	= 15.70216
Minimum	= 0.60	S.E.M.	= 2.91582
Maximum	= 61.90	Variance	= 255.05982
Sum	= 379.40	Coef. Var.	= 1.26283

Effluent turbidity

All Filters

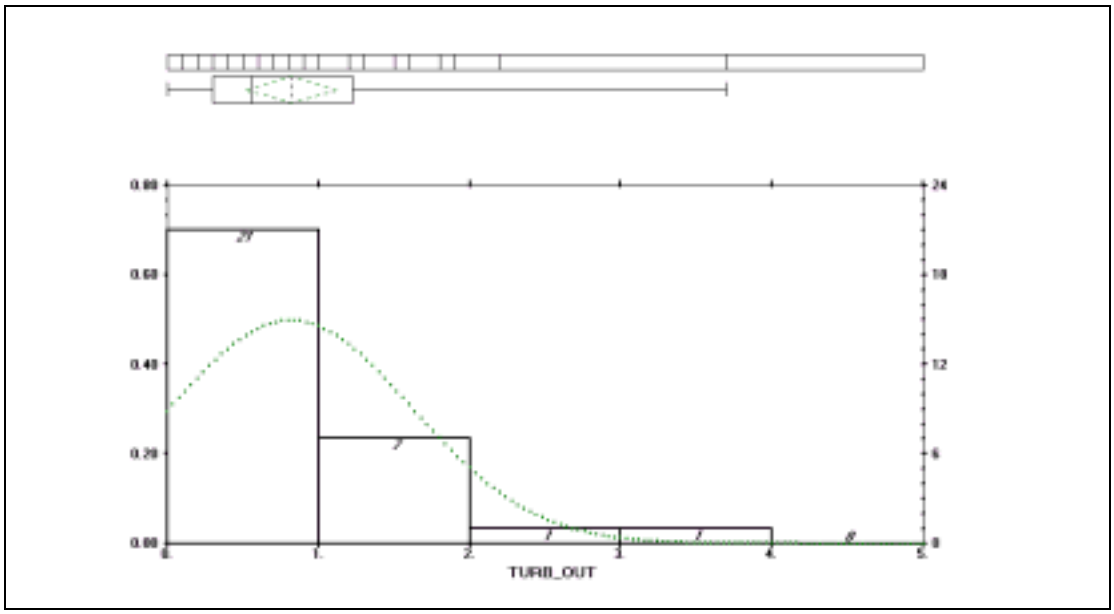


Descriptive Statistics

Variable Name is TURB_OUT

N = 39	
Mean = 0.94615	St. Dev (n-1) = 0.88521
Median = 0.60	St. Dev (n) = 0.87379
Minimum = 0.00	S.E.M. = 0.14175
Maximum = 3.70	Variance = 0.7836
Sum = 36.90	Coef. Var. = 0.93559

Filters That Were Working Properly



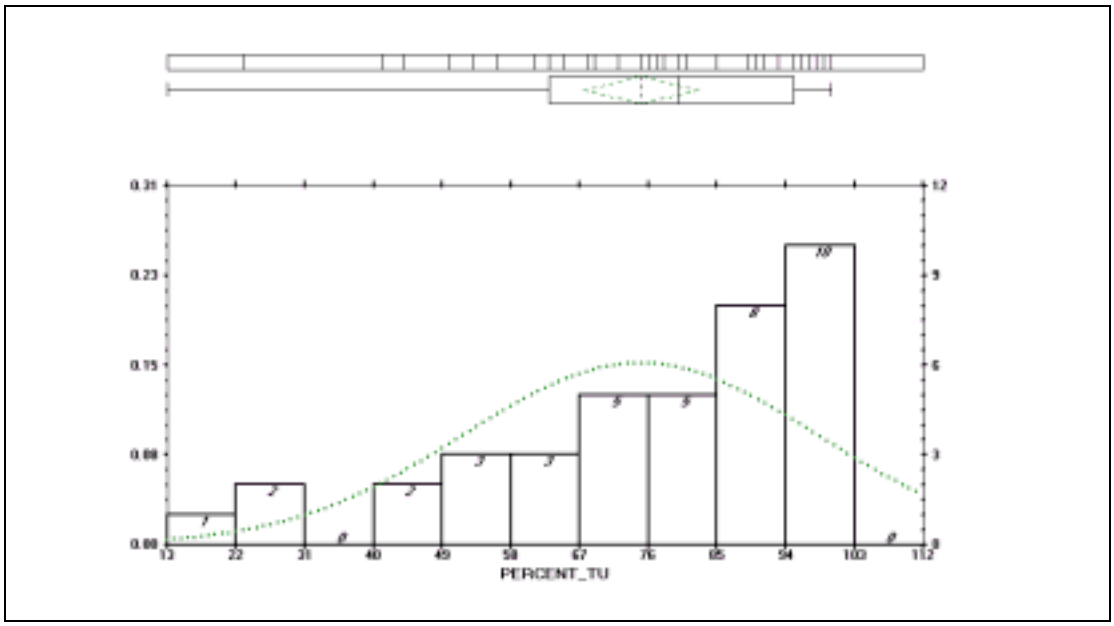
Descriptive Statistics

Variable Name is TURB_OUT

N = 30	
Mean = 0.82	St. Dev (n-1) = 0.80103
Median = 0.55	St. Dev (n) = 0.78757
Minimum = 0.00	S.E.M. = 0.14625
Maximum = 3.70	Variance = 0.64166
Sum = 24.60	Coef. Var. = 0.97687

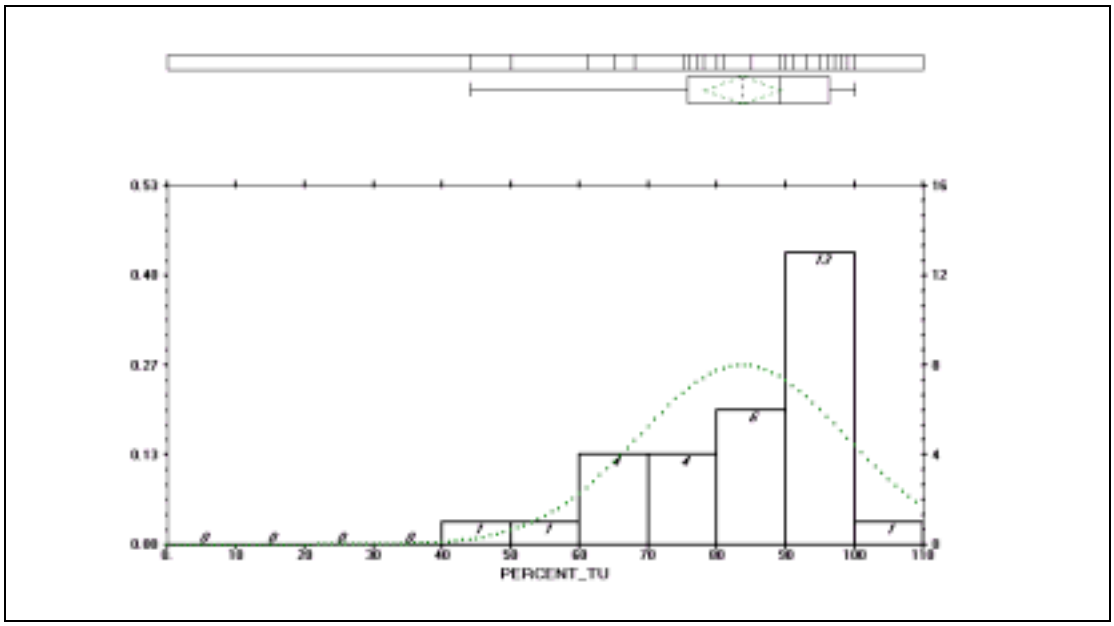
Percentage Turbidity Removal

All Filters



N	= 39		
Mean	= 74.97436	St. Dev (n-1)	= 23.06226
Median	= 80.00	St. Dev (n)	= 22.76467
Minimum	= 13.00	S.E.M.	= 3.69292
Maximum	= 100.00	Variance	= 531.86775
Sum	= 2924.00	Coef. Var.	= 0.3076

Filters That Were Working Properly



Variable Name is PERCENT_TU

N	= 30		
Mean	= 83.70	St. Dev (n-1)	= 14.96928
Median	= 89.00	St. Dev (n)	= 14.71768
Minimum	= 44.00	S.E.M.	= 2.733
Maximum	= 100.00	Variance	= 224.07931
Sum	= 2511.00	Coef. Var.	= 0.17884

APPENDIX C: FIELD TEST RESULTS

All Filters

Date	BSF #	Flow Rate (mL/min)	Turbidity			Microbial Removal		
			In	Out	% Turbidity Removal	H_2S producing organisms	Total Coliform	*E Coli*
January 8, 2001	1	500	1.9	0.1	95	Yes	Yes	Yes
January 9, 2001	3	180	29	0	100	Yes		
January 10, 2001	5	147	4.7	0.1	98	No		
January 10, 2001	6	N/A	2.7	0.3	89	Yes		
January 11, 2001	8	319	0.8	0.2	75	N/A		
January 11, 2001	9	333	8.5	0.3	96	Yes		
January 13, 2001	10	556	3.2	1.2	63	No		
January 13, 2001	11	577	3.9	0.6	85	Yes		
January 14, 2001	12	306	14.9	1.3	91	Yes	No	Yes
January 14, 2001	13	441	4.8	3.7	23	No	No	No
January 14, 2001	14	667	1.6	0.9	44	N/A		
January 14, 2001	15	500	3.8	1.5	61	No		
January 14, 2001	16	600	3.9	2.3	41	No		
January 14, 2001	17	600	18.5	3.7	80	Yes	Yes	Yes
January 14, 2001	18	667	32.3	2.2	93	Yes		
January 15, 2001	19	1000	1.8	0.5	72	No	No	No
January 16, 2001	20	789	0.9	0.4	56	Yes	No	No
January 16, 2001	21	455	1.3	1	23	No	No	No
January 16, 2001	22	469	25.1	0.4	98	N/A		
January 16, 2001	23	1000	6.1	0.4	93	Yes		
January 16, 2001	24	263	1.3	0.4	69	No	No	No
January 17, 2001	25	484	5.4	1.2	78	No	No	No
January 17, 2001	26	1000	1.6	1.4	13	No	No	No
January 17, 2001	27	405	1.9	0.6	68	Yes		
January 18, 2001	28	750	53	0.4	99	Yes	Yes	Yes
January 18, 2001	29	536	1.3	0.3	77	Yes		
January 18, 2001	30	375	61.9	1.9	97	Yes	Yes	Yes
January 18, 2001	31	333	0.6	0.3	50	Yes		
January 18, 2001	32	714	8.5	1.6	81	Yes		
January 18, 2001	33	1000	35	1	97	Yes	Yes	Yes
January 19, 2001	34	263	2.7	0.3	89	Yes		
January 19, 2001	35	53	27.5	0.7	97	Yes	Yes	Yes
January 19, 2001	36	429	2.3	0.8	65	Yes		
January 19, 2001	37	192	5	0.5	90	Yes	Yes	Yes
January 19, 2001	38	500	4.9	0.2	96	Yes	Yes	Yes
January 19, 2001	39	938	1.9	0.6	68	Yes		
January 20, 2001	40	405	3	1.4	53	Yes	No	No
January 20, 2001	41	250	12	1.8	85	Yes	Yes	Yes
January 20, 2001	42	319	1.7	0.4	76	Yes	No	No
Average		508	10.3	0.9	75	72%	47%	53%

Properly Functioning Filters

Date	BSF #	Flow Rate (mL/min)	Turbidity			Microbial Removal		
			In	Out	% Turbidity Removal	H_2S producing organism	Total Coliform	*E Coli*
January 8, 2001	1	500	1.9	0.1	95	Yes	Yes	Yes
January 9, 2001	3	180	29	0	100	Yes		
January 10, 2001	5	147	4.7	0.1	98	No		
January 10, 2001	6	N/A	2.7	0.3	89	Yes		
January 11, 2001	8	319	0.8	0.2	75	N/A		
January 11, 2001	9	333	8.5	0.3	96	Yes		
January 13, 2001	11	577	3.9	0.6	85	Yes		
January 14, 2001	12	306	14.9	1.3	91	Yes	No	Yes
January 14, 2001	14	667	1.6	0.9	44	N/A		
January 14, 2001	15	500	3.8	1.5	61	No		
January 14, 2001	17	600	18.5	3.7	80	Yes	Yes	Yes
January 14, 2001	18	667	32.3	2.2	93	Yes		
January 16, 2001	22	469	25.1	0.4	98	N/A		
January 16, 2001	23	1000	6.1	0.4	93	Yes		
January 17, 2001	25	484	5.4	1.2	78	No	No	No
January 17, 2001	27	405	1.9	0.6	68	Yes		
January 18, 2001	28	750	53	0.4	99	Yes	Yes	Yes
January 18, 2001	29	536	1.3	0.3	77	Yes		
January 18, 2001	30	375	61.9	1.9	97	Yes	Yes	Yes
January 18, 2001	31	333	0.6	0.3	50	Yes		
January 18, 2001	32	714	8.5	1.6	81	Yes		
January 18, 2001	33	1000	35	1	97	Yes	Yes	Yes
January 19, 2001	34	263	2.7	0.3	89	Yes		
January 19, 2001	35	53	27.5	0.7	97	Yes	Yes	Yes
January 19, 2001	36	429	2.3	0.8	65	Yes		
January 19, 2001	37	192	5	0.5	90	Yes	Yes	Yes
January 19, 2001	38	500	4.9	0.2	96	Yes	Yes	Yes
January 19, 2001	39	938	1.9	0.6	68	Yes		
January 20, 2001	41	250	12	1.8	85	Yes	Yes	Yes
January 20, 2001	42	319	1.7	0.4	76	Yes	No	No
Average		475	13	1	84	89%	75%	83%