Biological Sand Filters: Low-Cost Bioremediation Technique for Production of Clean Drinking Water

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ABSTRACT

Approximately 1.1 billion people in rural and peri-urban communities of developing countries do not have access to safe drinking water. The mortality from diarrheal-related diseases amounts to ~2.2 million people each year from the consumption of unsafe water. Most of them are children under 5 years of age—250 deaths an hour from microbiologically contaminated water. There is conclusive evidence that one low-cost household bioremediation intervention, biological sand filters, are capable of dramatically improving the microbiological quality of drinking water. This unit will describe this relatively new and proven bioremediation technology's ability to empower at-risk populations to use naturally occurring biology and readily available materials as a sustainable way to achieve the health benefits of safe drinking water. *Curr. Protoc. Microbiol.* 9:1G.1.1-1G.1.28. © 2008 by John Wiley & Sons, Inc.

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INTRODUCTION

The burden of microbiologically contaminated water is borne most heavily by the rural (largest, 80%) and peri-urban (fastest-growing) populations without access to safe water in developing countries—all need microbiologically clean water to sustain their lives and secure their livelihoods.

There is conclusive evidence that biological sand (biosand) filters are capable of dramatically improving the microbiological quality of drinking water. Biosand filters are based on a centuries-old bioremediation concept: water percolates slowly through a layer of filter medium (sand), and microorganisms form a bacteriological purification zone atop and within the sand to efficiently filter harmful pathogens from microbiologically contaminated water. Household-scaled biosand filters are a small adaptation of traditional large, slow sand filters such that they can uniquely be operated intermittently.

To use the simple, yet effective, on-demand biofiltration intervention, a person simply pours contaminated water into the household biosand filter and immediately collects treated water.

The purpose of the following comprehensive protocols is to facilitate knowledge transfer with the goal to empower vulnerable, poorest-of-poor populations in rural and peri-urban communities of developing countries, and to also promote using naturally occurring biology and readily available materials that they already possess as a cost-effective practical approach to combat poverty and inequality and achieve the health benefits of safe water by developing their own household water security solutions.

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CAUTION: Under ideal circumstances, a biosand filter can produce drinking water of high quality. However, this cannot always be assured or guaranteed due to variations in the construction and installation of the filter. This also applies to the consumption of water from the biofilter. It should be noted that a biosand filter cannot be relied upon to remove certain or all forms of water contamination.

CAUTION: If it is suspected that the community water source is contaminated with organic and inorganic industrial and agricultural toxicants, or in regions where the ambient air reaches freezing temperatures, biosand filtration should not be recommended as an appropriate water treatment technology.

STRATEGIC PLANNING

The performance efficiency of the biosand filter is limited by excessive turbidity, especially during the monsoon or rainy season where the performance of the filter will be compromised with excessive clogging, requiring frequent recovery of flow rate (see Basic Protocol 8). It is essential to obtain turbidity readings (see Basic Protocol 1) on the raw water source where biofiltration is being proposed as a potable water solution.

When working in partnership with village health workers among the rural poor with the challenge of providing affordable safe drinking water in every household using biosand filters, it is recommended to implement a comprehensive community-based multiple barrier approach (Nath et al., 2006). Education and training, emphasizing environmental awareness, hygiene, and sanitation are thus first necessities. Reduction of excessive turbidity and particulates by settlement or prefiltration or flocculation establishes a second barrier (Basic Protocol 2). Removal of parasites, protozoal cysts, bacterial pathogens, and in some situations removal of chemical contaminants (e.g., arsenic) by biosand filtration is the third barrier (Basic Protocol 3). The fourth and final barrier, safe storage in a closed, spigotted container and providing a disinfectant residual (see Basic Protocol 9) are all key aspects to strengthen local capacity to carry out sustainable community-based primary health care to prevent preventable illnesses and deaths caused by microbiologically contaminated water.

Selecting the Type of Biosand Filter

The three most common biological sand filters, as illustrated in Figure 1G.1.1, are based on the 60 liter (15 gallons) "BioSand" design developed by Dr. David Manz at the University of Calgary, Canada, in the 1990s.

As long as adaptations do not contravene the principles and protocols put forth that safeguard the bioremediation processes and functions of the filter, it may also be suggested that highly effective 15 to 20 gallon (60 to 80 liters) volume per day biological sand filters can be constructed by the household using readily available materials in their own community.

As illustrated in Figures 1G.1.1 and 1G.1.2, there are various materials that biosand filters can be constructed from, ranging from concrete, plastic, metal, or indigenous containers—each with its own benefits and drawbacks.

Strategically, the local availability of appropriate media (sand and gravel), parts, tools, and their respective costs will be critical predetermining factors in making decisions on the choice of construction method and corresponding materials used; therefore, stepwise one-fits-all construction protocols cannot be standardized. This flexibility of construction choice based on locally available resources will also provide the lowest cost—an important parameter for community acceptability and to ensure sustainability.

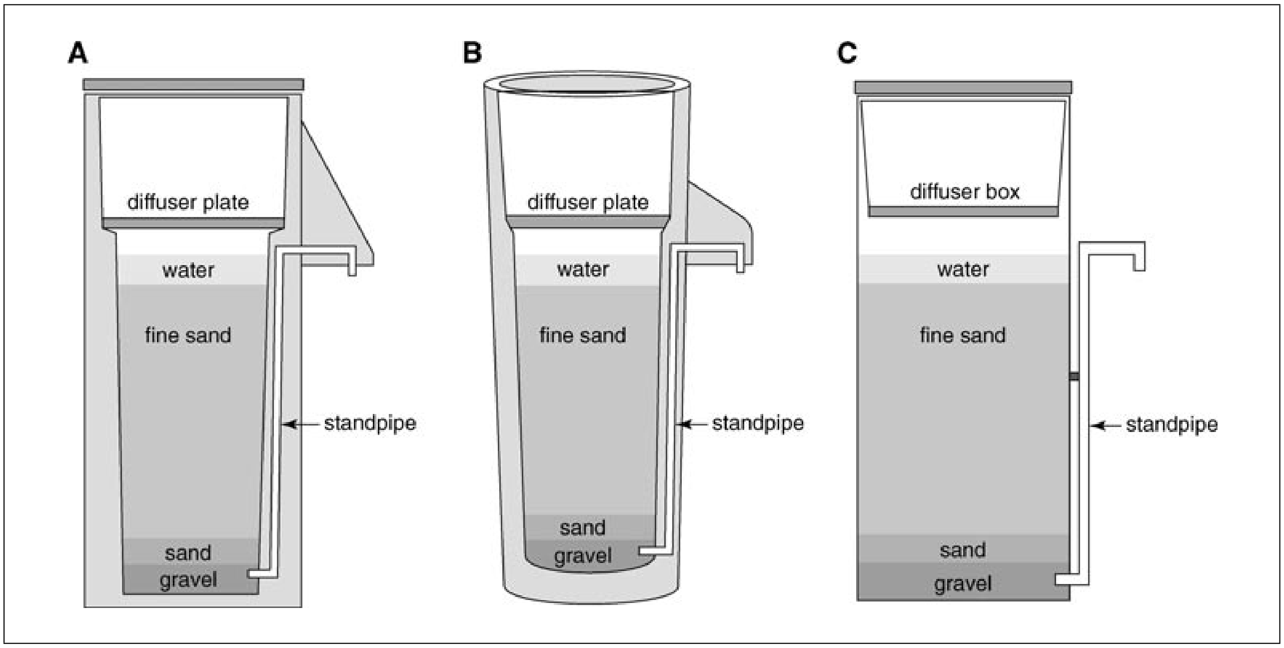

Figure 1G.1.1 Schematic diagrams of three common filters. (**A**) CAWST's concrete (BioSand) filter—high rates of user acceptance (over 300,000 filters worldwide). (**B**) BushProof's Concrete (BioSand) Filter—round shape provides additional strength and requires less materials. (**C**) Barrel Filter—locally built biosand filters made from plastic barrels or metal drums.

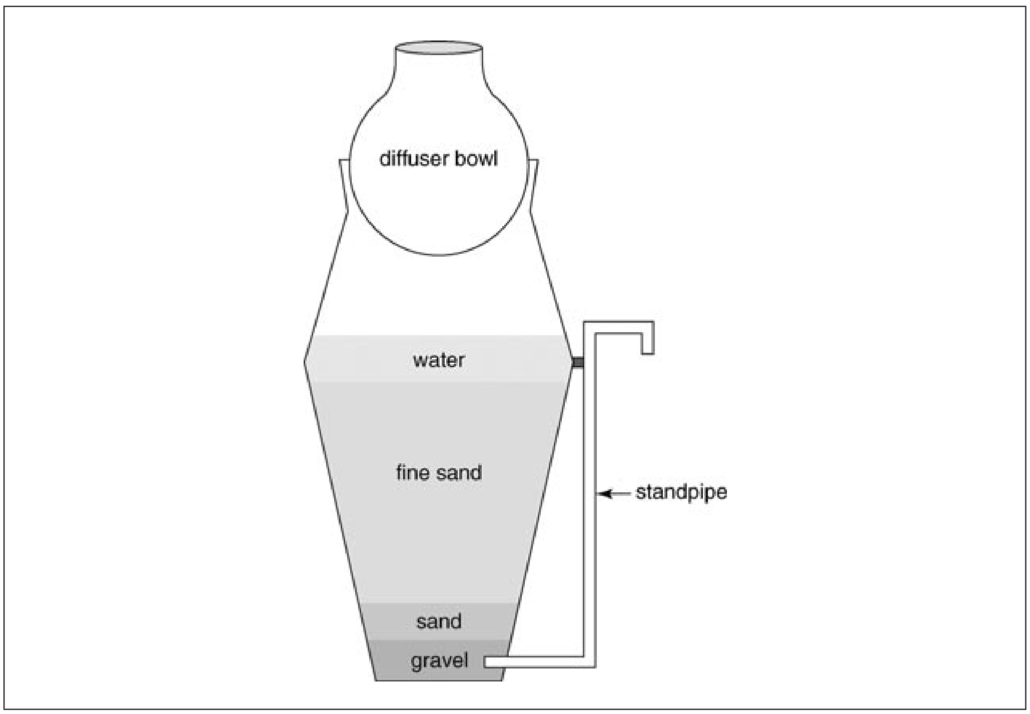

Figure 1G.1.2 Illustration featuring an indigenous biofilter constructed of clay jars.

Constructing the Biofilter

In an attempt to demystify biosand engineering to the essential principles, all on-demand household-scaled biological filters share five simple but critical design parameter commonalities featured in Figure 1G.1.3:

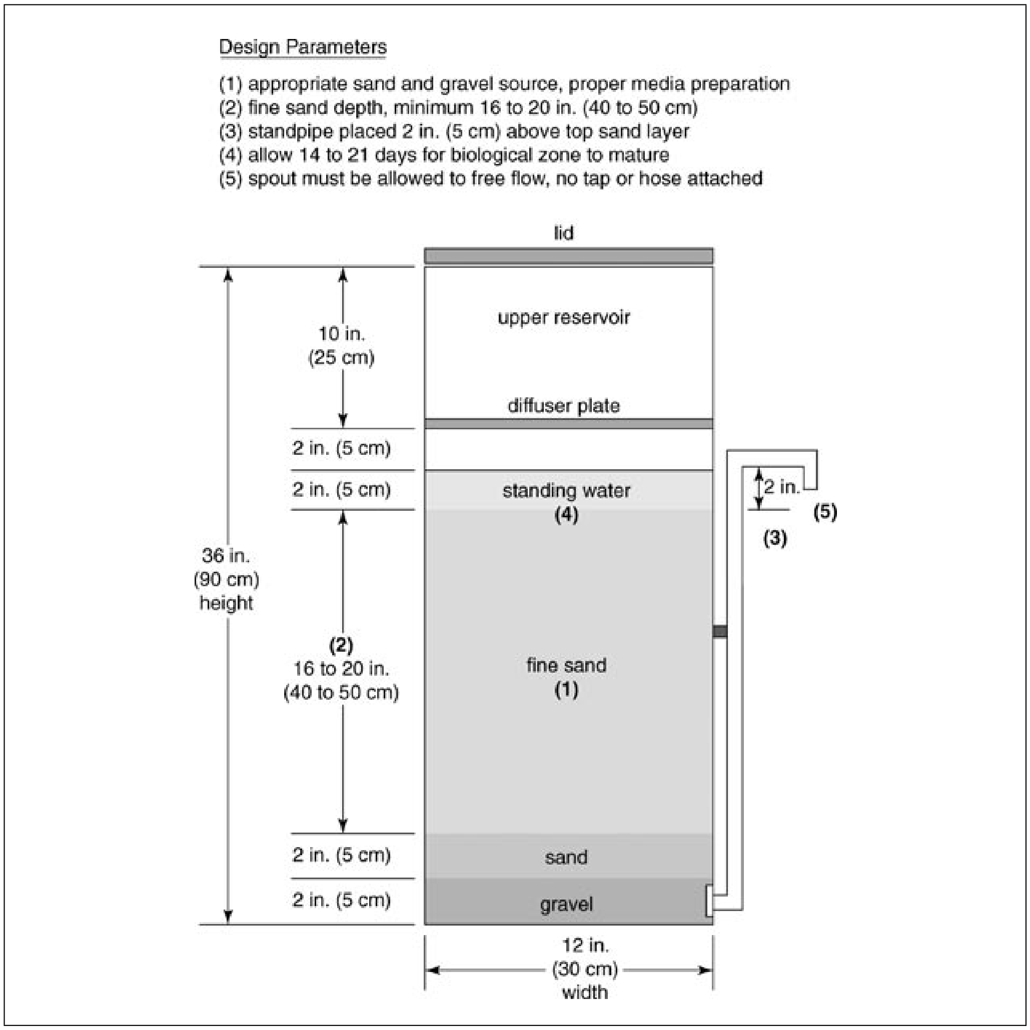

Figure 1G.1.3 Illustration highlighting major principles and generic size dimensions.

1. Biosand filters can be built wherever there is a good source of sand and gravel and where proper media preparation is undertaken (see Basic Protocol 4).

2. The most widely used version of the biosand filter is a concrete container filled with ~16 to 20 in. (40 to 50 cm) of fine sand. This is the absolute minimum fine sand requirement to ensure the best quality of water possible.

3. A layer of static standing water (the supernatant) is automatically maintained by placing the outlet pipe 2 in. (5 cm) above the level of the top sand layer.

4. Allow 14 to 21 days for the biological zone to mature.

5. Water must be allowed to flow freely from the filter—never plug or put a hose or tap on the outlet spout.

Further discussion of specific detailed methods of construction are not required as there are numerous methods and associated protocols readily available from various organizations for constructing the various featured configurations of biosand filters (see Key References).

Major Components of Biological Filters

Container

Durable water-tight "water safe" containers can typically be purchased or constructed in various shapes (square or round) and materials (e.g., concrete, metal, plastic, ferrocement, brick, or clay jars). The key is to find an appropriate-sized container that is readily available or can be constructed at a reasonable price in your area.

Lid

The lid can be made out of any material, but it must be clean and ideally fit tightly onto the container. A filter lid is essential to prevent excess biofilm growth by blocking sunlight and guarding against insects and other contaminants entering the filter.

Diffuser plate

The diffuser plate can also be made out of various common materials, such as plastic or metal. If made from sheet metal, ensure it is constructed out of good quality galvanized metal, or it will rust, either prematurely plugging the diffuser holes with rust or gradually increasing the diffuser hole size. A larger hole will result in disturbance of the schmutzdecke—a word derived from the German schmutz (dirt) and decke (covering)—or sand media.

Avoid wood, as it will attract mold growth and tend to shrink or warp, ultimately not fitting tightly inside the filter container, allowing potential disruption of the top sand layer.

A drip grid is a required feature of all diffusers to evenly distribut the water without disturbance of the schmutzdecke or sand media. On the bottom of the diffuser plate, measure and mark a 1-in. × 1-in. (2.5 cm × 2.5 cm) grid. At each intersection on the grid, pound a $^1/_8$-in. (3 mm) diameter hole through the diffuser material, using a hammer and nail. Smaller holes will restrict the flow through the filter; larger holes will result in disturbance of the schmutzdecke or sand media.

The primary functions of the diffuser plate are: (1) protecting the surface zoogleal biofilm—the schmutzdecke—and top layer of sand by dispersing the energy of water as it enters the filter, and (2) facilitating the addition of critical oxygen to the supernatant water through aeration process.

Filtrate standpipe and the standing water level (supernatant)

The standpipe is the essential component in all biosand filters. This simple but key design component automatically maintains the standing water level (the supernatant) to a constant depth when installed 2 in. (5 cm) above the top of the filtering sand. As illustrated, see Figure 1G.1.1, household-scaled biological filters can be made in various ways, but each configuration share this one simple but important design commonality.

The standpipe can be made out of $^1/_4$-in. (6 mm) i.d. tubing 3 feet (1 meter) long. The materials can vary from plastic or metal, such as copper, PVC pipe fittings, polyethylene, or vinyl tubing. The primary function of the supernatant, as set by the standpipe placed 2 in. (5 cm) above the filtering stand, is to keep the biological layer alive during pause periods. The schmutzedecke requires an aquatic environment and a constant influx of food and oxygen. If the static water level rises above 2 in. (5 cm), oxygen will not diffuse, creating a thinner biological zone. If the static water level drops below 2 in. (5 cm), then the inflowing water will disturb the sand and the biolayer may dry out due to excessive evaporation in high ambient temperatures.

Media (sand and gravel) bed

The media bed is composed of the following matrix of sand and gravel. Also refer to the discussion below: Media Selection and Preparation.

Filtering layer (fine sand)

Upper fine sand (filtering) layer—$^1/_8$ in. (3.15 mm) or less diameter sand. The depth of the filtering sand bed is 16 to 20 in. (40 to 50 cm). This is the absolute minimum fine sand requirement to ensure the best quality of water possible.

The actual volume of fine sand required is 25 quarts (~25 liters). The upper fine sand (filtering) layer is responsible for removal of pathogens and the establishment of the biological zone, including the schmutzdecke.

Support layer (coarse sand)

Support layer—$^1/_8$- to $^1/_4$-in. (3.125 to 6.25 mm) diameter sand, depth 2 in. (5 cm). Coarse sand volume required is 3 quarts (~3 liters). The purpose of the middle support layer is to prevent the sand mixing with the underdrain layer.

Underdrain layer (fine gravel)

Underdrain layer—$^1/_4$- to $^1/_2$-in. (6.25 to 12.5 mm) diameter gravel, depth should cover standpipe inlet [may be a depth of 2 in. (5 cm) or more]. Gravel volume required is 3 quarts (~3 liters). The purpose of the lower gravel layer is to allow unrestricted water flow out of the filter via the standpipe.

Adapting Biosand Construction for Available Materials and Community Needs

Again, as long as adaptations do not contravene basic construction parameters for the major components of biological filters, it is advocated that highly effective biosand filters can be constructed by the household using readily available materials in their own community.

Locating a source of appropriate sand and gravel

The effectiveness and efficiency of the filters is dependent on the community locating a source of uncontaminated sand and gravel.

Media Selection and Preparation

All biosand filters share a common feature, correct media (sand and gravel) selection and preparation.

Good sources of sand and gravel

Clean crushed rock from a quarry or gravel pit is the material of choice. The sand grains will have more surface area and the rough edges provide different ionically charged surfaces causing contaminants to be attracted to the sand grains.

If crushed rock is absolutely not available, the next choice would be sand from high on the banks of a river (that have not been submerged in water).

Poor sources for sand and gravel

Avoid riverbed sand and gravel. The grains are too smooth, round, and uniform in size. River sand is often contaminated with bacteria and organic material.

Sand and gravel should never come from a beach area. The grains are also too smooth, round, and uniform in size. It may also contain salts that dissolve into the filtered water.

Indicators the sand is appropriate for use in a biofilter

When you pick up a handful of the sand, the grains should be of different sizes and shapes and you should be able to feel the coarseness of the grains.

When you squeeze a handful of dry sand, the sand should all pour smoothly out of your hand.

Indicators the sand is NOT appropriate for use in a biofilter

When you squeeze a handful of dry sand, it should not ball up in your hand. If it does, it probably contains dirt or clay.

It should also not contain any very fine sand, silt, or organic material (e.g., leaves, grass, sticks, loam, clay, or dirt).

It should not contain microbiological contamination (avoid areas that have been used frequently by people or animals).

Selection criteria for appropriate sand and gravel

Grain size and quality of the sand are crucial to the effectiveness of a filter's performance. Grain size is important since larger or nonuniform sizes result in removal of less contaminants from the water. Alternatively, a finer grain size, by filling in the voids between larger grains, may render the media bed to be so compact as to offer an unacceptable flow rate due to high resistance. Quality of sand refers to the absence of fine silt or clay, which causes turbidity in the effluent.

As a last resort, a filter can be installed with contaminated river or beach sand. Initially, this will create a situation where the supposedly treated water will contain a greater density of indicator pathogens than the source water originally poured into the filter. Over time (up to 3 months), this situation will stabilize when all the food on the contaminated media has been consumed by the filter's normal biological processes. During this time period, it is highly recommended that filtered water from the biofilter be treated by an additional process such as household chlorination or SODIS (see Basic Protocols 9 and 10).

The Importance of the Schmutzdecke Layer

While locating and preparing proper sand and gravel are of great importance, the formation of the biological zone is perhaps the single most important component within the filter. Newly installed or recently cleaned filters do not effectively remove pathogens.

The biologically active zoogleal film develops on the surface of the sand filter and helps water purification by breaking down pathogens into inorganic compounds through chemical, microbiological oxidation, and predatory activity. The effectiveness of the biofilm relies on the following critical points: (1) a constant aquatic environment; (2) the biological zone needs food, therefore raw water should be intermittently fed within a consistent daily regimen [at least one 5-gallon (20 liter) bucket of water every day with minimum of 1 hr and maximum of 48 hr pause periods, a recommended pause period of 6 to 12 hr in-between feeding is suggested (CAWST, 2008)]; (3) oxygen is required for the metabolism process, and (4) sufficient water temperature are all essential to keep the biofilm microorganisms alive.

The schmutzdecke merges with the deeper distinct biological zone, a continuation of the area of biological action where microorganisms living below the schmutzdecke also help to consume and trap other microorganisms. The bacterial activity is most pronounced in the upper part of the filter bed and gradually decreases with depth as oxygen and food becomes scarcer to sustain life.

The biofilm and biological zone typically develop within two to three weeks (it may take up to 30 days) depending on the temperature and the biological content of the raw water. The water from the filter can be used during the first few weeks while the schmutzdecke is being established if a safer water source is not available, but chlorination is recommended at least during this time period. Over time the filter flow rate may decrease when the schmutzdecke becomes too thick and dense, requiring periodical maintenance (see Basic Protocol 8).

Guidelines for Operating a Biosand Filter

The combined use of the following recommended guidelines for operating a biosand filter will ensure the best quality of treated water.

1. Use a designated dirty container for collecting raw water from source.

2. Use the best sources of water (least contaminated) available: the better the source of water is, the better the treated water will be. A biosand filter can use any water source such as rain water, shallow wells, rivers, lakes, or surface water, but it should be taken from the same source consistently. Using the same source of water every day will improve the filter effectiveness. The water source should be the cleanest available since biosand filters cannot remove 100% of biological contaminants.

3. Over time, the microorganisms in the biological zone adapt to the "food" available in the untreated water source. If different water sources are used for each pour, that may result in an increased level of a contaminant that the microorganisms of the schmutzdecke are unable to consume or destroy. Several days may be required for the schmutzdecke to adapt to a new water source.

4. The diffuser plate must always be in place when pouring water into the filter: **never pour water directly into the filter without using the diffuser plate.**

5. The filter lid should always be kept on the filter.

6. Water must always be allowed to flow freely from the filter—never plug or put a hose or tap on the outlet spout. Plugging the outlet pipe could increase the water level in the filter, which could kill the biolayer due to lower oxygen diffusion into the standing water layer (supernatant) and/or resulting in a thinner biological zone that becomes anaerobic. Putting a hose on the outlet spout can drain (siphon) the water in the filter, dropping the water level below the sand layer, also, killing the biolayer.

7. Use a separate designated safe storage container container to safely store the filtered water. (See below for considerations when storing filtered water.)

8. Food should never be stored in the filter. It will attract insects. Since the water in the top of the filter is contaminated, it will in turn contaminate the food.

9. The treated water should be chlorinated after it passes through the filter to ensure the highest quality of water and to prevent recontamination. See Basic Protocol 9.

10. An ideal flow rate is 0.6 liters per min.

11. Having a pause period between filter usages is important. The in-between time when the filter is not actively filtering contaminated water is the pause period. A pause period of 6 to 12 hr is a suggested time, which allows the biological zone to remain vibrant by consuming the pathogens that have been introduced daily. The percentage removal of biological contaminants is inversely proportional to the flow rate through the filter because the greater biological removal of contaminants takes more time. However, if the pause period is extended for too long, the microorganisms will eventually consume all of the food supply and then die off. This will reduce the filter's treatment efficiency when it is used again.

12. One 5-gallon (20 liter) bucket of water should be poured into the filter every day to maintain the schmutzdecke and the biological zone. A biofilter is most efficient when operated consistently. The maximum volume of daily water that can be treated amounts to a total of 15 to 20 gallons or 60 to 80 liters (CAWST, 2008) depending on the schedule of the household, for instance, filter feeding can occur once in the morning, noon, evening, and later with 6 hr pause periods in-between each feeding.

Storing Filtered Water Safely

It is important to remember that water collected and stored from a filter can be recontaminated before being consumed by the household. To prevent water from becoming contaminated again, follow these recommendations.

1. Use a designated safe storage container for collecting and storing treated water. A safe container has a lid and a narrow opening to prevent recontamination due to dipping with dirty cups or hands. A container with a tap or spigot to access the water is ideal.

2. Keep the container off the ground and away from insects and animals.

3. If possible, do not treat more water than required for daily use.

4. At regular intervals (only when dirty), clean the outside of the storage container.

READING SOURCE WATER TURBIDITY

Biological filters have limits to the amount of turbidity of the raw water source being poured into the filter. High amounts of suspended particles present in the turbid water settle in the top sand layer, leading to rapidly diminishing flow rates. In turn, requiring the filter to be cleaned frequently involves disturbing the biological layer, leading to diminished filter performance for several days thereafter. The preferred turbidity rate is <50 NTU (Nephelometric Turbidity Units). Higher turbidity levels (>50 NTU) will require prefiltration (CAWST, 2008).

Quantitative Estimate of Turbidity

BASIC PROTOCOL 1

The following straightforward procedure provides a reasonably accurate quantitative estimate of turbidity.

Materials

Turbidity gauge (see Support Protocol)

Additional reagents and equipment for turbidity treatment (Basic Protocols 2 and 10)

1. Fill the tube with water until the black and white disk on the bottom of the newly constructed gauge is no longer visible.

2. Read the gauge at the nearest marked water level.

   A simpler alternative test to measure the turbidity is to use a 2-liter clear plastic soft drink bottle filled with water. Place this on top of a black and white disk. Look down through the bottle from the top, if you can see the black and white disk the water probably has a turbidity of <50 NTU.

3. Perform the appropriate treatment based on the following turbidity guidelines:

   a. *If the turbidity reading is 50 NTU or greater before filtration*: Perform turbidity pretreatment as recommended (see Basic Protocol 2) to eliminate the inconvenience of frequent declogging of top layer of fine sand.

   b. *If the turbidity reading is >5 after filtration*: Use a disinfection process such as chlorine addition or solar disinfection (SODIS) in conjunction with the sand biofilter (see Basic Protocol 10).

   No health-based guideline value for turbidity has been proposed within WHO Drinking Water Guidelines *(http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html)*. Generally, water with a turbidity of <5 NTU is usually acceptable in households, although this may vary with local circumstances.

SUPPORT PROTOCOL

Building a Simple Turbidity Gauge

The following simple do-it-yourself turbidity gauge can be easily constructed at a low-cost.

Materials

1-in (2.5 cm) diameter PVC end cap
Waterproof marking pen
Glass or clear plastic tubing, 1-in (2.5 cm) diameter, 28-in. (70 cm) length
PVC cement (glue)
Measuring tape

1. On the inside of the PVC end cap, draw a secchi disk using the waterproof marking pen by splitting the PVC circle into 4 equal quadrants using the marking pen (Catherman, 2006) as illustrated in Figure 1G.1.4.

2. Close one end of glass or plastic tube with the PVC end cap and cement in place.

   This end should be leakproof.

3. With the marking pen and measuring tape, mark the levels of turbidity, as illustrated in Figure 1G.1.4 (Rau, 2003).

OPTIONS FOR PRETREATING SOURCE WATER

Highly turbid water (>50 NTU) will require pre-filtration procedures to ensure the best quality of water possible. If the raw water source exceeds the previously stated design parameter for turbidity (50 NTU), the filter will clog up rapidly and may produce filtrate (outlet water) exceeding the intended filter performance values for turbidity (1 NTU), see Anticipated Results.

BASIC PROTOCOL 2

Alleviating High Turbidity

A particular challenge for most household-based water treatment technologies is high turbidity, i.e., >50 NTU. The efficiency of the filter is limited by the turbidity of the water source, especially during monsoon season where performance of the filter will be compromised. You can make a pretreatment filter out of old sari cloth, linen, or other fabrics.

Materials

Collected water
Filter container
Sari cloth or other fabrics

1. Let collected water settle (sedimentation) in the container so that solids sink to the bottom

   In some situations, this may be all that is necessary, especially if water is allowed to sit overnight. If so, settled water can be poured directly in the filter. If not, proceed with fabric straining.

2. Remove the lid from the filter container.

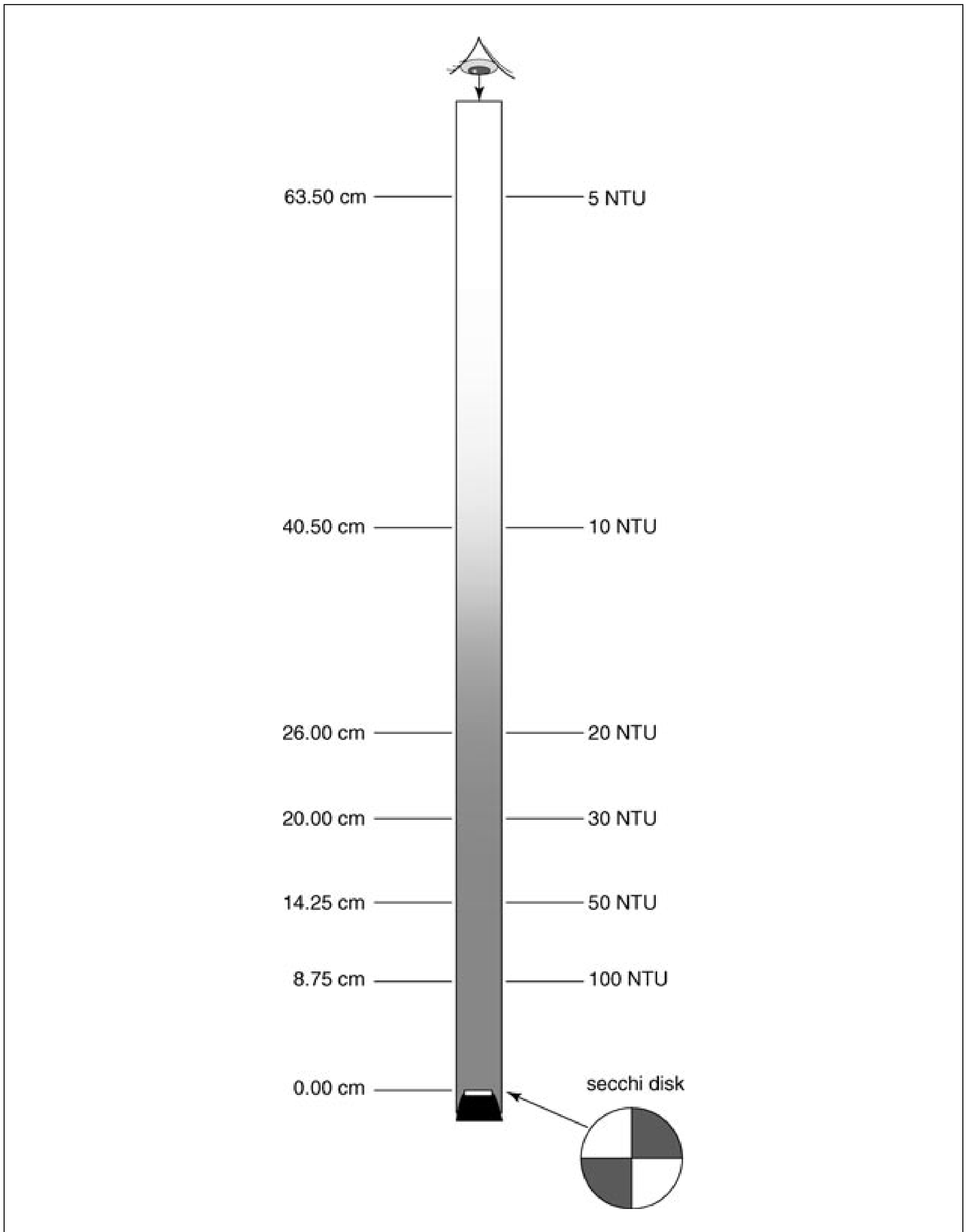

Figure 1G.1.4 Diagram of a home-brew turbidity gauge.

3. Fold the old sari cloth or other fabric four times and tie it over the mouth of the filter container.

   Old cloth is more effective because the worn fibers make the pores smaller and better for filtering.

4. Slowly pour the high turbidity water through the cloth and into the filter.

5. When finished pouring the untreated water through the cloth, remove by untying the folded cloth from the filter, wash the cloth, and expose to sunlight to dry.

   Alternatively, in many countries, there are also indigenous coagulation solutions using native plants, such as moringa seeds, known as drumstick or horseradish tree in India, or benzolive tree in Haiti and the Dominican Republic, or malunggay in the Philippines.

BASIC PROTOCOL 3

Adapting the Biosand Filter for Arsenic Removal

Arsenic is a natural element found in groundwater and is an important public health concern; fecal-contaminated drinking water poses immediate risks to human health for the majority. In countries such as Bangladesh, India, Vietnam, and many others, biosand technology can be modified to reduce both waterborne pathogens and certain toxic chemicals, such as arsenic, to acceptable concentrations with very little additional cost and a simple modification.

The simple modification of adding nails to a sand biofilter affects arsenic removal, as illustrated in Figure 1G.1.5. The nails, when exposed to air and water, rust very quickly, producing iron oxide (common red rust) which is an excellent adsorbent for effectively filtering out arsenic contaminants. The arsenic-loaded iron particles are flushed through the diffuser plate and trapped on top of the fine sand. The purpose of the stones and brick chips is to disperse the water over the nails to promote further absorption.

This ingenious arsenic depletion solution was developed by researchers at Massachusetts Institute of Technology (MIT), Environment and Public Health Organization (ENPHO)

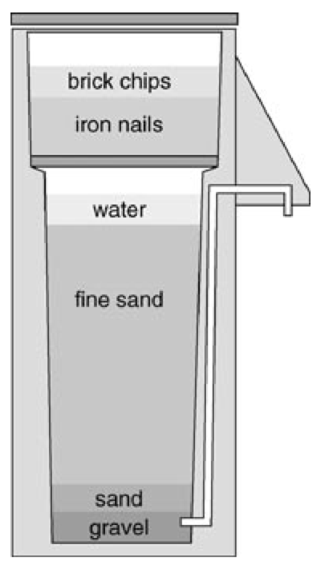

Figure 1G.1.5 Arsenic filter—a simple adaptation for removing both pathogens and arsenic based on biosand remediation and iron hydroxide adsorption principles.

of Nepal, and Rural Water Supply and Sanitation Support Programme (RWSSSP) of Nepal, based on slow sand filtration and iron hydroxide adsorption principles.

Anticipated results for the modified biosand filter are best summarized in the Centre for Affordable Water and Sanitation Technology (CAWST) document entitled: A complete summary of field and laboratory testing for the biosand filter is available for download at the following link: *http://www.cawst.org/assets/File/BSF_Literature_Brief.pdf.*

Materials

Water (from the best source possible)
11 lb (5 kg) of nongalvanized iron nails, length <3/4 in. (20 mm)
Filter containing diffuser box (see Strategic Planning)
Small broken brick chips or stones, 2- to 4-in. (5 to 10 cm) diameter

1. Wash the nongalvanized iron nails.

2. Place all nongalvanized iron nails in the diffuser box that should already be in place.

   It's important that the iron nails are evenly distributed and cover the diffuser.

3. Wash brick chips or stones with the best available water.

4. Add brick chips or stones on top of iron nails.

   The purpose of the brick chips is to protect the underlying nails from dispersing due to the force of incoming source water to be treated.

5. The filter is now ready to remove arsenic from source water poured into the filter.

   Over time the holes in the diffuser may clog due to exfoliated rust. If so, make the diffuser holes bigger using a 1/4-in. (0.6 mm) nail.

6. Once a year, remove the iron nails, break apart, wash thoroughly, and return the nails back into the diffuser basin, covering again with the brick chips or stones.

   The nails' arsenic adsorption capacity will last years before new nails will need to be added. The hypothesis is that as the iron nails get rusted, the rusted iron particles become exfoliated and fall into the fine sand layer. This exfoliation exposes new iron surface, allowing more arsenic to be adsorbed. Annual washing of the iron nails can help to expose additional iron surface for improved adsorption capacity (Ngai et al., 2006).

CONSTRUCTING THE SAND BIOFILTER

Preparing Media for Use in a Biosand Filter

BASIC PROTOCOL 4

The following protocol describes the steps in preparing sand and gravel for use in a sand biofilter. As the first step, mixed sand and gravel must be separated into its different-sized grain sizes by passing through a series of constructed sieves. *The rate of filtration is influenced by grain size, so this is an important protocol for the operation of a biofilter*.

Next the sand and gravel will be washed to remove fine silt, clay, and other impurities that the media may contain.

Refer to Strategic Planning for factors important in selecting a source of sand and gravel. As a last resort, if biologically contaminated water has been used to wash the sand and gravel, place the media in the sun to dry—the solar radiation will inactivate any possible attached pathogens. If this is not possible, remember that pathogens within the water or attached to sand grains will be consumed by the filter's normal biological processes or, when exposed to an anaerobic environment within the filter, will not survive.

Materials

Mixed sand and gravel
Water (from the best source possible)

Materials for building three wooden sieves including:
1-in. × 4-in. (2.5 cm × 10.00 cm) lumber to construct three sieves, three 8 foot (2.4 m) lengths
1-in. × 1-in. (2.5 cm × 2.5 cm) wood strapping, three 8 foot (2.4 m) lengths
1/2-in. (12 mm) screen, 1/4-in. (6 mm) screen, and 1/16-in. (∼1.5 mm) mosquito screen, screens must be metal, not nylon or fiberglass
Tape measure
Hammer
Nails
Saw
Shovels
Tarp
5-gallon (20 liter) buckets

Sieve the mixed sand and gravel media

1. If sand and gravel is wet, dry in sun.

   The solar radiation will inactivate many possible attached pathogens. Also, sieving is a lot easier if the media is dry.

2. Construct three sieves, using the lumber and the 1/2-in. (12 mm), 1/4-in. (6 mm) screen, and the 1/16-in. (∼1.5 mm) mosquito screen (see Fig. 1G.1.6).

   The suggested size is ∼16-in. (40 cm) × 22-in. (56 cm) for the three sieves. For the mosquito screen it is necessary to add a piece of 1/2-in. (12 mm) screen under the finer screen for additional support. The 1-in. × 1-in. (2.5 cm × 2.5 cm) strapping is measured and cut to the same lengths as sieve frames. The strapping will be used to cover the screen edges where the screens were nailed to the frames.

3. Using a shovel, pass the mixed sand and gravel through the constructed 1/2-in. (12 mm) sieve. Discard the media that doesn't pass through.

   For a simplified understanding of size grading that is going to take place using the screens, please reference Figure 1G.1.7.

4. Using a shovel, pass the mixed sand and gravel that passed through the 1/2-in. (12 mm) sieve through the 1/4-in. (6 mm) sieve. Keep the media that doesn't pass through the 1/4-in. (6 mm) sieve.

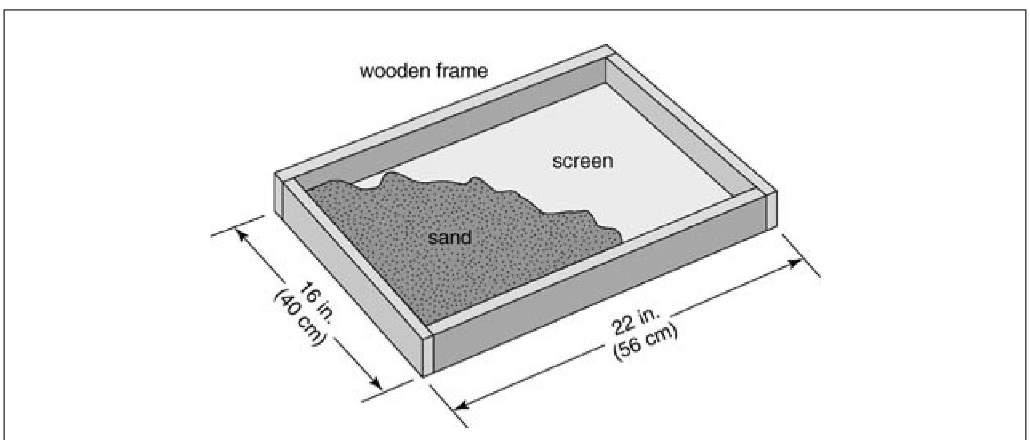

Figure 1G.1.6 Diagram of constructed wooden sieve.

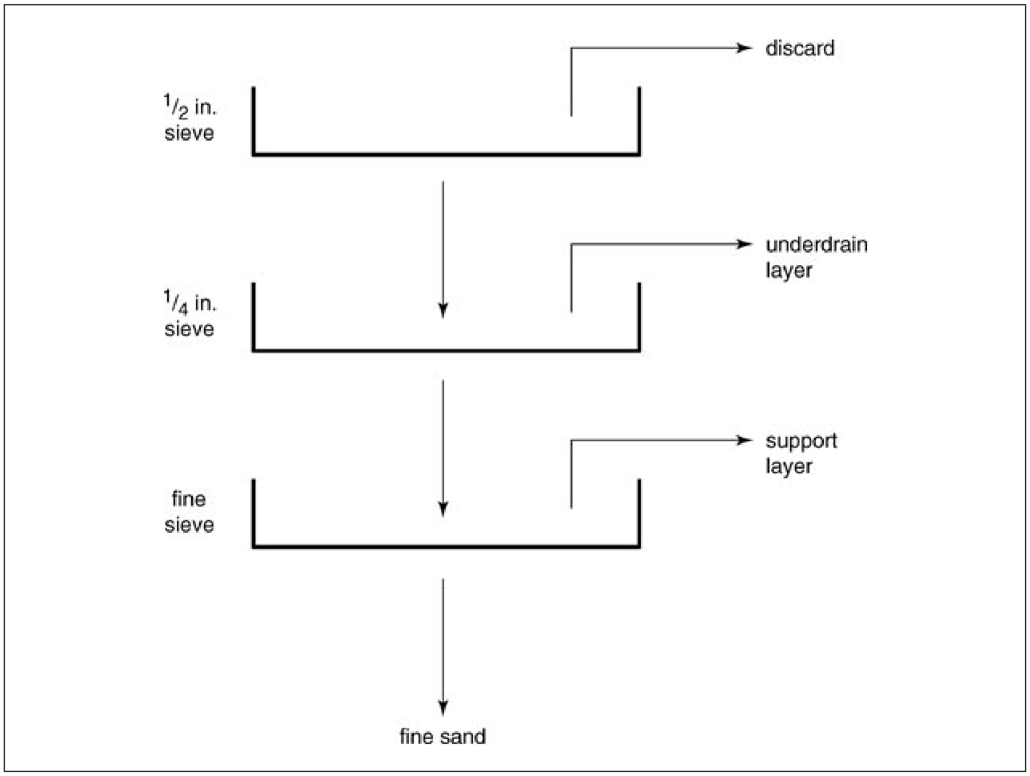

Figure 1G.1.7 Steps needed to sieve the three different grades of media.

The underdrain (gravel) media layer is composed of gravel that passed through the ½-in. (12 mm) sieve but was held back by the ¼-in. (6 mm) sieve. The purpose of this media layer is to allow the treated (effluent) water unrestricted flow out of the filter container and into the standpipe.

5. Using a shovel, pass the mixed sand and gravel that passed through the ¼-in. (6 mm) sieve through the mosquito sieve. Keep the media that doesn't pass through the mosquito sieve (fine gravel), as well as the sand that passed through the mosquito sieve.

   The support (fine gravel) media layer is composed of sand particles that passed through the ¼-in. (6mm) sieve but were held back by the mosquito screen sieve. The purpose of this media layer is to prevent the fine filtering sand from mixing with the underdrain layer.

   The filtering media layer is composed of fine sand that has been sieved through the fly or mosquito mesh. It is this layer that is responsible for removal of pathogens and the establishment of the biological zone, including the schmutzdecke. Please note that it takes substantial sieving to reach the required volume of fine sand as this is the deepest layer of the filter.

6. Store the sand and gravel in a protected dry area away from possible human or animal contamination.

7. Cover the sieved sand and gravel with the tarp until needed.

Wash the underdrain gravel

8. Place a small amount (½-in., or 12 mm) underdrain gravel in a bucket.

9. Place double the amount of water in the same bucket.

10. Using your hand, swirl the underdrain gravel a few times around the bucket.

11. Pour the dirty water out of the bucket. To help conserve water, pour into a waste water container and allow the water to settle for reuse.

12. Repeat steps 8 to 11 until the water in the bucket remains clear and contains no fine particles.

13. Clean the remaining underdrain gravel using steps 8 to 12.

Wash the support gravel

14. Place a small amount of $^1/_4$-in. (6 mm) middle support gravel in a bucket.

15. Place double the amount of water in the same bucket.

16. Using your hand, swirl the middle support gravel a few times around the bucket.

17. Pour the dirty water out of the bucket. To help conserve water pour into a waste water container and allow the water to settle for reuse.

18. Repeat steps 14 to 17 until the water in the bucket remains clear and contains no fine particles.

19. Clean the remaining middle support gravel using steps 14 to 18.

Wash the upper filtering sand

20. Now place an even smaller amount of upper filtering sand in a bucket.

21. Place double the amount of water in the same bucket.

22. Using your hand, swirl the upper filtering sand ∼10 times around the bucket.

    This time, do not wash the fine sand until the water is clear; the residual water should be mildly dirty in the bucket.

23. Quickly decant the mildly dirty water out of the bucket.

    As you wash, count the number of times that you decant the bucket. It takes time and practice with the following flow rate test (see Basic Protocol 5) to determine how much the fine sand has to be washed.

24. Repeat steps 20 to 23 until all the remaining fine sand has been washed.

    Once you have initially determined how much the fine sand has to be washed, this will be used as a guideline for future media washes. The filtering sand is washed to ensure an effective size (ES) of 0.10 to 0.25 mm and uniformity coefficient (UC) of 1.5 to 2.5 (CAWST, 2008).

Dry the media

25. If biologically contaminated water has been used to wash the sand and gravel, place the media in the sun to dry.

    The solar radiation will inactivate many possible attached pathogens. If this is not possible, remember that pathogens within the water or attached to sand grains will be consumed by the filter's normal biological processes or when exposed to an anaerobic environment within the filter and will not survive.

26. Once dried, store the sand and gravel in a protected dry area away from possible human or animal contamination. Cover the sieved sand and gravel with the tarp until needed.

BASIC PROTOCOL 5

Installing the Media

Incorrect sand media installation can result in flow rates that are too low or too high, with subsequent problems developing.

Materials

Water
Household chlorine bleach solution (see Basic Protocol 9)

Filter (see Strategic Planning)
Materials for correct media installation including:
  2 in. (5 cm), 3 quarts (~3 liters) of washed ½-in. (12 mm) gravel
  2 in. (5 cm), 3 quarts (~3 liters) of washed ¼-in. (6 mm) gravel
  20 in. (50 cm), 25 quarts (~25 liters) of washed fine sand
  Stick, 40 in. (100 cm) long
  Measuring tape
  Black magic marker pen
  Diffuser plate or box (see Strategic Planning)
Materials for testing filter flow rate including:
  Measured container (1 liter pop bottle is adequate)
  Stop watch
Materials to disinfect the standpipe including:
  3-foot (1 meter) garden hose
  Hose clamps
  Funnel
  Bleach-soaked cloth

Place the media in the filter container

1. First, place the empty filter inside the home in an appropriate place (i.e., its final location).

2. Make sure the drain hole, standpipe, or outlet pipe is clear and unobstructed.

3. Place a stick inside the filter.

4. Using a black magic marker, draw a mark across the stick where it meets the top edge of the filter.

5. Measure and mark a second line 2 in. (5 cm) down from the first. Remove the stick.

6. Fill the filter container half full of water.

   The water doesn't need to be uncontaminated; it can be from a raw water source that eventually will be treated. Water is required to be inside the filter before adding sand media to prevent pockets of air from being trapped within the media. If air pockets do develop while placing media, this has the potential to slow the flow rate results.

7. Pour or place the lower underdrain gravel into the filter, level out the surface.

8. Place the stick back into the filter, placing the bottom of the stick on the newly placed lower underdrain gravel.

   When the second line matches up with the top edge of the filter container, enough gravel has been added.

9. Measure and mark a third line 2 in. (5 cm) down from the second line.

10. Pour or place the middle support gravel into the filter, level out the surface.

11. Place the stick back into the filter, placing the bottom of the stick on the newly placed middle support gravel.

    When the third line matches up with the top edge of the filter container, enough middle support gravel has been added.

12. Place a bucket under the standpipe.

13. Ensuring that there is always water above the sand surface, quickly pour the majority of washed upper filtering sand into the filter. Continue adding sand until water starts pouring out of the standpipe.

    A random distribution of different sand grain sizes is critical to the proper operation of the filter. Adding sand quickly maintains the random distribution by not allowing the different sizes of grains to settle into layers.

14. Wait until the water stops pouring out of the standpipe.

    When the water stops pouring out of the spout, the water level is equalized.

    The water level in the filter is determined by the spout. Due to a siphoning effect, the water will stop coming out of the filter when the water is at the same level as the bottom of the spout.

15. Level out the surface of the upper filtering sand.

16. Measure the depth of the water above the upper filtering sand.

17. If the water depth is <2 in. (5 cm), remove sand until the water depth equals 2 in. (5 cm).

18. If the water depth is >2 in. (5 cm), continue to add washed upper filter sand into the filter until the water depth is 2 in. (5 cm).

19. When the water depth equals 2 in. (5 cm), once again level out the surface of the sand.

    This 2 in. (5 cm) of standing water will be the supernatant. Any changes in the water depth above the sand surface will cause a change in the biological zone disrupting the efficiency of the filter. A water depth of >5 cm results in lower oxygen diffusion and consequently a thinner biological zone. A high water level can be caused by a blocked outlet spout or by an insufficient amount of sand media. As the water depth increases, the oxidation and metabolism of the microorganisms within the biological zone decrease. Eventually the layer dies off and the filter becomes ineffective.

Flushing the filter

When all three layers of media have been installed, and the supernatant water depth equals 2 in. (5 cm) perform the following steps.

20. Place the diffuser plate into the filter container.

    The diffuser plate must be above but not touching the surface of the water at its resting level. That would greatly reduce the amount of oxygen in the standing water layer, affecting the survival of the schmutzdecke.

21. Place a waste water container (bucket) under the outlet pipe or standpipe.

    The waste water captured can be reused.

22. Start pouring the cleanest water available into the filter (<50 NTU), continue pouring water until the water starts running clear out of the outlet or standpipe.

    This may take 10 to 20 gallons (40 to 80 liters).

    If the water doesn't run clear after 25 gallons (100 liters), the gravel or sand was too dirty to start with. It is probably easiest to take the media out, wash in pails, and then place back in.

Testing filter flow rate

The amount of water that flows through the biosand filter is controlled by the size of sand media contained within the filter. If the rate is too fast, the efficiency of bacterial removal may be reduced. If the flow rate is too slow, there will be an insufficient amount of treated water available from the filter to meet the needs of the users. The flow rates of a biofilter are found from measuring the time it takes to fill up a container of a known volume with water.

23. Place the measured 1-liter container under the outlet or drainpipe spout.

24. Fill the filter container completely to the top with water.

    The flow rate through the filter decreases as the height of the water added into the influent reservoir drops.

25. With the stopwatch, time how long it takes the 1 liter container to be filled completely with filtered water—ideally, it should be 0.6 liter per min (or 100 sec per liter).

    Experimentation may be necessary to achieve the desired flow rate.

    If the flow takes a longer time (>100 sec) to fill the 1 liter container, the flow rate is too slow. The filter is still functional, but it will require more maintenance than normally required due to frequent clogging. Since flow rates are controlled by the screening and washing of sand, the sand should be washed more to achieve the desired flow rate. The slow flow rate can sometimes be improved by disturbing the upper sand layer with your fingers and scooping out the dirty water. If this doesn't work, scoop out a few inches of upper filtering sand which contains too many fine particles and rewash, and replace back into the filter.

    If the flow takes a shorter time (<100 sec), the flow rate is too fast, and the efficiency of treatment will be compromised. Since flow rates are controlled by the screening and washing of sand, the sand should be washed less to achieve a slower flow rate. In this instance, the fine media should be taken out and replaced with finer media (less washed).

    It can take up to 45 min for the 5 gallons (20 liters) of poured water to completely pass through the filter. The flow rate of 0.6 liters per min is based on the top reservoir being full of water. The actual flow of water will drop off as the water level (hydraulic head) drops.

Disinfecting the standpipe

The following steps are required to disinfect the underdrain gravel and standpipe of any possible contamination. This procedure is only to be implemented during the initial commissioning of the filter.

26. Fit and clamp the garden hose over the spout.

27. Fit the funnel at the free end of the garden hose.

28. Hold the funnel higher than the spout, and pour ∼1 quart (1 liter) of bleach solution into the funnel.

    The bleach solution equals 3 drops per quart (liter)—see Basic Protocol 9.

29. Hold the funnel higher than the spout for 2 min.

30. Remove the garden hose from the biofilter and drain the bleach solution from the hose.

31. Wipe the spout with a bleach-soaked cloth.

32. Add 5 gallons (∼20 liters) of water to the top of the filter.

    Never pour chlorine bleach solution into the top of the filter as chlorine will kill important, purifying organisms.

33. Wait 30 min for the bleach to be flushed out.

    The flushed water containing chlorine is not suitable for drinking or cooking.

34. Place the lid on the filter.

BASIC PROTOCOL 6

OPERATING THE BIOSAND FILTER

Educate all of the filter users, including children on the correct operation for daily use of the filter.

Materials

Raw (untreated) water
Biosand filter including a diffuser plate (see Strategic Planning)
Buckets

1. Use a dedicated "dirty" bucket for fetching raw source water.

2. Place a dedicated "safe" storage container under the spout.

   Place the container as close to the spout as possible to reduce dripping noise and prevent recontamination.

3. Remove the lid on the filter.

4. Make sure the diffuser plate is installed.

   The diffuser must always be in place when pouring water into the filter never pour water directly onto the sand layer.

5. Slowly pour raw (untreated) water into the filter daily, at least 5 gallons (20 liters), twice per day to assist in the establishment of the biolayer [first 14 to 21 days (may take up to 30 days)].

   Based on the recommended flow rate of 0.6 liters per min and the time required for pause periods, the biosand filter can effectively treat 15 to 20 gallons (60 to 80 liters) per day (CAWST, 2008).

   Thereafter, the family can establish a rate of usage that fulfills the family's daily water needs. For example, the filter can be used in the morning, noon, and evening with 6 hr pause periods in between each 5 gallon (20 liter) raw source water input.

   The pause periods are very important because they allow time for the microorganisms in the biological layer to consume the pathogens contained in the water, thereby increasing the hydraulic conductivity of the filter. Consequently, the biosand filter is most effective and efficient when operated intermittently.

   Use the best source of water (least contaminated) available—the better the raw water, the better the treated water will be. Using the same source of water every day will establish a constant biolayer and improve the filter's effectiveness.

6. Replace the filter lid onto the filter.

   Water must be allowed to flow freely out of the standpipe—never plug the spout or connect a hose to end of spout. Doing so will alter the standing water level in the filter, thus potentially harming the biolayer.

   During the first few weeks while the schmutzdecke (biolayer) is being established, the filtrate water can be used if a safer water source is not available, but chlorination is recommended (see Basic Protocol 9) at least during this time.

MAINTAINING THE SAND BIOFILTER

Once the household biological filter has been installed and is operational, periodically the following two primary maintenance protocols will be required. These are periodical disinfection of filter container and cleaning the biolayer when the flow rate is insufficient.

Periodic Disinfection (Cleaning) of Filter Container

BASIC PROTOCOL 7

Clean the spout regularly (every day) with soap and clean water or a chlorine cleaning solution. Regular cleaning of the filter spout will be required due to exposure to insects, animals, and dirty hands of children and other family members.

Clean the entire outside surface of the filter regularly (only when dirty) with soap and water or a chlorine cleaning solution.

IMPORTANT NOTE: Never pour chlorine cleaning solution into the top of the filter.

Recovering the Flow Rate

BASIC PROTOCOL 8

Over time the flow rate of the filter will decrease with usage because of increased accumulation of inorganic and organic material on the filter bed surface. This is a naturally occurring process and recovery of the flow rate can easily be restored with the following simple cleaning protocol.

Better water quality is actually produced at a reduced flow rate due to increased contact time with the ripened biological zone. Thus, this cleaning procedure should only be undertaken when the flow rate has become inconvenient to the family's daily needs.

Materials

Soap
Water
BioSand filter with a diffuser plate (see Strategic Planning)

1. Remove the lid, making sure that the diffuser plate is in place.
2. Pour enough water into the influent reservoir to the half-full mark, then remove the diffuser plate.
3. Gently disturb the surface of the upper filtering sand layer with fingers, ever mindful not to disturb the surface any deeper than 1 cm.
4. Remove suspended turbid water.

   The water in the influent reservoir will now be holding inorganic and organic materials in suspension that can be easily removed with a small container or cup.

5. Discard the turbid contaminated water in an appropriate location.
6. Return the diffuser plate and lid onto the filter.
7. Pour one 5-gallon (20 liter) bucket filled with water.
8. If the recovery of the flow rate is unsuccessful upon first attempt, repeat steps 1 to 7 as many times as necessary to regain the desired flow rate.

   Be mindful that after disturbing the surface, the removal efficiency declines somewhat, but increases very quickly (may take up to 1 week) to its previous level as the biofilm is re-established.

9. Wash hands with soap.

DISINFECTING EFFLUENT WATER

It is recommended that a disinfection process such as chlorine addition or solar disinfection (SODIS) be used in conjunction with the biosand filter as a post barrier.

There are limitations to SODIS and chlorine disinfection. SODIS limitation is the need to have numerous bottles for each household. Chlorination is ineffective against pathogens such as the zoonotic (referring to pathogens of animal origin that also infect humans) protozoan Cryptosporidium. Furthermore, both SODIS and chlorination disinfection are ineffective with higher turbidity in the water. A benefit of the SODIS method is that it's relatively inexpensive. Alternatively, chlorination requires the household to incur additional costs. The following techniques can be used for effluent disinfection. If the disinfection protocols are done properly, the filtered water will be of the highest quality. Investigators will have to determine the most appropriate method consistent with their purpose and needs and with the availability of resources.

BASIC PROTOCOL 9

Bleach (Free Chlorine) Disinfection of Effluent Water

Residual "free chlorine" disinfection is used to provide a safeguard against recontamination of treated water within the safe storage container. Household bleach is the most common affordable form of free chlorine. The following protocol will demonstrate how to disinfect water with household bleach.

Materials

Household bleach
Clean water
Clean empty container

1. Add 1 cup (240 ml) of household bleach to a clean empty container.

   Household bleach can contain different amounts of chlorine, 3.5% and 5% being the most common. To get the correct measure of chlorine needed to disinfect water, a 1% (final) stock solution is prepared (Conant, 2005).

2. Fill the container with the clean water.

3. Cover the top and shake for ~30 sec.

4. Let the container sit for 30 min. The stock solution is now ready.

   Add the following amounts of stock solution to the water that has been filtered through the sand biofilter:

   3 drops stock solution to 1 quart (~1 liter)
   12 drops to 1 gallon (4 liters)
   1 teaspoon (5 ml) to 5 gallons (20 liters)

   It is important to add enough stock solution to not only kill pathogens in the water, but, to have some chlorine still available in the water as a last barrier to ensure water quality until the time of consumption. The excess chlorine is called "free chlorine" and can easily be identified by the slight chlorine smell and taste of the disinfected water which is still safe to consume.

   If the filtered water is cloudy, twice as much of the stock solution will be required.

   Highlighting an additional benefit of biosand intervention—filtration reduces organic carbon in the water; thus, the filters also reduce the formation of chemical by-products. WHO states that "... the risks to health from these by-products are extremely small," posing no significant health risk.

   Instead, post-chlorine disinfection has to be recognized as potentially being a deterrent towards household acceptance due to lack of product accessibility or the unpleasant odor, taste, and the additional costs that will need to be incurred by the household.

Solar Disinfection (SODIS) of Effluent Water

SODIS is a low-cost, effective way to improve the microbiological quality of drinking water using solar radiation (sunlight) to destroy pathogenic microorganisms. The mechanism of disinfection is heat plus UV-A (wavelength 320 to 400 nm) radiation.

Recent laboratory and field experiments indicate that a number of low-cost additives are capable of accelerating the SODIS process in both sunny and cloudy weather. These additives included 100 to 1000 mM hydrogen peroxide (both at room temperature and at elevated temperatures), 0.5% to 1% lemon or lime juice, and copper metal or aqueous copper plus ascorbate (with or without hydrogen peroxide; Fisher et al., 2008).

Materials

Biosand filtered water
1- to 2-liter clear bottles (e.g., soda bottles)

1. Obtain 1- to 2-liter clear bottle(s).

   1- to 2-liter soda bottles have a better surface/volume ratio.

2. Wash the bottles well if it's the first time using the bottles.

3. Fill one or many 1- to 2-liter clear plastic bottles $^3/_4$ full with biosand filtered water.

   Over time replace old or scratched bottles. Do not use green- or brown-colored plastic bottles—they do not transmit UV-A radiation. Use transparent bottles only.

4. Shake the bottle(s) for 20 sec.

   Shaking adds air bubbles to the water, which will assist in disinfecting the water faster.

5. Lay the bottle(s) horizontally in the sun.

   Pick a location where the bottles will not be disturbed by shade, people, or animals.

6. Leave the bottle(s) in the sun for at least 6 hr; 2 days if the sky is cloudy. If the water temperatures rises $>50°C$, the disinfection process is $3\times$ faster.

7. Consume the water.

   The UV radiation intensity is reduced by turbidity and water depth in the containers. Water should have a low turbidity (<30 NTU) and the water depth in containers should not exceed 10 cm (EAWAG, undated).

   Solar disinfection is most effective in countries close to the equator.

   Alternatively, in many countries, using UV lamp disinfection may be another option where a source of electricity is available (see Internet Resources).

COMMENTARY

Background Information

Household-sized biological filters are simple in design; what is surprising are the complex purification processes that combine and take place inside the filter to provide water treatment. The principle processes are sedimentation, mechanical straining (filtering), adsorption (electrostatic), and most interestingly, a biological process (NSFC, 1997).

Biological filtration

The bioremediation process starts when raw turbid water is poured onto the filter's porous sand bed. Suspended particles and organic colloidal (viscous, gelatinizing) substances are deposited and absorbed (Ellms, 1928) within the top 400 mm of sand (Muhammad et al., 1996). The more organic matter (e.g., algae, diatoms, bacteria, protozoa, and worms) contained in the raw water, the quicker the sand grains become gelatinously coated, in turn decreasing the pore size between sand grains.

As the jelly-like density gradually increases over a 2- to 3-week period, the greatest density forms on top [2 to 4 in. (5 to 10 cm)] of the sand layer. The filter matures or "ripens" with the creation of a surface zoogleal film (schmutzdecke) at the $^1\!/_2$-in. (1.5 cm) sand-water interface, while the bottom level of the media is a particularly hostile environment starved of oxygen, nutrients, and temperature required to sustain life for bacteria such as intestinal bacteria (i.e., *Escherichia coli*) and other disease-causing pathogens.

The fundamental importance of the self-purifying power of the biological ecosystem is illustrated by the living microorganisms naturally contained within the biological zone. Algae and diatoms use photosynthesis to take in carbon dioxide and release oxygen which becomes available for oxidizing organic particles and for beneficial bacterial predation activities (Ellms, 1928). In turn, protozoa and worms feed on pathogenic bacteria and other disease-causing pathogens.

A filter's microbiological ecosystem is aerobic and requires oxygen to thrive (Buzanis, 1995). The increased presence of dead cell material further decreases the pore sizes which increases filtration efficiency, but, also requires additional oxygen to thwart the possibility of anaerobic conditions (Smethurst, 1992). Depending on increased oxygen solely through photosynthesis is limited by: (1) the turbidity (cloudiness) of the filtrate water, and; (2) the secondary function of the filter lid, which is to inhibit clogging (maintenance) caused by possible exponential schmutzdecke growth by the naturally occurring photosynthesis process. Instead, the additional critical oxygen is acquired through oxygen diffusion between the influent reservoir and the intermittently refreshed standing water (supernatant) layer. The finely balanced equilibrium between consistent oxygen and nutrient influx and microorganisms' metamorphosis results in a living system providing extremely efficient pathogen (disease-causing organisms) removal from filtrate water.

Emerging biosand technology

The HydraAid Filter—International Aid recently introduced a plastic biosand water filter (Fig. 1G.1.8). The HydraAid Filter will provide clean, safe drinking water at the rapid rate of up to 12 gallons (48 liters) per hr.

The JAL Filter—Mr. Brett Gresham created a unique biofiltration pathogen removal design (Fig. 1G.1.9) while serving in Afghanistan during the early 1990s. This filter produces the same controlled environment based on biosand principles using just one layer of fine sand, and no standpipe is required.

Importance of bioremediation dissemination

Biosand filters have gained acceptance by the World Health Organization (WHO) as a viable household water treatment (HWT) technology. The WHO is presently "developing guidelines that will establish microbial reduction benchmarks and propose minimum criteria for protocols to verify HWT system performance (WHO, 2007)." In the meantime, "There is now conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household stored water" and will reduce the attendant risks of "diarrheal and other enteric diseases by 6 to 50% (Sobsey, 2002)." "A preliminary health impact study (to be published in 2008) estimates a 30% to 40% reduction in diarrhea (CAWST, 2008)" within at-risk populations. The real challenge now is to facilitate the rapid dissemination of this proven bioremediation technology to developing countries.

Critical Parameters

Multiple indicator tools required

"Between 1972 and 1999, 35 new agents of disease were discovered (WHO, 2003)." Waterborne pathogens of importance, such as *E. coli* O157:H7 and Cryptosporidium are amongst this group. A single traditional microbial indicator (i.e., *Escherichia coli*) primarily used for water quality monitoring is inadequate to determine Cryptosporidium cysts, Giardia, and additional emerging water-related diseases of unknown etiology. There is a need for accurate, low-cost multiple indicator tools that can be applied in remote areas of developing countries to extend the multiple barrier approach to the potential risks of emerging water-related microbial pathogens.

Further research

Two groups amongst the major causes of diarrhea worldwide and a significant cause of mortality amongst children are small round-structured waterborne viruses (caliciviruses) and rotaviruses. Presently, there is concern that biosand filters may have a low rate of virus inactivation, therefore further research is required.

Affordability

Variations in regional conditions and availability of local materials contribute to the variability of trying to provide construction cost estimates which are beyond the scope of the provided protocols. As a general guideline, concrete biosand water filters range from $12

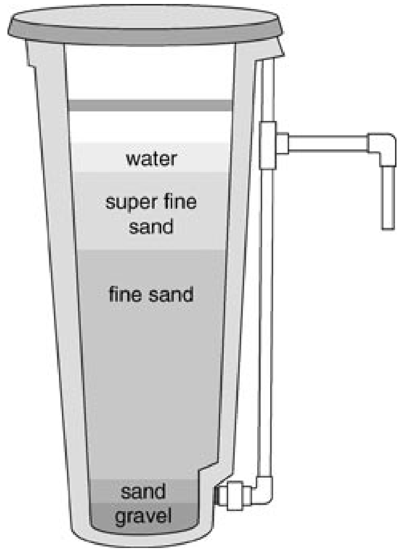

Figure 1G.1.8 International Aid's plastic HydraAid (BioSand) filter—lighter weight, stores and filters up to 47 liters (15 gallons) per hour.

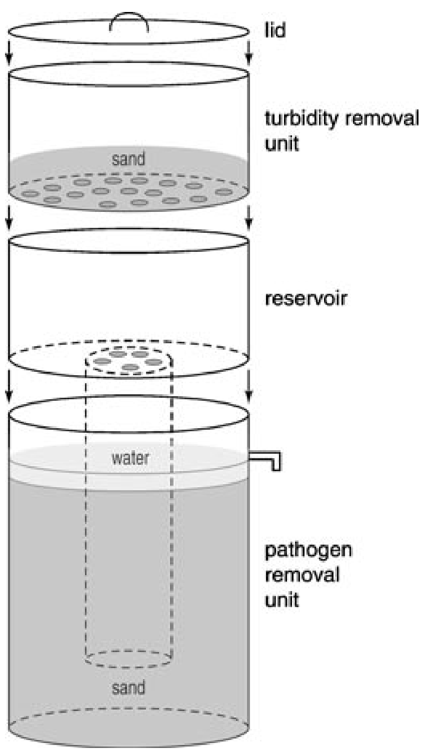

Figure 1G.1.9 Schematic diagram of the JAL filter. No standpipe and only one layer of sand required; lightweight and inexpensive to build.

to $30 US. A multibarrier approach as described increases costs and may limit use by some of the world's poorest people.

Drawbacks

There is no one-size-fits-all biosand filter. Each has its own drawbacks, for example, concrete-made filters require a welding shop to construct a steel mold. Plastic drums of consistent size are hard to locate. Metal filters require a tin smith. Ceramic containers tend to break easily. Industrial produced plastic filters may experience challenging logistics.

Table 1G.1.1 Troubleshooting Guide for Biofilter Implementation

Problems	Solutions
Preparing sand and gravel media	
Unsieved material was mixed with pile of sieved media	Prepare the media by re-sieving mixed pile
Uncertain whether the sand has been washed clean	Place a small amount of sand, and stir in a clear glass of water, allow to settle—if you can't see the sand surface within 3-5 sec, the sand needs to be washed further
Suspicion that dissolved salts exist in filtered water	Ensure that media is not beach sand
Uncertain of gauge size for sieving screens.	Ensure that screen sizes are 2, 4, and 14 gauge
Assembling the biofilter	
The diffuser plate or box floats when water is poured into the filter	Placing a rock or other weight on top of diffuser will stop it from floating
Metal diffuser plate or box is rusting	Ensure that sheet metal is of good quality galvanizing
Uncertain whether to build diffuser plate or box	A diffuser box is will be required for arsenic treatment
Using the biofilter	
Water isn't running clear after filter flush	Ensure that media is taken out of filter and rewashed
The diffuser plate is touching the standing water during pause period	Ensure that the diffuser plate is positioned at least 2 in. (5 cm) above the standing water level
Experiencing problems with air pockets in the filter media	Re-installation of sand and gravel will be necessary. The schmutzdecke and biological zone will need to be re-established with a ripening time of 14 to 21 days.
The top layer of sand is uneven	Ensure that the diffuser plate fits snuggly against the container walls
The flow rate slows down when water in the influent reservoir drops	This is a normal occurrence due to drop in hydraulic head
The flow rate is too low	Most likely caused by top layer of sand being clogged, flow rate recovery maintenance required or check to make sure diffuser plate holes are not too small or are plugged
Chlorine bleach was accidentally poured into the top of the filter	Re-installation of sand and gravel will be necessary after being thoroughly washed and dried in the sun to ensure sand is clear of chlorine. The schmutzdecke and biological zone will need to be re-established with a ripening time of 14 to 21 days.
The standing water depth is no longer 2 in. (5 cm)	Add or remove sand. Initially the sand may settle over time and require more sand to be added.
Maintaining the filter	
Water inside the filter has drained away	Ensure that a hose hasn't been attached to spout that initiated siphon action
Noticed higher turbidity during rainy season	Ensure a turbidity pretreatment process is initiated
There is an irritating dripping noise from the spout	Ensure that the safe storage container has a small opening and is positioned as close as possible to the spout
Removal of arsenic	
The holes in the arsenic diffuser box are plugged with iron rust	Make the holes bigger (∼3/16 in.)
Purchased nails for arsenic treatment seem to be oily	Ensure that nails are uncontaminated and nongalvanized

Greatest obstacle

In most countries the greatest obstacle is procuring sand and gravel to meet the media specifications for the filter, and to a lesser degree the availability of components from local suppliers (see Strategic Planning).

Troubleshooting

Table 1G.1.1 outlines some of the more common problems that may be experienced in performing the basic and supportive protocols from this unit. This is not an exhaustive list; others may be encountered.

Anticipated Results

A fully established (ripe) schmutzdecke will perform at 90% to 99% efficiency (CAWST, 2008), removing biological pathogens, but, it will take ∼14 to 21 days (ripening period) of daily use to establish the bioremediation zone and the schmutzdecke (may take up to 30 days), depending on the temperature and turbidity (biological content) of the source water. Until the development of the schmutzdecke, the filter will only be performing between 30% to 70% efficiency (CAWST, 2008). The water from the filter can be used during the 14 to 21 day start-up period, but, effluent disinfection (Basic Protocols 9 and 10) is highly recommended during this time period to ensure pathogen free water quality.

Anticipated results under field conditions with fully established schmutzdecke should be: (1) *E. coli* bacteria removal of >97%; (2) protozoa and helminths removal of >99%; (3) removal of 50% to 90% of organic and inorganic toxicants; (4) removal of 90% to 95% of iron; and (5) removal of 85% to 90% arsenic with design modification known as Kanchan Arsenic Filter (see Basic Protocol 3).

Under field conditions, the biosand filter limitations are: (1) cannot remove some dissolved contaminants (e.g., hardness, salt, calcium, and magnesium); (2) cannot remove some organic chemicals (e.g., pesticides and fertilizers or color); and (3) cannot guarantee 100% pathogen-free water—it is recommended to disinfect the water after it has passed through the biosand filter (see Basic Protocols 9 and 10).

Additional laboratory and field testing results are best summarized in the Centre for Affordable Water and Sanitation Technology (CAWST) document entitled: A complete summary of field and laboratory testing for the biosand filter (see Key References).

Time Considerations

The simple design facilitates procedures in the unit to be completed in a timely manner. In a developing country context, the longest period required will be invested in procuring uncontaminated sand and gravel and in finding local suppliers for specific filter components to ensure sustainability.

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Internet Resources

http://www.who.int/household_water/network/en/

The International Network to Promote Household Water Treatment and Safe Storage.

http://manzwaterinfo.ca/

Dr. David Manz's internet-based cooperative discourse for the Biosand Water Filter.

http://www.who.int/water_sanitation_health/monitoring/jmp2005/en/index.html

Link to the report Water for life: Making it happen. This report, prepared by the WHO/UNICEF Joint Monitoring Program, makes it clear that achieving the International Decade for Action Water for Life 2005–2015 target of access to safe drinking water and basic sanitation will bring health and dignity to millions of the world's poorest people.

http://www.medrix.org/water.html#UVWater Treatment

Medical Education and Development of Resources through International Exchange (MEDRIX)—provides a UV lamp water treatment (with optional sand filter) system handbook available upon request.

http://www.biosandfilter.org

A very useful Website, which contains detailed technical information (guidelines) on how to build the metal mould, how to produce the round concrete, and provides description and drawings for plastic or metal drum biosand filter construction.

http://web.mit.edu/watsan/worldbank_summary.htm

Massachusetts Institute of Technology-Kanchan Arsenic Filter (KAF). Project promotes KAF technology.

http://www.hydraid.org/

International Aid's new plastic HydrAid BioSand Water Filter initiative.

http://www.jalmandir.com/filtration/biosand/biosand-filters.html

Clearinghouse for Low-cost Household Water Treatment Technologies—provides overview of biosand filtration technology.

http://www.jalfilter.org

Provides description, photographs, and schematics drawings for JAL filter construction.

http://www.safewaterintl.org/

Safe Water International's development initiative toward a lightweight collapsible filter container and safe storage pouch combination.

http://www.cawst.org

The Centre for Affordable Water and Sanitation Technology (CAWST) is a Canadian humanitarian organization that provides training, education, and technical consulting in water and sanitation to organizations working with the poor in developing countries.

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