# Slow Sand Filters

If you surface water sources for household use, slow sand filtration - or more accurately biologically active filtration - may be an effective choice for water treatment. Slow sand filters can remove up to 99.99 percent of turbidity, bacteria, viruses, and Giardia lamblia cysts without the need for chemical flocculents or the use of electrical power. Slow sand filtration is a preferred technology for customers who:

- Wish to use surface water (ponds, streams, springs)
- Use daily volumes that make cartridge use impractical
- Have no access to electrical power
- Cannot or do not wish to use chemical treatment

## Rapid Sand vs. Slow Sand Filtration

Two types of sand filters are used for water treatment - rapid sand and slow sand. Rapid sand filters filter at a rate of 1 to 2 gallons per minute per square feet (gpm/ft2) and use physical straining to trap solids in the pores between sand particles throughout the bed. To increase the capacity to filter, rapid sand filters often use flocculent (polymers) to stick particles together into larger particles that can then be more easily strained out. 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. This process is performed frequently, often daily. The injection of flocculent needs to be constant and precisely metered. Jar testing is necessary to determine the effectiveness of dosing of the flocculent. A skilled worker is necessary to maintain a rapid sand filter properly.

Slow sand filters work very differently. The much slower flow rate of .04 to .16 gpm/ft2 results in a much different character to the sand bed. Because of the slow rate, particles tend to settle in the very top layers of the sand. More importantly, a rich biological matrix develops in the top layers of the sand. The matrix, commonly called the Schmutzedecke, is composed of a wide variety of tiny organisms including bacteria, algae and various other single and multiple cell organisms. This matrix lives off whatever is passing through it in the water stream. Pore size of the bed is less important because a bacteria passing through can't touch anything without being stuck and consumed. This way slow sand filters can remove particles smaller than the space between sand particles. At some point, the biological layer begins to plug up with the filtered material and debris. Flow becomes substantially reduced.

## Maintaining a Slow Sand Filter

Most of the maintenance issues involving slow sand filtration can be minimized with careful preparation and planning. 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 matrix and disrupt the intricate interrelationships of sand and microscopic life. How do you clean a slow sand filter? 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. To accomplish this, the filter vessel is drained. Workers using either shovels or tractors scrape the top 1/2-inch of sand and discard it. Then the filter is refilled with water. Since the biological layer has been removed, filtered water is run to waste until the biological layer re-establishes itself - ranging anywhere from days to weeks. After many scrapings, the sand bed gets shallower and at some point new sand needs to be placed on the bed. After some years, small amounts of material accumulate deeper in the sand bed to an extent that require removal of all the sand and replacement. Scraping the filter bed is probably the most significant labor expense in slow sand filter maintenance. One report estimated that scraping requires 25 to 50 hours per 1,000 square feet per year, approximately two to five hours per month.

In recent years, a new method of cleaning slow sand filters has emerged. Operators of a West Hartford, CT, slow sand filter developed a method called wet harrowing. Water above the sand is drained slowly to a depth of 15 inches or so. The upper layer of sand is raked or harrowed while water is being drained off above the filter bed. The harrowing releases fine suspended particles that have accumulated. These particles are washed off by the water as it drains through valves above the filter bed. Advantages of wet harrowing are significant. The most obvious is the labor savings. The filter does not have to be drained completely, and the sand does not have to be physically removed. More importantly, the biological layer is stirred up, but not destroyed by exposure to air. This means that the filter does not need to go through a lengthy re-ripening period. Often the filter is back to normal operation within hours instead of days to weeks.

Since sand is not being removed, the sand bed retains its original depth and does not require periodic additions of new sand. Typically, if a slow sand filter is designed and operated properly, the sand should not need replacement for five to ten years. How do you know when the filter needs to be cleaned? As material is pulled from the water in the Schmutzedecke layer, head loss increases. This head loss can be easily measured with the use of piezometers; clear tubes open to the atmosphere extending on the outside from the bottom of the filter to above the normal waterline. As head loss increases, the level of water in the tube will drop as atmospheric pressure overcomes the push of water through the filter. When the water level in the tube drops to 15 to 18 inches below the level in the filter, the filter needs to be cleaned.

## Pretreatment to Reduce Maintenance

Sediment tanks to remove settled solids, and course media roughing filters to reduce excess turbidity, reduce the solids load on slow sand filters. If turbidity exceeds 20 nephelometric turbidity unit (ntu) for any time exceeding a few days, a roughing filter should be installed. Roughing filters can reduce turbidity by 50 to 80 percent and reduce the amount of maintenance on slow sand filters considerably. Roughing filters are built as either upflow, downflow or horizontal flow depending on solids loading and method of cleaning desired. Media is usually layered course to fine gravel. Selecting the right filter for the application is a very important step. For high demand situations, slow sand filters may require too much land area to be practical. Where high turbidity is a problem certain times of the year, pretreatment must be addressed.

These things considered, slow sand filters can provide high quality water from surface water sources. They are particularly valuable for the small rural homestead or community. New methods including wet harrowing, reduce the steps involved in maintaining slow sand filters and allow the filters to be returned to service rapidly by personnel with minimal training. Surface water is sometimes the only available safe water source for rural homeowners. But treating surface water can present real headaches for the water treatment professional. Typical problems encountered can be caused by high suspended solids, turbidity, coliform bacteria, viruses, *Giardia* and agricultural runoff.

Conventional remedies usually involve media filtration, cartridge filters and chlorination, which can require high maintenance and cost. The careful metering of chemicals makes some health officials wary of their use by homeowners. However, slow sand filtration can help solve some of these problems. Slow sand filters have been used for more than 150 years. Today, they are popular in developing countries and in some municipalities and state parks in the United States. The proven ability of slow sand filters to remove turbidity, bacteria and viruses resulted in renewed interest by the U.S. Environmental Protection Agency (EPA) and the American Water Works Association (AWWA) in the 1980s. Recently, innovative packaging of slow sand filter plants has made this technology available to rural homeowners.

Common features of slow sand filters include the following:

- 2 or more vessels 6 to 8 feet deep
- An underdrain assembly for collecting treated water
- A gravel support layer around and over the underdrain
- A sand layer on top of the gravel 3 to 4 feet deep
- Controls to regulate flow rate
- Head loss measurement devices
- Filtration rate of .04-.16 g/ft$^2$/minute.

Raw water enters the vessel at the top . When operating, the vessels are kept full, leaving a three-foot layer of water -- the supernatant -- above the filter sand. This layer provides some treatment through sedimentation, but more importantly provides head to drive the water through the filter sand for extended periods of time. The slow filtration rate allows the development of a naturally occurring layer of organisms to thrive in the top few inches of sand. This layer, the Schmutzedecke, is responsible for removing up to 99.99 percent of bacteria, viruses, *Giardia* cysts and turbidity in the water passing across it. The Schmutzedecke is composed of a wide variety of life forms including algae, bacteria copepods, rotifers and many other invertebrates. Deeper in the bed, other processes occur that remove even more contaminants. Sedimentation, mechanical filtration and static electrical charge continue to polish the water.

The flow rate -- the speed and consistency of the flow -- is very important. Violent pressure changes that occur by opening and closing valves and rapidly changing the rate of flow can affect the filter's ability to work properly. Careful design of flow controls and the use of storage tanks to accommodate varying usage demands are important features in slow sand filter systems. As the filter works, suspended solids build up in the Schmutzedecke, which will eventually need cleaning. Head-loss meters are necessary to monitor solids accumulation. Site glasses open to the atmosphere and attached to the bottom of the filter vessel show the condition of the filter. As solids accumulate, the water level in the tube drops. The filter should be cleaned when the level drops between 12 inches and 24 inches. The frequency of cleaning depends on raw water quality, but typically filters are cleaned every 2 to 10 weeks.

## Sand Filter Drawbacks

Two problems often encountered by end-users of slow sand filters are high turbidity and organics in the water. High turbidity -- greater than 20 nephelometric turbidity units (ntu) -- can quickly clog a slow sand filter, resulting in short periods between cleaning. This may be one reason why slow sand filters became unpopular in the early 20th century. There are simple remedies, however. Sedimentation tanks and gravel roughing filters are very effective at reducing turbidity. Roughing filters can reduce turbidity by 50 to 80 percent and can provide excellent pretreatment for slow sand filters. Conventional slow sand filters are not effective at removing organics, which tie up chlorine, or pesticides. However, by using a layer of granular activated carbon (GAC), organic carbon and pesticides can be significantly reduced. This minimizes exposure to pesticides and reduces the amount of chlorine required to establish any necessary residual. Reducing chlorine and organics lowers costs and the risk of producing and exposing customers to trihalomethanes (THMs).

Another problem with slow sand filters is construction costs. Traditionally, slow sand filters have been made of concrete and pipe. The innovative use of molded polyethylene structures has distinct advantages. First, the engineering cost is reduced because it is amortized over the number of filters manufactured. Second, the cost of producing polyethylene filter vessels is much less than the construction and pouring of concrete forms. Finally, the materials used in polyethylene components can be certified as non-toxic, while materials for cast-in-place filters require testing of each installation. Additional advantages of polyethylene slow sand filters include transportability, durability and rapid set-up time. A polyethylene filter plant can be installed, loaded and started in hours compared with a built-in unit, which might require months to construct.

The best and simplest slow sand filter setup for a rural user is gravity-fed from a spring. Water is piped from the spring directly into the slow sand filter. Treated water flows into a storage tank that distributes the water downhill to the end-user; gravity ensures continual water pressure. But this configuration is not always possible. From a stream or pond, water may be pumped directly into the filter using an appropriately sized pump or a pump, pressure tank and pressure switch. After the storage tank, another pump, pressure tank and pressure switch can be used to provide water at suitable pressure to the user. Additions to the system may include chlorinators after the filter, ultraviolet (UV) after the filter and roughing filters before the filter if high turbidity or solids loads are anticipated. When designed and operated properly, the filter should be harrowed every two months. The sand should last 5 to 10 years. Even a small slow sand filter is capable of filtering 1,400 gallons per day. For the last 150 years, slow sand filters have been making drinking water safe throughout the world. With the recent discoveries of better maintenance methods, amendments to media and innovative packaging, this technology provides another tool for treating challenging water problems.

## Installation

For a Bio-Sand filter to operate properly, it must be installed and commissioned correctly. Make a checklist and use it to ensure that you have everything you'll need before you head out to install a filter. A filter maintenance guide (such as a laminated sheet) should be left with the users of each filter. This guide could be attached to the filter or placed on a wall adjacent to the filter. Always consider the safety issues related to moving the filter. There can be injuries due to strains of the back, arms, and knees. Watch out for crushing or pinching of fingers and toes under or behind the filter. Keep in mind the size of the filter (12" x 12" x 36") and its weight (160 Lbs - plus an additional 100 Lbs of media). It can be difficult and awkward to move this large object. It is important to determine a good location for the filter. Locating the filter inside the home is important not only for filter effectiveness, but also for the convenience of the user. If the users can access the filter easily, they will be more likely to use and maintain it. Once filled with media, the filter should not be moved. The filter should be placed:

- In a protected location away from sunlight, wind, rain, animals, and children
- Preferably inside the home
- Near the food preparation or kitchen area (depending on the space and layout of the house)
- Where it can and will be used and maintained easily
- On level ground
- So that water can easily be poured in the top

- Where there's adequate room for hauling and pouring pails of water into the filter, and storing the filtered water

**Placing the Media**

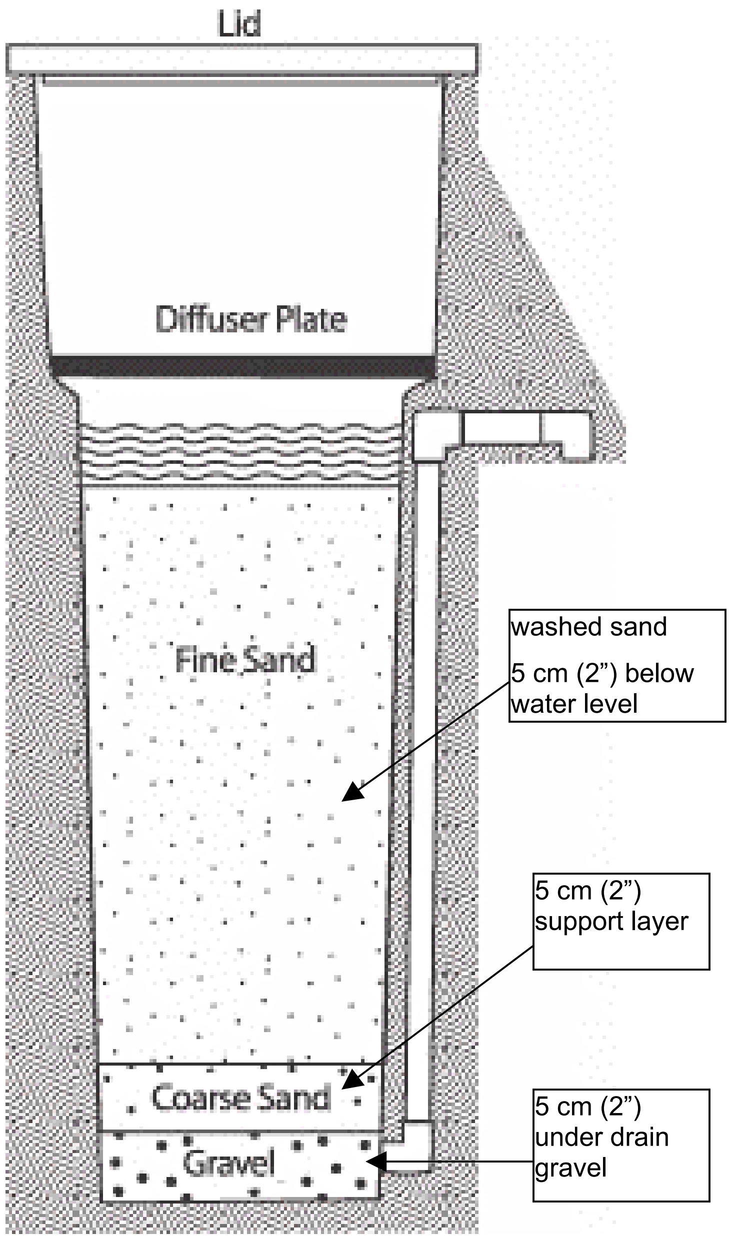
Tools Needed:

- Approximately 3 liters of washed ½" gravel
- Approximately 3 ¼ liters of washed ¼" gravel
- Approximately 25 liters of washed sand
- A stick (approximately 40" long, 1" x 2" is preferred)
- Measuring tape
- At least 2 buckets of water

1. Ensure that the drain hole (the standpipe opening at the bottom inside of the filter) is clear and unobstructed (i.e. is not covered by concrete and is not plugged by any debris.) The flow rate through the copper pipe without any media in the filter should be 1 liter / 25 seconds. *Tip: This step should have been done when the filter was removed from the mold, however, double check now before you get too far into the installation.*
2. Ensure that the inside of the filter has been cleaned out (including dirt, dust, and oil from the mold).
3. Place a stick inside the filter so that it's touching the bottom of the filter.
4. Draw a horizontal line on the stick where it meets the top edge of the filter.
5. Measure and mark a line 2" down from the first line.
6. Fill the filter half full of water. *The media must always be added with water already in the filter to prevent pockets of air from being trapped within the media.*
7. Add approximately 2" of under drain (½") gravel to the filter.
8. Level out the gravel, and use the stick to measure how much has been added. Place the bottom of the stick on the gravel. When the 2$^{nd}$ line on the stick lines up with the top edge of the filter, you have added enough gravel. *Ensure that the gravel covers the drain hole near the bottom of the filter.*
9. Measure and mark a line 2" down from the second line.
10. Add approximately 2" of support layer (¼") gravel to the filter.
11. Level out the gravel, and use the stick to measure how much has been added. Again, place the bottom of the stick on the gravel. When the 3$^{rd}$ line on the stick lines up with the top edge of the filter, you have added enough gravel.

Quickly pour approximately 20 liters of washed sand to the filter (ensuring that there is always water above the surface of the sand). Note: A random distribution of different sand grain sizes is critical to the proper operation of the filter. Adding the sand quickly maintains the random distribution by not allowing the different sizes of grains to settle into layers.

12. Continue adding smaller quantities of sand until water starts to pour out of the spout. (Again, make sure that there is always water above the surface of the sand. Add water if necessary.) 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.




13. Smooth out the sand and then measure the depth of the water above the sand bed.
14. **If the water depth is less than 2”:** remove sand until the depth is 2” (with the sand surface level and the water level equalized).
15. **If the water depth is more than 2”:** repeat steps 13 to 17 until the water depth is 2”.
16. Smooth out the surface of the sand so that it’s as level as possible.

**Flushing the Filter**

Tools Needed:

- ► Diffuser
- ► 40 – 80 liters of water

1. Place the diffuser plate on the ledge inside the filter. Ensure that it fits snugly. Note: The diffuser must not be 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 Schmutzedecke.
2. Place a receiving container under the spout. The water that it captures can be reused.
3. Pour the cleanest available water into the filter (turbidity < 30 NTU).

4. Observe the water coming out of the spout.
5. Continue adding water to the filter until the water coming out of the spout is clear. This may take 40-80 liters (10-20 Gallons). Note: If the outlet water doesn't run clear after 100 liters (25 Gallons), the gravel or sand was too dirty to start with. It is probably easiest to take the media out, wash it in pails, and then place it back in the filter.

**Test Flow Rate**

Tools Needed:

- ► Measuring container with 1 liter mark
- ► Stopwatch
- ► Bucket

1. Fill the filter to the top with water.
2. Place your measuring container under the spout to collect the outlet water.
3. Measure the time it takes to fill the container to the 1 litre mark. It should take between 50 – 80 seconds.
4. If it takes longer than 80 seconds, the flow rate is too slow.

   - ► The filter will still work, but it may clog faster and more often, requiring more maintenance
   - ► If it takes too long to get a pail of water, the user may not like the filter and may use untreated water
   - ► The flow rate can be improved by "swirling" the top layer of the sand and then scooping out the dirty water
   - ► If a few "swirl & dumps" do not improve the flow rate substantially, the sand is either too fine or too dirty – you will have to rewash the sand

5. If it takes less than 50 seconds to fill the measuring container to 1 litre, the flow rate is too fast.

   - ► The filter may not function effectively
   - ► The media should be replaced with finer media (less washed)
   - ► A less preferable option is to run a considerable amount of water through the filter until the flow rate decreases (due to the capture of finer particles and faster growth of the biolayer)

Note: The flow rate through the filter decreases as the height of the water in the influent reservoir drops. As the water level reaches the diffuser, treated water may only drip out of the filter spout. It can take 40 – 90 minutes for the 20 liters in the reservoir to completely pass through the filter.

**Disinfect the Spout**

Tools Needed:

- 3' of garden hose that just fits over the filter spout
- 1 hose clamp (if available)
- Funnel (can be made from the top of a soda or water bottle)
- Bleach solution (1/2 teaspoon bleach to 2 liters of water). *Note: Do NOT pour chlorine bleach into the top of the filter!*

1. Place the garden hose over the filter spout.
2. Clamp the hose in place with the hose clamp.
3. Place the funnel on the other end of the garden hose.

4. Hold the funnel higher than the top of the filter, and pour 2 liters of bleach solution into the funnel.
5. Hold in place for 2 minutes.
6. Remove the garden hose and drain the bleach solution
7. Wipe the outside of the spout with a clean, bleach-soaked cloth.
8. Add 20 liters of water to the top of the filter to flush the bleach out. Instruct the user not to use this water for drinking or cooking.
9. Place the lid on the filter.

## Operations

### Establishing the Biolayer

- The schmutzdecke or biolayer is the key bacteria removing component of the filter
- Without it, the filter removes some contamination through screening of the particles and microorganisms (only 30-70% removal efficiency)
- A good schmutzdecke will remove 90-99% of biological pathogens
- It may take 10 – 20 days to establish the schmutzdecke
- 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
- The schmutzdecke is NOT usually visible – it is not a green slimy coating on top of the sand

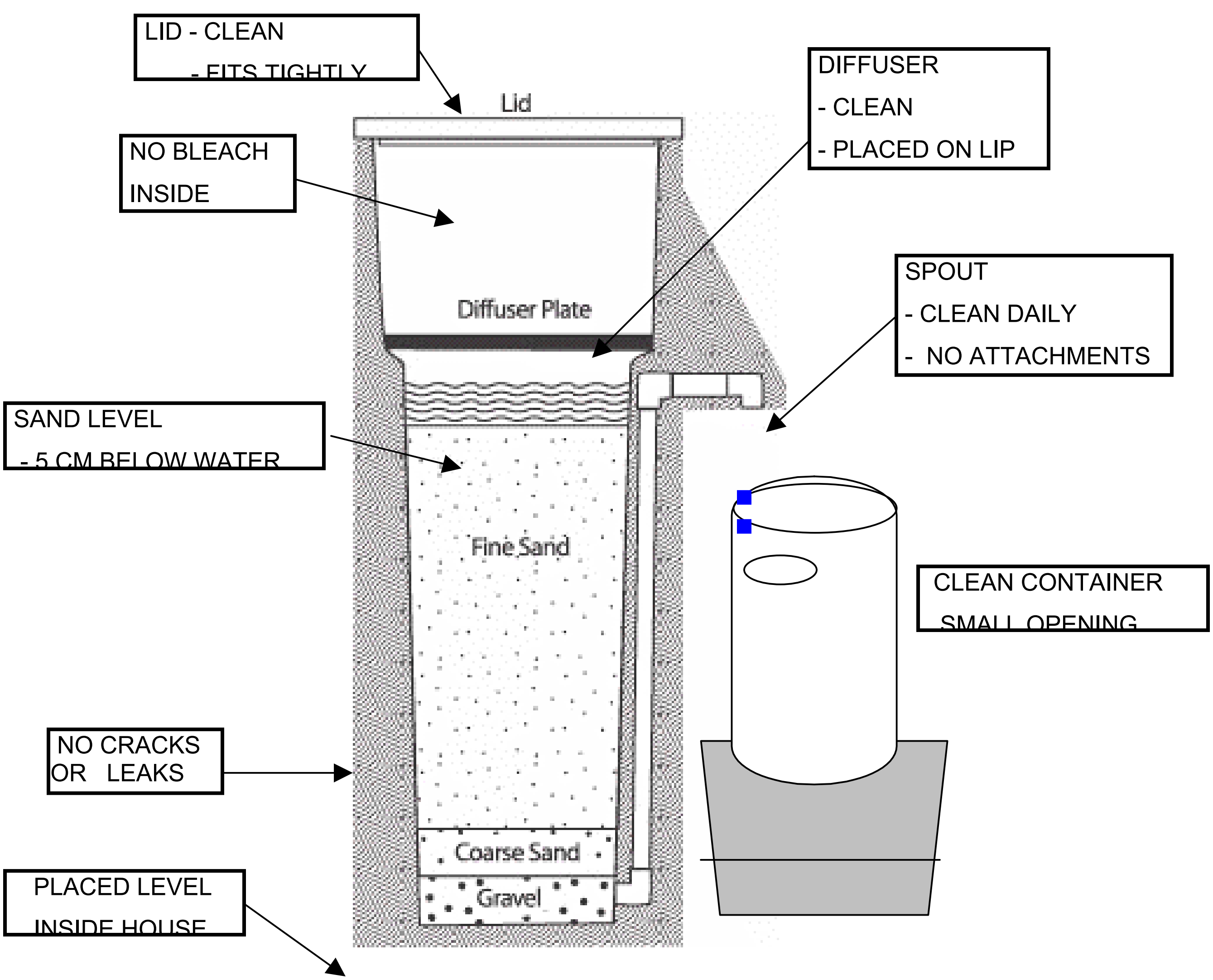
**Daily Use**

1. Educate all of the users, including children, on how and why the filter works and on the correct operation and maintenance. Children are frequently the main users of the filter.
2. Slowly pour raw (untreated) water into the filter daily (at least 20 liters, twice per day)
3. Using the same source of water every day will improve the filter effectiveness

4. Use the best source of water (least contaminated) available – the better the raw water is, the better the treated water will be
5. Pre-filter or settle raw water if not relatively clear – less than 50 NTU - A simple test to measure the turbidity is to fill a 2 liter clear plastic soft drink bottle with raw water. Place the bottle on top of large print such as the CAWST logo on this manual. If you can see the logo, the water probably has a turbidity of less than 50 NTU.
6. The diffuser must always be in place when pouring water into the filter – never pour water directly onto the sand layer
7. The lid should always be kept on the filter
8. Use a designated bucket for fetching raw water
9. Use a designated safe storage container to hold the treated water that has:

   ► a small opening to prevent recontamination due to dipping with cups or hands
   ► a tap or spigot

10. Place the receiving container as close to the spout as possible (i.e. place it on a block) to reduce dripping noise and prevent recontamination. The dripping noise can be irritating. The closer you place the container to the spout, the less dripping noise there is. A container with a small opening also reduces dripping noise.
11. Water must always be allowed to flow freely from the filter – never plug the spout or connect a hose to it. Plugging the spout could increase the water level in the filter, which could kill the biolayer due to lack of oxygen. Putting a hose or other device on the spout can siphon or drain the water in the filter, dropping the water level below the sand layer.
12. No food should be stored inside the filter. Some users want to store their food on the diffuser plate because it is a cool location. The water in the top of the filter is contaminated, so it will contaminate the food. Also, the food attracts insects to the filter.
13. The treated water should be chlorinated after it passes through the filter to ensure the highest quality of water and to prevent recontamination (1-5 drops/liter or up to 1 teaspoon/gallon)



## Maintenance

Once a filter has been built, installed, and is operational, though minimal, there is some key maintenance that is required. The two primary requirements are disinfecting the spout and cleaning the biolayer when the flow rate is insufficient. Follow-up visits to ensure proper use and maintenance of the filters should be built into the hygiene education program.

### Disinfection

- The spout will become contaminated during normal use via dirty hands, animals, or insects
- Clean the spout every day with soap and water or a chlorine cleaning solution
- Wash the receiving container every second day with soap and water or a chlorine cleaning solution
- Do NOT pour chlorine bleach into the top of the filter!
- The entire filter should be cleaned regularly (lid, diffuser, outside surfaces)

### Swirl and Dump

The flow rate through the filter will decrease over time as the schmutzdecke develops and fine particles are trapped in the upper layer of the sand. Users will know when the “swirl & dump” is required because the flow rate will drop to an unacceptable level. The filter is still effectively treating the water at this point; however the length of time that it takes to get a bucket of water may become too long and be inconvenient for the user. Alternately, you can measure the flow rate (as above) and if it is less than 0.3 liters/minute, “swirl & dump” maintenance is required.

1. Remove the lid of the filter.
2. Add 4 liters (1 gallon) of water to the top of the filter.
3. Remove the diffuser.
4. “Swirl” your hand around in the standing water at least 5 times – the water will become dirty. You can insert your fingers up to the first knuckle in the sand layer while “swirling” around across the entire surface area of the sand, but do not mix the surface layer deep into the filter.
5. Scoop out some dirty water with a small container (i.e. a cup or a pop bottle cut in half).
6. Discard the dirty water outside the house in an appropriate location (remember it is contaminated water).
7. Repeat this “swirl and dump” technique until all the water has been dumped out of the filter.
8. Replace the diffuser.
9. Pour 20 liters (5 gallons) of water into the top of the filter.
10. Measure the flow rate (as above).
11. Repeat steps 1 through 10 until the flow rate is acceptable (close to 1 liter/minute).
12. Wash your hands with soap and clean water - you have been handling contaminated water.

The following general checks can be made at any time by the users:

1. Check that the filter is in an appropriate location (indoors, protected from the weather, animals, and insects) and is level
2. Look for drips of water or wet spots under the filter, which indicate a leak in the concrete box
3. Check that the lid is tight fitting and clean on the inside and outside
4. Make sure the diffuser is clean and is sitting properly on the concrete lip
5. Make sure the holes in the diffuser are not plugged – periodic cleaning may be needed
6. Check that the surface of the sand is smooth and level (use a small straight object to smooth the sand ONLY if necessary)
7. Make sure the surface of the sand is 2” (5cm) below the water level.
8. Note: the sand may settle over time and more will have to be added. Add (or remove) sand if the standing water depth is not 2”.