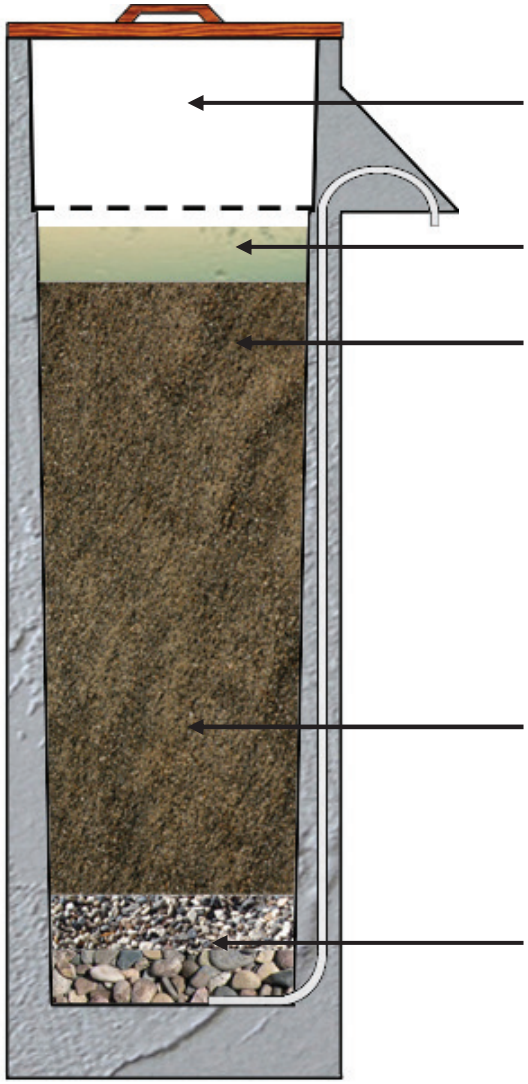
2.4 How Does the Biosand Filter Work?

The biosand filter has five distinct zones: 1) inlet reservoir zone, 2) standing water zone, 3) biological zone, 4) non-biological zone, and 5) gravel zone.



1. Inlet Reservoir Zone - Where water is poured into the filter.

2. Standing Water Zone – This water keeps the sand wet while letting oxygen pass to the biolayer.

3. Biological Zone – Develops at the top 5-10 cm (2-4”) of the sand surface. The filtration sand removes pathogens, suspended particles and other contaminants.

As in slow sand filters, a biological layer of microorganisms (also known as the biolayer or schmutzedecke) develops at the top 1-2 cm (0.4-0.8”) of the sand surface.

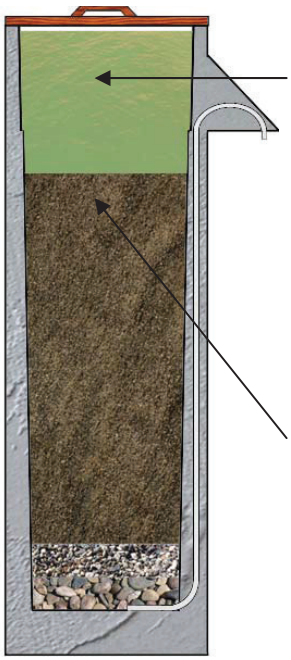
4. Non-Biological Zone – Contains virtually no living microorganisms due to the lack of nutrients and oxygen.

5. Gravel Zone – Holds the sand in place and protects the outlet tube from clogging.

Pathogens and suspended solids are removed through a combination of biological and physical processes that take place in the biolayer and within the sand layer. These processes include: mechanical trapping, predation, adsorption, and natural death.

- **Mechanical trapping**. Suspended solids and pathogens are physically trapped in the spaces between the sand grains.
- **Predation**. Pathogens are consumed by other microorganisms in the biolayer.
- **Adsorption**. Pathogens become attached to each other, suspended solids in the water, and the sand grains.
- **Natural death**. Pathogens finish their life cycle or die because there is not enough food or oxygen for them to survive.

Contaminated water is poured into the reservoir on an intermittent basis. The water slowly passes through the diffuser and percolates down through the biolayer, sand and gravel. Treated water naturally flows from the outlet tube.

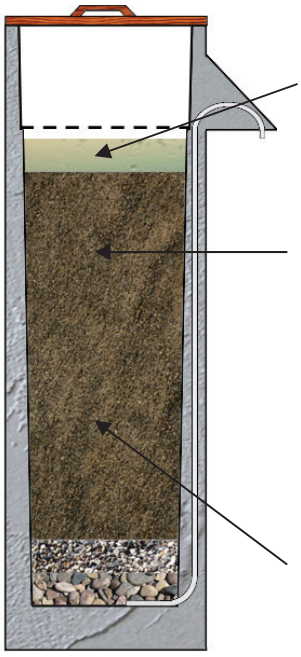


During the Run

The high water level pushes the water through the diffuser and filter (also called the hydraulic head). The water level in the reservoir goes down as it flows evenly through the sand. The flow rate will slow down over time because there is less pressure to force the water through the filter.

The inlet water contains dissolved oxygen, nutrients and contaminants. It provides the oxygen required by the microorganisms in the biolayer.

Larger suspended particles and pathogens are trapped in the top of the sand and they partially plug the pore spaces between the sand grains. This also causes the flow rate to slow down.



Pause Period

The water finally stops flowing. The standing water layer will be at the same height as the end of the outlet tube. Some oxygen from the air diffuses through the standing water to the biolayer.

The pause period allows time for microorganisms in the biolayer to consume the pathogens and nutrients in the water. The flow rate through the filter is restored as they are consumed. If the pause period is too long, the biolayer will eventually consume all of the pathogens and nutrients and eventually die off. This will reduce the removal efficiency of the filter when it is used again. The pause period should be a minimum of 1 hour after the water has stopped flowing up to a maximum of 48 hours.

Pathogens in the non-biological zone die off due to the lack of nutrients and oxygen.

3 Biosand Filter Operation

The following sections describe how to properly use the biosand filter to ensure the highest level of treatment efficiency.

3.1 Water Source

The biosand filter can be used with any water source such as rainwater, deep groundwater, shallow groundwater, rivers, lakes or other surface water. The source should be the cleanest available since the filter is not able to remove 100% of the pathogens and turbidity. If the source water is very contaminated, the filtered water may still have some contaminants.

Over time, the biolayer becomes adapted to a certain amount of contamination from the source water. If source water with a different level and type of contamination is used, the biolayer may not be able to consume all of the pathogens. It may take the biolayer several days to adapt to the new source water, level of contamination, and nutrients. **It is recommended to consistently use the same source water to ensure the highest treatment efficiency.**

The turbidity of the source water is also a key factor in the operation of the filter. Higher turbidity levels will plug the filtration sand layer more quickly. As such, maintenance will be required more often to ensure a convenient flow rate for the user. **It is recommended to use a sedimentation method if the source water turbidity is greater than 50 NTU.** A simple test to measure the turbidity is to use a 2 litre clear plastic bottle filled with the source water. Place this on top of large print such as the CAWST logo on this manual. If you can see this logo looking down through the top of the bottle, the water probably has a turbidity of less than 50 NTU.

3.2 The Biolayer

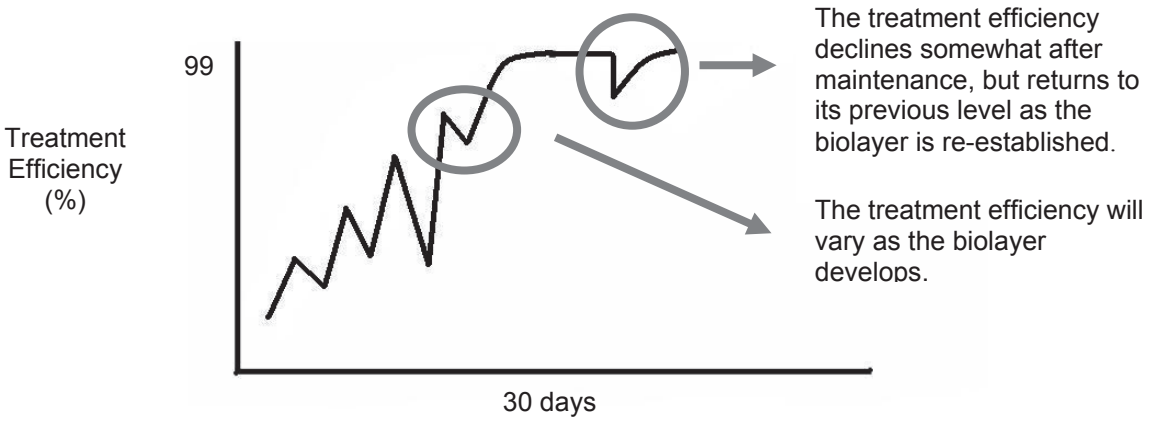
The biolayer is the key component of the filter that removes pathogens. Without it, the filter removes about 30-70% of the pathogens through mechanical trapping and adsorption. The ideal biolayer will increase the treatment efficiency up to 99% removal of pathogens.

It may take up to 30 days for the biolayer to fully form. During that time, both the removal efficiency and the oxygen demand will increase as the biolayer grows. The biolayer is NOT visible – it is NOT a green slimy coating on top of the sand. The filtration sand may turn a darker colour, but this is due to the suspended solids that have become trapped.

The water from the filter can be used during the first few weeks while the biolayer is being established, but disinfection, as always, is recommended during this time.

Figure 1 illustrates how the biolayer works. The process may vary as some filters require a shorter or longer period of time to establish the biolayer depending on the amount and source of water being used.

Figure 1: How the Biolayer Works



3.3 Filter Loading Rate

The biosand filter has been designed to allow for a filter loading rate (flow rate per square metre of sand surface area) which has proven to be effective in laboratory and field tests. There is a recommended filter loading rate for each biosand filter design. For the concrete Version 10 biosand filter, it has been determined to be not more than 400 litres/hour/square metre.

3.4 Pause Period

The biosand filter is most effective and efficient when operated intermittently and consistently**. The pause period should be a minimum of 1 hour after the water has stopped flowing up to a maximum of 48 hours.**

The pause period is important because it allows time for the microorganisms in the biolayer to consume the pathogens in the water. As the pathogens are consumed, the flow rate through the filter may be restored. If the pause period is extended for too long, the microorganisms will eventually consume all of the nutrients and pathogens and then eventually die off. This will reduce the removal efficiency of the filter when it is used again.

3.5 Standing Water Layer

Correct installation and operation of the biosand filter requires a standing water depth of approximately 5 cm (2”) above the sand during the pause period. The standing water depth can be 4-6 cm, but ideally it should be at 5 cm (2”).

A water depth of greater than 5 cm (2”) results in lower oxygen diffusion and consequently a thinner biolayer. A high water level can be caused by a blocked outlet tube, an insufficient amount of sand installed in the filter or the sand settling in the first few weeks of use.

A water depth less than 5 cm (2”) may evaporate quickly in hot climates and cause the biolayer to dry out. A low water level may be caused by too much sand being put into the filter during installation.

3.6 Maintenance

The spaces between the sand grains will become plugged with suspended solids over time. As a result, the flow rate will slow down. **A slower flow rate is not an issue in terms of water quality.** In fact, the slower the flow rate, the better the water quality. However, it may become slow enough that it is inconvenient for the user and they may choose to not use the filter at all.

When the flow becomes much slower than the recommended rate, the user will need to do basic maintenance (called the “swirl and dump”) to restore it. As well, users will need to clean the outlet tube, safe storage container, diffuser, lid, and outside surfaces of the filter on a regular basis.

Instructions on how to do maintenance are provided in Stage H of this manual.

3.7 Disinfection

Although the water may look clear after filtration, it is still necessary to disinfect it to ensure the best water quality possible. The biosand filter removes most, but not all of the bacteria and viruses. The most common methods used around the world to disinfect drinking water are:

- Chlorine disinfection
- Solar disinfection (SODIS)
- Solar pasteurization
- Ultraviolet (UV) disinfection
- Boiling

When water has high levels of turbidity, pathogens “hide” behind the suspended solids and are difficult to kill using chemical, SODIS and UV disinfection. The biosand filter reduces the turbidity and is a necessary step to improve the effectiveness of these disinfection methods.

3.8 Safe Water Storage

People do a lot of work to collect, transport and treat their drinking water. Now that the water is safe to drink, it should be handled and stored properly to keep it safe. If it’s not stored safely, the treated water quality could become worse than the source water and may cause people to get sick. **Recontamination of safe drinking water is a common issue around the world** and has been documented in several cases.

Safe storage means keeping treated water away from sources of contamination, and using a clean and covered container. It also means drinking water from the container in a way so that people don’t make each other sick. The container should prevent hands, cups and dippers from touching the water, so that the water isn’t recontaminated.

There are many designs for water containers around the world. A safe water storage container should have the following qualities:

- Strong and tightly fitting lid or cover
- Tap or narrow opening at the outlet
- Stable base so it doesn't tip over
- Durable and strong
- Should not be transparent (see-through)
- Easy to clean

Other safe water handling practices include:

- Using a container to collect and store untreated water and using it only for untreated water
- Using a different container to store treated water - never use this container for untreated water
- Frequently cleaning out the storage container with soap or chlorine
- Storing treated water off the ground in a shady place in the home
- Storing treated water away from small children and animals
- Pouring treated water from the container instead of scooping the water out of it
- Drinking treated water as soon as possible, preferably the same day

Sometimes it is difficult for rural and poor households to find or buy a good storage container. **The most important things are to make sure that it is covered and only used for treated water.**

The following tools and materials are needed for preparing the gravel and sand:

Tools:

- 12 mm (½") sieve
- 6 mm (¼") sieve
- 1 mm (0.04") sieve
- 0.7 mm (0.03") sieve
- Shovels
- Wheelbarrow (if available)
- Several large containers approximately 40 cm (15") deep
- Small clear container with lid

Materials:

- Covers (e.g. tarps or plastic sheets), roof or building to keep the sand from getting wet and contaminated
- Clean water
- 12 mm (½") gravel
- 6 mm (¼") gravel
- 0.7 mm (0.03") sand

See Appendix 2 for instructions on how to construct the sieves.

The following tools and materials are needed for building the metal diffuser box and lid:

Tools:

- Long straight edge or ruler (at least 120 cm (48"))
- Tape measure
- Square or right angle
- Marker
- Metal cutters suitable for 28 gauge galvanized steel
- Drill with 3 mm (1/8") drill bit
- Hammer
- Folding tool (e.g. bending brake) for bending 28 gauge sheet metal
- Anvil or steel plate set in a vice to hammer sheet metal against

Materials:

- 1 sheet of galvanized flat sheet metal (2438 mm x 1219 mm (4' x 8'), 28 gauge thick (0.46 mm or 0.018"))

Note: A single sheet makes 4 diffuser boxes (with some waste). For costing purposes; 3 sheets can make 15 boxes. No other materials are needed to construct the lid and diffuser box.

The following tools and materials are needed for installing one filter:

Tools:

- Tape measure
- A stick [approximately 100 cm (40”) long, 2.5 cm x 5 cm (1” x 2”) is preferred]
- Diffuser
- Storage container
- Watch
- Measuring container with 1 litre mark
- 1 m (3’) of hose that just fits over the outlet tube
- Hose clamp (if available)
- Funnel (can be made from the top of a pop or water bottle)

Materials:

- Approximately 3 litres of washed 12 mm (½”) gravel (drainage layer)
- Approximately 3¼ litres of washed 6 mm (¼”) gravel (separating layer)
- Approximately 25 litres of washed 0.7 mm (0.03”) sand
- 40-80 litres (10-20 gallons) of water
- Chlorine

Stage B – Locate the Sand and Gravel

Selecting and preparing the filtration sand and gravel is crucial for the treatment efficiency of the biosand filter. While not complicated, the steps in preparing the filtration sand must be followed exactly as presented. Poor selection and preparation of the filtration sand could lead to poor performance and a considerable amount of work to rectify the problem.

Recommended Source

Crushed rock is the best type of filtration sand since it has less chance of being contaminated with pathogens or organic material. This sand also has less uniform sizing of the grains. A mixture of grain sizes is required for the proper functioning of the filter.

Gravel pits or quarries are the best place to obtain crushed rock, and are common in most parts of the world. You can also ask local construction, road work, or brick manufacturing companies to find our where they get their source of crushed rock.

At first, quarry rock may not seem proper for sieving due to the large amounts of dust. You can select the rock load and the crusher properly to ensure that large chunks of rock and dust are minimal. Often, you can even sieve the load at the quarry site and only pay for what you take. This greatly reduces waste and the cost.

Crushed rock may be difficult to locate, more expensive, and require transportation to your production site. However, it is critical in providing the best water quality and is worth the extra time, effort and cost.

Tip: CAWST is aware of crushed rock sources in many countries. If you have difficulties finding a local source, please contact CAWST and we may be able to connect you with a source already being used by other project implementers.

cawst@cawst.org

Other Sources

If crushed rock is absolutely not available, the next choice is sand from high on the banks of a river (that has not been in the water), followed by sand found in the riverbed itself. The last choice is beach sand.

River sand is usually contaminated with pathogens (from human and animal excreta) and contains organic material (e.g. leaves, sticks). Putting contaminated sand in the biosand filter may actually result in worse water quality than the original source water used. This happens because the organic matter is a food source for pathogens and helps them to grow and multiply in the filter until all of the food is consumed.

River sand needs to be disinfected and the organic material removed if it is going to be used as filtration sand. You can disinfect the sand by using chlorine or placing it in the sun. Disinfection will kill the pathogens; however it will not remove all of the organic material. This can only be done by heating the sand to very high temperatures to burn

Stage C – Prepare the Sand and Gravel

SIEVE THE SAND AND GRAVEL

Tools:

- 12 mm (½") sieve
- 6 mm (¼") sieve
- 1 mm (0.04") sieve
- 0.7 mm (0.03") sieve
- Shovels
- Wheelbarrow (if available)

Materials:

- Covers (e.g. tarps or plastic sheets), roof or building to keep the sand from getting wet and contaminated
- Face mask (optional)
- Gloves (optional)

Steps:

1. The sand must be passed through the 12 mm (½") sieve, the 6 mm (¼") sieve, the 1 mm (0.04") sieve, and the 0.7 mm (0.03") sieve, in that order.
2. Discard the material that does not pass through the 12 mm (½") sieve.
3. Store the material that is captured by the 6 mm (¼") sieve – this is used for your drainage gravel layer.
4. Store the material that is captured by the 1 mm (0.04") sieve – this is used for your separating gravel layer.
5. Store the material that is captured by the 0.7 mm (0.03") sieve – A portion of this material is used to make the concrete filter box while the other portion is sieved further to make the filtration sand.
6. The material that passes through the 0.7 mm (0.03") sieve is the filtration sand that goes into your filter. If constructing concrete filters, this sand should NOT be mixed with cement because it is too fine and will not produce good quality concrete.

Tips:

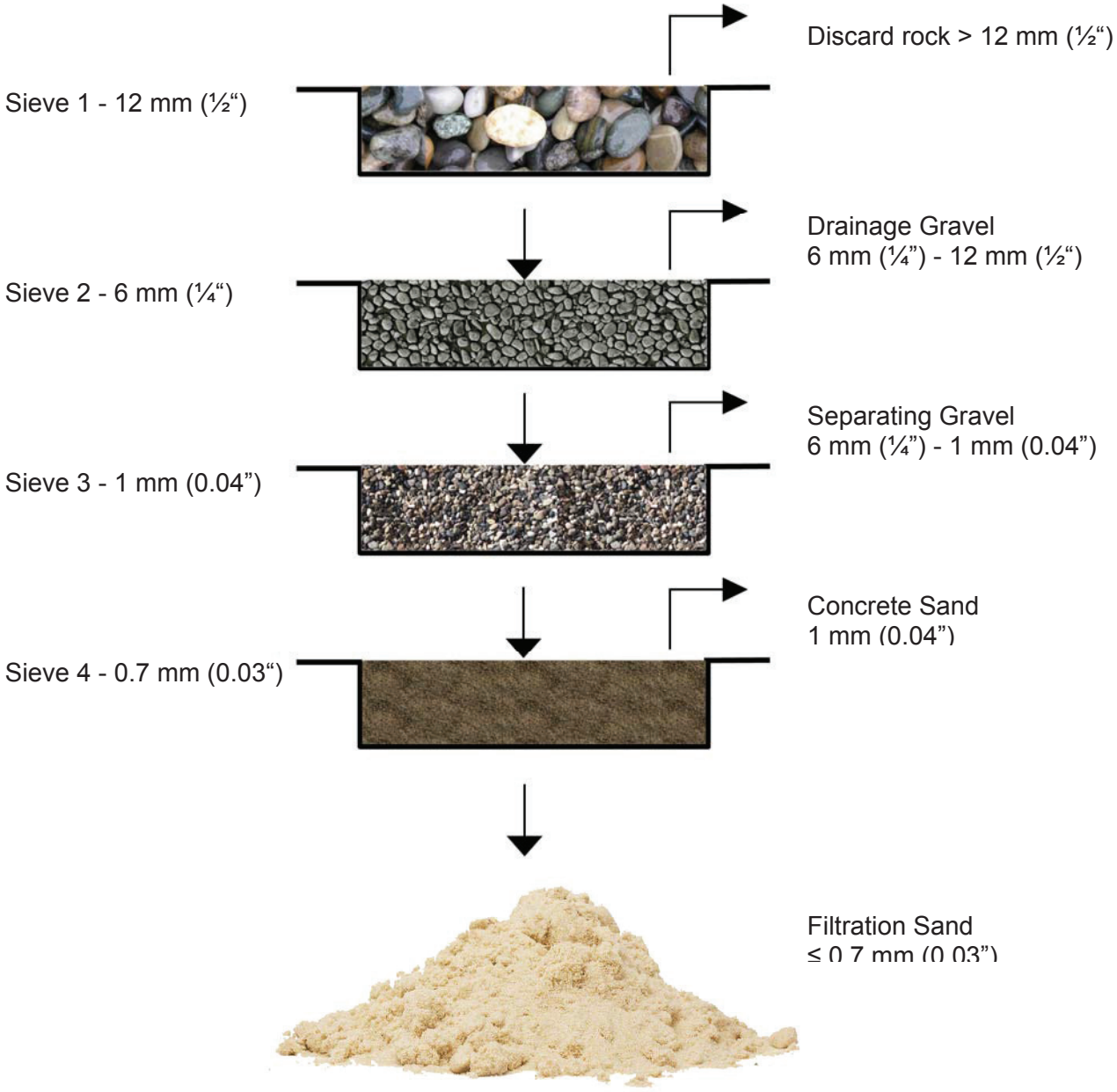
- When sieving, look under the sieve and watch the falling material. If very little or no material is falling out, then you can stop sieving that batch of sand or gravel.
- Any debris (e.g. wood, plastic, grass) found in the sand or gravel while sieving should be removed.
- Don't place too much sand or gravel on the sieves. Excess weight will cause the sieve to rip or break.

Tips:

- **Sieving sand is a lot easier if the sand is dry.** Wet or damp sand often plugs the screens making it difficult to sieve. If possible, leave the sand to dry in the sun beforehand. Then, store it under tarps or under a roof or in a building to protect it from moisture. During the dry season, you can prepare a large amount of sand and stockpile it under cover to prevent the sand from becoming wet.
- Wet sieving is a process which occurs when the sand is wet and can not, under any circumstances, be dried in the sun. It uses clean water to force the sand through the sieves.
- While sieving, ensure that you keep your piles tidy and separate so that they do not mix with each other or with unsieved sand. Poor sand quality due to stray rocks and mixing sieved sand sizes will reduce the treatment efficiency of the filter. If this happens, you will have to sieve the sand again.

Tidy and separate piles will keep the sand and gravel from mixing together

Filtration Sand and Gravel Sizes



Filtration Sand
≤ 0.7 mm (0.03”)

Concrete Sand
1 mm (0.04”)

Separating Gravel
6 mm (¼”)

Drainage Gravel
12 mm (½”)

WASH THE FILTRATION SAND

Tools:

- Small clear container with lid
- Several large containers approximately 40 cm (15”) deep

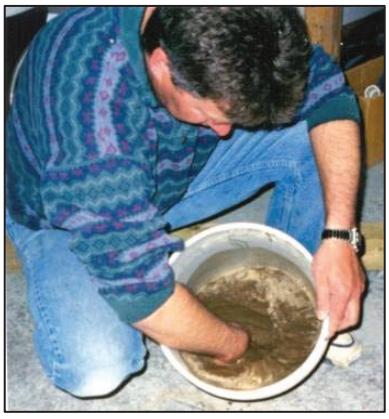
Materials:

- Clean water
- 0.7 mm (0.03”) sand

1. Put a small amount of the 0.7 mm (0.03”) sand in the container (approximately 10 cm (4”) deep).
2. Put double the amount of water in the container.
3. Using your hand, swirl the sand around the container 10 times very quickly, making sure your fingers touch the bottom of the container and get all of the sand moving.
4. Quickly decant the dirty water.
5. Repeat steps 1 to 4 as many times as determined in the flow rate testing section.

Tip: Do NOT wash the sand until the water in your container is clean. This residual water should still be somewhat dirty. It takes time and practice to be able to know how much to wash the sand.

6. Wash the rest of the sand using the same method (steps 1 to 5).
7. Place all of the sand and gravel on a tarp or concrete surface in the sun to dry. This step is especially important if the sand, gravel, or the wash water might be biologically contaminated.
8. Store the sand under cover once it is dry. You can also package it in bags or containers to make it ready for transport and installation (see Stage G Installation).



Unlike the gravel, the water in your container should not run clear. It will take practice to know how many times you will need to wash the sand.

JAR TEST

- The first time you wash the sand, it is necessary to experiment with the washing procedure in order to determine the proper number of washes.
- Wash the sand as described in steps 1 to 5 above. As you wash, count the number of times that you decant your container.
- Initially, it is a trial and error process – but that is why its important to count how many times you wash the sand, so that once you get the correct flow rate, you can repeat the same process. To **estimate** if the sand has been washed adequately, put some sand into a clear container with an equal amount of clear water. Put the lid on and swirl it. Looking from the side of the container, 3-4 seconds after you stop swirling, you should be able to see the surface of the sand.
- Your sand and gravel sources may vary so the number of times that you wash the sand will have to be adjusted periodically, but after some time you should develop the ability to know when the sand has been adequately washed, just by looking at the wash water in your container.

Not washed enough

About right

Washed too much

FLOW RATE TEST

- For the final test of the sand, install a biosand filter on site using your filtration sand and gravel, and test the flow rate. The flow rate should be 0.4 L/minute when the filter is installed.
- If the flow rate is much greater than 0.4 L/minute, the sand has been washed too much. You must decrease the number of times that you wash the sand. A flow rate that is too fast is not acceptable – the filter will not be effective.
- If the flow rate is much less than 0.4 L/minute, the sand hasn't been washed enough. You must increase the number of times that you wash the sand. The filter will still function if the flow rate is too slow, but it may plug more often, requiring more frequent maintenance. If the flow rate is just slightly less than 0.4 L/minute, it can be left as is – as long as the flow rate isn't so slow that it is inconvenient for the user.

TEST FLOW RATE

Tools:

- Watch
- Measuring container with 1 litre mark
- Storage container

Materials:

- 12 litres (3 gallons) of water

Steps:

1. Fill the filter reservoir to the top with water.
2. Place the measuring container under the outlet tube to collect the filtered water.
3. Measure the time it takes to fill the container to the 1 litre mark. The flow rate should be at a maximum of 0.4 litre/minute (see table to the right to convert seconds per litre into litres per minute).

Seconds per Litre	Litres per Minute
100	0.60
110	0.55
120	0.50
133	0.45
150	0.40
171	0.35
200	0.30

4. If the flow rate is very slow (less than 0.3 L/minute, taking more than 3 minutes to fill the measuring container to 1 litre):

- The filter will still work but it may plug faster requiring more frequent maintenance.
- If it takes too long to filter a pail of water, the user may become impatient and use unfiltered water instead.
- 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. In this case, the sand hasn’t been washed enough and needs to be replaced.

5. If the flow rate is faster than 0.4 L/minute, the filter may not work efficiently. In this case, the sand has been washed too much and needs to be replaced. 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 solids and faster growth of the biolayer).

Note: The flow rate through the filter decreases as the height of the water in the reservoir drops. As the water level reaches the diffuser, treated water may only drip out of the outlet tube. It can take 40–90 minutes for the 12 litres in the reservoir to completely pass through the filter.

Stage H – Operation, Maintenance and Follow-Up

ESTABLISHING THE BIOLAYER

The biolayer is the key component of the filter that removes pathogens. Without it, the filter removes about 30-70% of the pathogens through mechanical trapping and adsorption. The ideal biolayer will increase the treatment efficiency up to 99% removal of pathogens.

It may take up to 30 days for the biolayer to fully form. During that time, both the removal efficiency and the oxygen demand will increase as the biolayer grows. The biolayer is NOT visible – it is NOT a green slimy coating on top of the sand. The filtration sand may turn a darker colour, but this is due to the suspended solids that have become trapped.

The water from the filter can be used during the first few weeks while the biolayer is being established, but disinfection, as always, is recommended during this time.

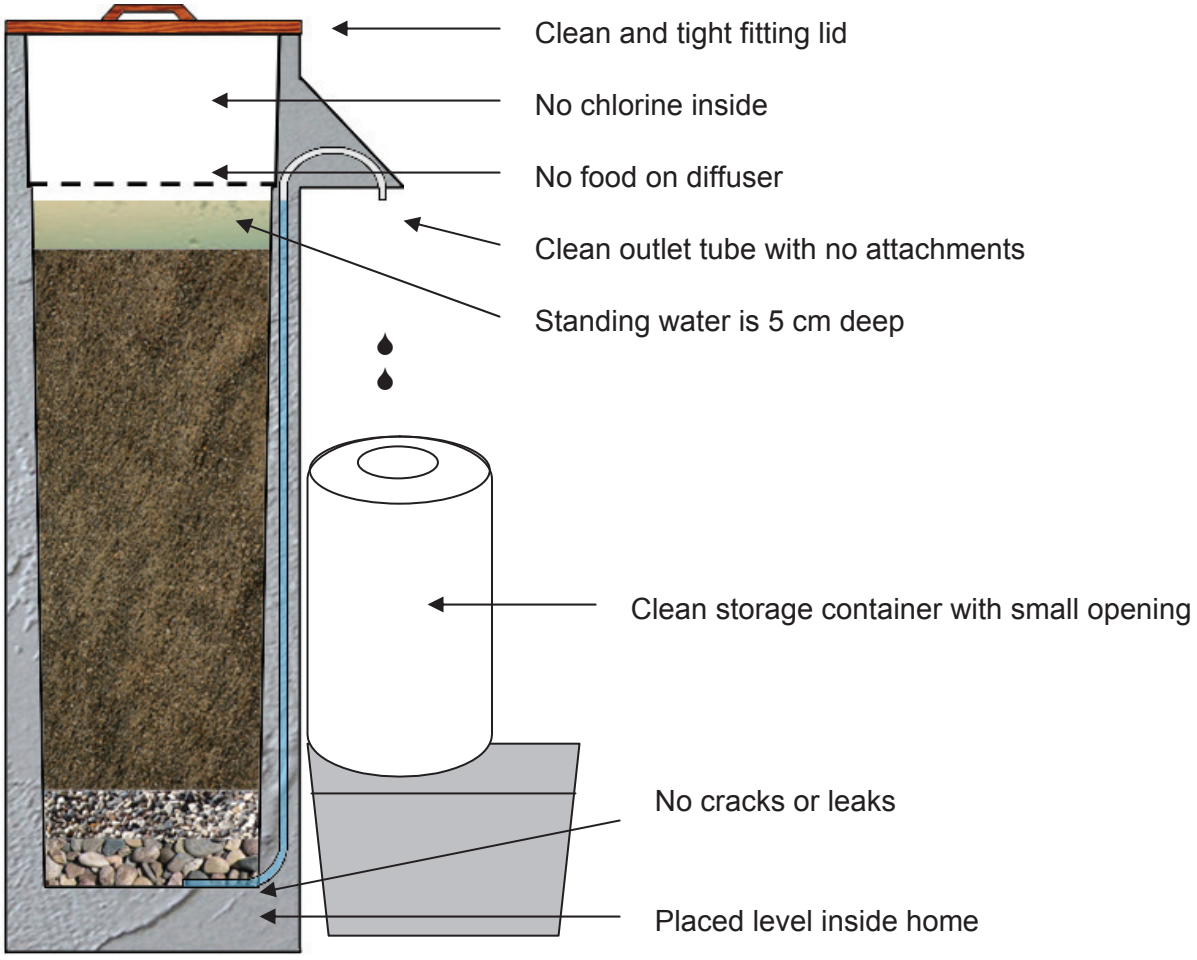
DAILY USE

All household users, including children, need to be taught how and why the filter works and about its correct operation and maintenance. Children are frequently the main users of the filter. Proper use includes the following practices:

- Use the filter at least once every 1-2 days, preferably 2-4 times each day
- Use the same source of water every day to improve the treatment efficiency
- Use the best source of water (least contaminated) that is available – the better the source water, the better the treated water will be
- The turbidity of the source water should be less than 50 NTU. If it is more turbid, then sediment or strain the water before using the biosand filter.
- The diffuser must always be in place when pouring water into the filter – never pour water directly onto the sand layer. Slowly pour the water into the filter.
- The lid should always be kept on the filter
- Use a separate container for collecting the source water
- Use a separate safe storage container that has the following qualities:
    - Strong and tightly fitting lid or cover
    - Tap or narrow opening at the outlet
    - Stable base so it doesn't tip over
    - Durable and strong
    - Should not be transparent (see-through)
    - Easy to clean
- Store treated water off the ground in a shady place in the home
- Store treated water away from small children and animals
- Drinking treated water as soon as possible, preferably the same day

- Water must always be allowed to flow freely from the filter. Do **NOT** plug the outlet or connect a hose to it. Plugging the outlet tube 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 outlet can also siphon or drain the water in the filter, dropping the water level below the sand layer and drying out the filter.
- Do **NOT** store food inside the filter. Some users want to store their food on the diffuser 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.
- The filtered water should always be disinfected to ensure the highest quality

Tip: The sound of water dripping from the outlet into the storage container can be irritating. The closer you place the container to the outlet, the less noise there will be. A container with a small opening also reduces dripping noise and prevents recontamination of the filtered water.



MAINTENANCE

There is some key maintenance tasks that are required after a filter has been installed and used regularly.

- The outlet tube will become contaminated during normal use via dirty hands, animals, or insects. Clean the outlet tube regularly with soap and water or a chlorine solution.
- Clean the inside of the treated water storage container when it looks dirty, when you do regular maintenance or at least once a month. **Do NOT pour chlorine into the top of the filter – it will kill the biolayer.** To clean the storage container:
    - Wash your hands before cleaning the container
    - Scrub the inside of the container with soap and treated water
    - Empty the soapy water through the tap
    - Rinse the container with a little treated water
    - Add chlorine to water in the storage container – let it sit for 30 minutes – if chlorine is not available, let the container air dry
    - Empty the remaining water through the tap
    - Clean the tap with a clean cloth and chlorine solution (such as bleach)
- The entire filter should be cleaned regularly (e.g. lid, diffuser, outside surfaces).

Chlorine works well to disinfect the treated water and clean surfaces, but do NOT pour chlorine into the top of the filter.

SWIRL & DUMP

The flow rate through the filter will slow down over time as the biolayer develops and suspended solids 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 container of filtered water may become too long and be inconvenient for the user. Alternately, you can measure the flow rate and if it is less than 0.1 litre/minute, then the "swirl & dump" maintenance is required.

Steps:

1. Remove the filter lid.
2. If there is no water above the diffuser, add about 4 litres (1 gallon) of water.
3. Remove the diffuser.
4. Using the palm of your hand, lightly touch the very top of the sand and move your hand in a circular motion; be careful to not mix the top of the sand deeper into the filter.
5. Scoop out the dirty water with a small container.
6. Dump the dirty water outside the house in soak pit or garden.
7. Make certain the sand is smooth and level.
8. Replace the diffuser.
9. Wash your hands with soap and water.
10. Set up the storage container to collect the filtered water.
11. Refill the filter.
12. Repeat the swirl & dump steps until the flow rate has been restored.

The biolayer has been disturbed by the swirl and dump, but it will develop again over time. **It is recommended to disinfect the filtered water during this time.**