Guidelines

Preparation of Media for the BioSand Water Filter

Three Layer System

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The purpose of preparing and publishing these guidelines on the internet is to provide a readily available technical reference to all those involved in BioSand Water Filter manufacture, funding, use, evaluation or support.

Introduction

The three layer system was developed for use by individuals or organizations that produce a few hundred household BioSand Water Filters in a central manufacturing facility per year. This remains the most common type of manufacturing operation world wide. The three layer system can be implemented with a minimum of capital investment, locally available materials and using simple manual techniques. (See Guidelines for Preparation of Media for the BioSand Water Filter Four Layer System for instructions pertaining to preparation of media when producing larger numbers of filters (several hundred or thousands) per year.)

The three layer system requires a thorough understanding of the filtering procedure and how the filter media affects the quality of the treated water. It is very important that the techniques presented in this document be followed as close as possible. The apparent simplicity of the three layer system seems to invite ad hoc modifications to the technique and filter performance (and acceptance) suffers as a result.

Following is a description of the three layer system and how it may be implemented. Only essential concepts are presented. Ultimately, local manufacturers must develop their own techniques and procedures while adhering to the fundamentals expressed in these guidelines.

Detailed instruction and demonstration of filter media selection and preparation is provided in workshops on the manufacture and use of the BioSand Water Filter and in shorter workshops focussed specifically on filter media production.

Description of the Three Layer System

The three layer system requires the preparation of three types of media; the underdrain layer, separation layer and one filtering layer.

Consider the following sketch of a cross-section of a filter bed in a BioSand Water Filter that uses the three layer system.

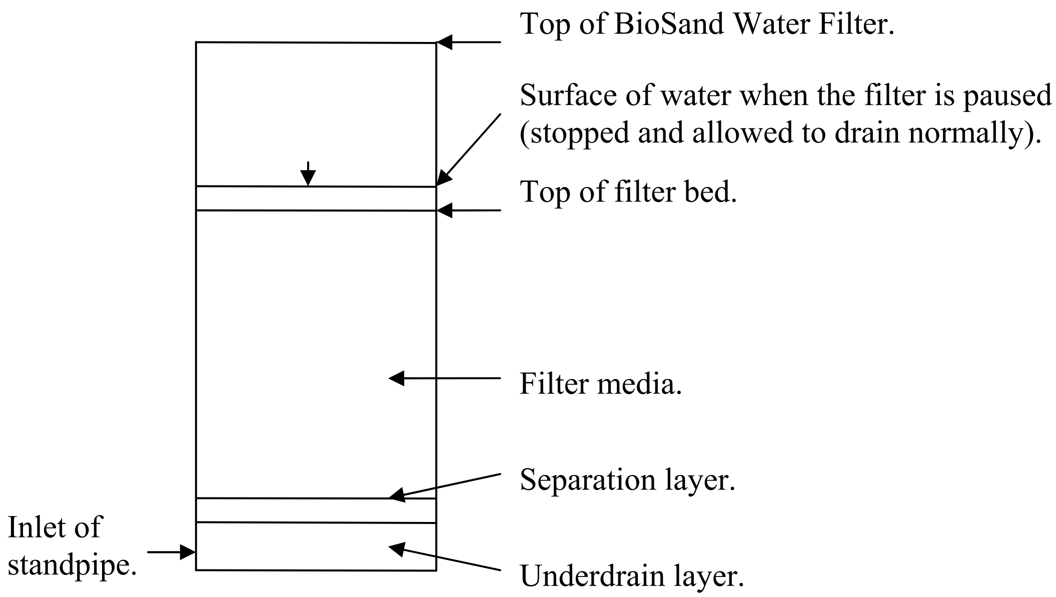

Figure 1. Cross-section of the filter bed of a typical BioSand Water Filter using the three layer media system.

A description of each of the various layers follows:

1. Underdrain layer: Allows vertical drainage through the filtering layer and allows filtered water unrestricted access to filter standpipe. The thickness of the underdrain layer must be sufficient to cover the inlet to the filter standpipe (located at the inside bottom of the filter body) with 2 cm of underdrain material. The underdrain layer is composed of particles ranging in size from 6.25mm to 12.5mm (1/4 to 1/2 inch) in diameter. The total depth of the underdrain may be 8 cm or more. The thickness of the underdrain layer is the same throughout the layer.
2. Separation layer: Prevents filter media from entering the underdrain layer and the standpipe. The separation layer should be 3 cm in thickness. The separation layer is composed of particles ranging in size from 3.125 mm to 6.25 mm (1/8 to 1/4 inch) in diameter. The thickness of the separation layer is the same throughout the layer.
3. Filter media: Responsible for removal of particles and micro organisms including viruses, bacteria, parasites and helminths. Flow of water through the filter is controlled by the selection and preparation of the filter media. The largest particles comprising the filter media must be less than 3.125 mm or 1/8 inch in diameter. The thickness of the filter media should be no less than 40 cm. The thickness of the filter media is the same throughout; that is, the top surface must be level after installation.

Media Installation Instructions

The only way to evaluate prepared filter media is to install it in a full-scale BioSand Water Filter. The following installation procedure is very similar to that used when installing filters for actual use. Procedures for post-filtration disinfection are not included.

Media installation proceeds as follows:

1. The first step is to determine the maximum depth of the media in the filter. If the filter walls are made of plastic and are transparent it is possible to make all depth measurements from outside the filter. If the filter body is not transparent, (concrete), then it is necessary to fill the filter to the point where water is just starting to drip from the standpipe. At this time the depth of water in the filter is equal to the depth of the media plus the paused water depth. A piece of wood that is 1 or 2 cm in diameter and 10 cm longer than the depth of the filter may be used to measure media depth. The wood is placed on the bottom of the empty filter and held vertical. A second similar but shorter piece of wood is placed across the top of the filter and the vertical piece is marked with a pencil immediately above the horizontal piece. The distance from the bottom of the vertical piece of wood to that mark will be equal to the depth of the inside of the filter plus the thickness of the horizontal piece of wood.
2. Using a measuring cup or similar container add underdrain media such that it covers the inlet to the standpipe with 2 cm of material. (Cups should be filled and levelled.) The top of the underdrain layer must be perfectly level. Typically, your hand is used to level the top of the layer. If your arm is too short a piece of wood can also be used. It is normal for the water to become quite turbid and it will not be possible to see the media through it. The measuring stick is now very useful. The depth of media required to cover the inlet to the standpipe is noted and a second mark is added to the vertical stick a distance equal to the depth of the underdrain layer below the first mark. The depth of the media can be conveniently measured by placing the horizontal piece of wood across the top of the filter and positioning the vertical piece against it. When the depth is exactly correct the second mark and the top of the horizontal piece will be the same. Record how many cups of underdrain media were used. The number of full and partial cups of media will be used to determine how much underdrain media will be supplied with the filter.
3. Put the diffuser basin into position and add water until there is approximately 10 cm standing above the underdrain material. (The diffuser basin is used to prevent the water from disturbing the media when poured into the filter.) Remove diffuser basin.
4. Prepare to add the separating media. Add a second mark to the vertical piece of wood 3 cm below the first mark. Using the measuring cup carefully add 3 cm of separating media. Again, the top of the separating layer must be perfectly level. Record how many cups of separating media were used.
5. Put the diffuser basin into position and add another 10 cm or so of water. Remove diffuser basin. There should never be more than 20 cm or so of water in the filter when media is being added.
6. Place marks on the vertical piece of wood equal to the thicknesses of the filtering layer.

7. Carefully measure the amount of filtering media required to bring the filter bed to the mark that indicates the top of the layer. (Note that media should ALWAYS be added to water and added quickly - almost dropped in. By adding media to water there is no danger of trapping air in the media which can stop the flow of water through a process known as air binding. By adding the media very quickly into no more than 20 cm of water there is no danger the particles will separate with coarse falling into place first followed by the fine particles, a process known as stratifying. The stratifying effect greatly decreases the flow of water through the filter and is avoided using this procedure.) Record the amount of media used to complete the second filtering layer. (Place a bucket under the standpipe to capture any water that may dribble from the standpipe outlet during media installation.)
8. Clean surface of the media by adding sufficient water to fill the portion of the filter interior above the top of the filter media with 20 cm or so of water. Remove the diffuser basin. Using your hand or a brush, vigorously stir up the water above the media surface. Your fingers can penetrate the top of the media by a 1/2 cm but no more. The vigorous agitating action will cause the top of the media layer to be release particulate material that would otherwise plug it off. Once sure that all material is suspended that can be suspended a cup is used to remove as much of the very turbid water from the filter as possible. Wait a few seconds to allow the media to settle before starting this process. Care should be taken not to remove any of the media by allowing the cup to scoop into the media surface. The cleaning action can be repeated as often as required. Level the top of the media as a last step of the cleaning process. The effect of this cleaning is to maximize the flow of water through the filter bed that has just been installed.
9. Measure the flow rate through the filter by replacing the diffuser basin and adding enough water to completely fill the filter. Using a calibrated measuring cup or a plastic container such as an empty water or soda pop bottle, (any of the plastic bottles will work though 500 ml and 1 litre bottles work the best), measure how long it takes to fill this bottle with filtered water, which will still look very turbid. (Note that after three or more 20 litre buckets of water are added to the filter the water will flow very clear.) Calculate the actual flow rate through the filter by dividing the volume filtered measured in litres by the time required to produce the volume in minutes. Compare this flow to the objective flow rate for the filter. The objective flow rate is calculated by multiplying the surface area at the top of the media measured in square meters by 600 litres per hour per square meter. For example if the surface area of the filter, at the top of the media, is 0.1 square meter, the objective flow rate is 0.1 square meters times 600 litres per square meter per hour equals 60 litres per hour or 1 litre per minute.
10. If the flow rate as measured is above or below the objective flow rate the procedure for washing the filtering media must be adjusted. This is described later.

Selection of Crushed Rock for Media Preparation

The preferred source of material with which to produce the filter media is crushed rock from a rock quarry. This material can be expected to be very clean and free from organic and microbial contamination. There is usually an opportunity to acquire large quantities of raw materials exhibiting consistent particle size distribution.

Ideally, the material is very hard, a quartzite or granite. Very soft material such as crushed limestone can also be used. Mudstones that contain oxidized iron or manganese should be avoided as they will likely contaminate and color the water as it is filtered. A potential problem with softer rocks, (like limestone and mudstone) is that some particle rubbing and grinding always occurs during handling and transport resulting in the production of unwanted fines,. From a consumer perspective the color of the rock should be as light as possible though any color is actually satisfactory provided the color does not transfer to the water during the filtering process.

Crushed rock is often available in a size already very close to that needed for the underdrain layer and separation layers and may be purchased directly. Very little waste will result when processed.

Crushed rock for the preparation of the filter media and separation layer is usually the finest material in the quarry. Often it is considered waste material. The material used for the filtering layer MUST contain particles varying in size from very fine, almost dust size, to larger than 1/8 inch or the opening of the filtering sieve. Material that is all dust simply won't work as the flow through it will likely be too low or require considerable preparation to make work. Material that does not contain any fines cannot work either because the flow rate through the media will be too large.

Media delivered to the processing site should be protected from the weather and risk of contamination from weather, animals or humans. This may require a roofed working area and a concrete floor. Drying media outdoors will require a large concrete pad with good exposure to the sun. The entire media processing area should be secured with appropriate fencing or walls that also allow good access for trucks.

Every shipment of unprocessed media should be evaluated, using appropriate particle size evaluation techniques, to insure that the media supplied is similar to previous shipments that were used to establish media preparation procedures and filter bed design. Particle size distributions can very considerably from shipment to shipment. However, it is reasonable to assume that individual shipments are more-or-less homogenous and it is advisable to obtain the largest shipments that can be managed.

If it is determined that the particle size distribution of a shipment is different from previous deliveries, the media preparation procedure may need to be evaluated and changed if necessary.

<u>Media Contamination</u>

Clean (uncontaminated) media is free from toxins and any organic material, living or dead. Media at risk of contamination with toxic substances by virtue of being near industrial activity or affected by waste disposal activities should be completely avoided. Surface accessible deposits of sands and gravels, including gravel pits, beaches and river banks, usually contain significant organic material due to vegetation accumulation and human and animal activities. Only media obtained from rock quarries that produce material from solid rock formations can be expected to be contamination free.

Media contamination occurs due to the presence of individual organic particulate material, (pieces of plants, animals, insects, seeds, etc.), and organic material that was originally dissolved or suspended in water and is now attached to individual rock particles. Organic material is food for micro-organisms, a few of which might be pathogenic (disease causing). Standard practice is to test for the presence of pathogen indicator micro-organisms such as fecal colliform bacteria (found in the intestinal tracts of warm blooded animals and present in the many billions per gram of human feces), Escherichia colliform or e-coli bacteria (dominant colliform bacteria found in intestinal tracts of warm blooded animals) and total colliform bacteria that includes all forms of colliform bacteria including those that naturally live in the soil or associated with other forms of life. If colliform bacteria are present it is normal to find similar numbers of fecal colliform and e-coli bacteria and tens times their number of total colliform bacteria. These colliform bacteria are NOT usually pathogenic themselves. (There are notable exceptions such as the 0157 strain of e-coli, which is very dangerous.) Rather, their presence is used as an indicator of the possible presence of other, serious pathogenic organisms, resulting from direct contamination by human feces or animals that could carry the same pathogens (parasites such as Giardia and Cryptosporidia).

It is possible to evaluate media contamination by taking a gram of filter media (straight from the quarry or after the media preparation process), washing it in one litre of sterilized water (boiled and cooled river water) and having it tested for the presence of any one or more of the indicator organisms. The testing should be performed by a reputable local laboratory. Laboratory instructions must be carefully followed. If any of the indicator organisms are present the media is at risk of being contaminated and must be further evaluated with respect to the possible cause of the contamination (lack of protection at the quarry, handling, etc.). Other sources of crushed rock may need to be found.

It may be possible to wash the organic particulate material from the rock media; but it is not possible to remove the organic material attached to the rock particles themselves. Micro-organisms will continue to grow on the particles as long as there is food (organic material) available. When all of the food is consumed the micro-organism will disappear and the media is 'clean'.

It is possible to disinfect the media by heating it or soaking it in disinfectants such as chlorine bleach. The rock particles will still have 'disinfected' organic material attached. The disinfected media is quickly contaminated once the media is installed in a filter and water containing living micro-organisms is poured through it. The media will appear contaminated, based on bacteria tests on the treated water, until all of the attached organic material has been consumed by the micro-organisms and they no longer exist within the filtering, separation or underdrain media itself. It is common to observe more bacteria in the filtered water than in the unfiltered water. The media will appear contaminated for a period of several months.

Sieve (Screen) Selection.

(For purposes of this document sieve size and screen size are used interchangeably.)
Selecting screen sizes of approximately 12.5 mm (1/2 inch), 6.25 mm (1/4 inch), and 3.125 mm (1/8 inch) (or slightly smaller but never smaller than the holes in typical mosquito netting) can produce useful results. Rock particles larger than 12.5mm (1/2 inch) will be discarded. All material smaller is potentially useful.

Material for making the 12.5 mm or ½ inch and the 6.25 mm or ¼ inch opening sieves can be obtained from most hardware stores where it is known as 'hardware cloth'. It is usually sold in imperial opening sizes or 1/2 and 1/4 inch and can be purchased in rolls. It is used for reinforcing concrete and is quite inexpensive. Any material with approximately the same size openings will work. Local sourcing is very important.

Hardware cloth can also be purchased with 1/8 inch opening but zinc coated metal mosquito screening works the best.

A set of production sieves should be manufactured with which to evaluate media produced for performance in an actual BSF and to develop media production procedures. To be useful the small production screens should be approximately 60 cm long, 45 cm wide and about 10 cm deep. Larger screens are heavy and awkward to use.

A set of very small screens, 30 cm by 30 cm or smaller are useful for evaluating possible supplies of crushed rock or evaluating purchased material for consistency.

Screening Machines

Mechanically operated screening machines are not usually justified. Labour costs are usually not very high and media production can provide much needed employment. As production grows commercial screening machines or 'home made' screening machines can be useful and cost effective. (A simple internet search is useful for identifying the various designs, scales, costs and availability of screening machines around the world.)

Media Preparation

The parameters available to control the flow rate through the filter are media selection, screen or sieve opening size and media washing.

As mentioned earlier the flow rate through the BioSand Water Filter is controlled by the selection, sieving and washing of the filtering media. Washing is considered once the selection and sieving is completed.

Normally, the media bed should be installed and the flow rate evaluated before it is washed. Media produced from crushed rock rarely contains substantial quantities of fine silt or clay, which *must* be washed from the media in all circumstances, prior to attempts to install it in a filter. If the flow rate is too high the media is simply too coarse and finer material, or material containing more fine particles, must be found. Usually the flow rate is too low and must be increased. This is achieved by washing the finest particles from the filtering media.

Soaking dry media in water or simply wetting it twenty-fours prior to washing will improve and greatly speed up the washing process.

Washing is performed by filling 15 to 20 litre capacity buckets with 3 to 5 litres of the media that is going to be washed. The bucket is filled to one-third to one-half full with water and angled slightly (fifteen degrees or so). Using your hand (maybe wearing rubber gloves as the media is abrasive) or using a suitable flat piece of wood, the mixture of water and media is 'stirred' ten to twenty times. Stirring requires that your hand or the stick touches the bottom of the bucket and the stir moves all the way around the outside of the bucket. The water is then carefully poured from the bucket into a waste water receiving container. This water can be allowed to settle and reused if necessary. When pouring the water from the bucket it is very important not to lose any of the media that is NOT suspended in the water. The process of adding the same amount of media to the bucket, pouring the same amount of water into the bucket, stirring the media and water in exactly the same way and number of times and pouring the water from the media in an appropriate fashion is known as a 'wash'. Filtering media may require several washes before enough 'fines' are removed that the flow rate is satisfactory. Of course the flow rate can ONLY be evaluated by actually installing the washed media in a BioSand Water Filter. Quality control can be quite good provided the 'washers' are conscientious and supervisors are diligent.

The underdrain and separating media is washed in exactly the same way except that they are both washed until the water poured from the bucket is CLEAR; that is, contains NO fines. It is very important to wash these layers thoroughly as they 'clean or rinse' very slowly after installation, shedding particulates over a long period of time in normal filter use in contrast to the filtering layers which 'clean' very quickly even if not washed at all.. Washing underdrain and separating media with cement mixers or other kinds or rotating drums may be practical.

Note that while washing may NOT be essential for preparation of media used in the filtering layer**, the media used for the separation and underdrain layers is ALWAYS washed.**

If the material is received damp it usually must be dried before sieving is successful. If it is later determined that the media will be washed then it might be advisable to consider washing all of the unprocessed raw material prior to drying.

Bagging and Storage of Prepared Media

Prepared filter media (all three layers) should be bagged in clean, water-proof sacks. Labelling should be waterproof. The media for each layer should be bagged separately. Each bag should contain slightly more media than is necessary since supplying insufficient media can present serious problems at time of filter installation. Some settling of the filtering media will likely occur after it has been installed for some time and the extra media can be used to bring the filtering layer to the desired depth. The bags of prepared media should be protected from weather and contamination.

Quality Control Considerations

Periodically, it is useful to evaluate the unprocessed crush rock to determine if its characteristics (particle sizes) are changing. This is best achieved with a set of small sieves. The percentage of material captured on these sieves relative to total sample will remain constant if the particle size variation in the bulk sample is constant. If the particle sizes are thought to have changed significantly then it may be important to evaluate the entire media production process. Often problems of this nature become known from the people who are installing the filters in the field. They may complain of the filter production being too high or too low and these MAY suggest that the processed material is changing due to changes in the characteristics in the unprocessed crushed rock OR media production is not being performed carefully enough.

Water Supply, Clarifying and Reuse

Media preparation requires the use of significant quantities of water. Ideally, media cleaning should occur near an abundant supply of water clean enough for media preparation. The water may be slightly turbid and be considered unsafe for human consumption but it should NOT contain pathogens that can penetrate the skin (e.g. Schistosomiasis). Wash water produced during media preparation is contaminated with excess sediment and should not be disposed of without allowing most of the particles to settle. It is definitely preferable to clarify the wash water (even using small amounts of coagulant such as alum) and reuse the clarified water. Media preparation operations that clarify and reuse their wastewater may be located quite far from the raw water supply.

Actual Installation Considerations

Should the raw material supply used for producing the top and second filtering layers vary with time (this is quite probable) it may be impractical to try to alter the media production procedures to keep up with the variations in the characteristics of the resulting filtering media. Rather, it may be practical to install the filter bed using a standard procedure, which would result in flow rates near the maximum allowable. Flow rates should NOT exceed the objective flow rate but can be significantly less. As mentioned consumers may not accept a filter with flow rates that are too low and steps may need to be taken to mitigate the problem. A variety of strategies may be used to alter flow rates without negatively impacting on the integrity of the filter design. These are as follows:

1. If the flow rate is too **low** some of the filtering layer can be removed (up to 1 cm for the three layer system). If it is still too low there may be a problem with media installation (stratifying or air binding might have occurred) and the wet filtering material should be scooped out to just above the separation layer (easily done) and then reinstalled. Should this procedure not work it is possible that there may be a problem with the standpipe being plugged. This problem can be evaluated by pouring water through the standpipe

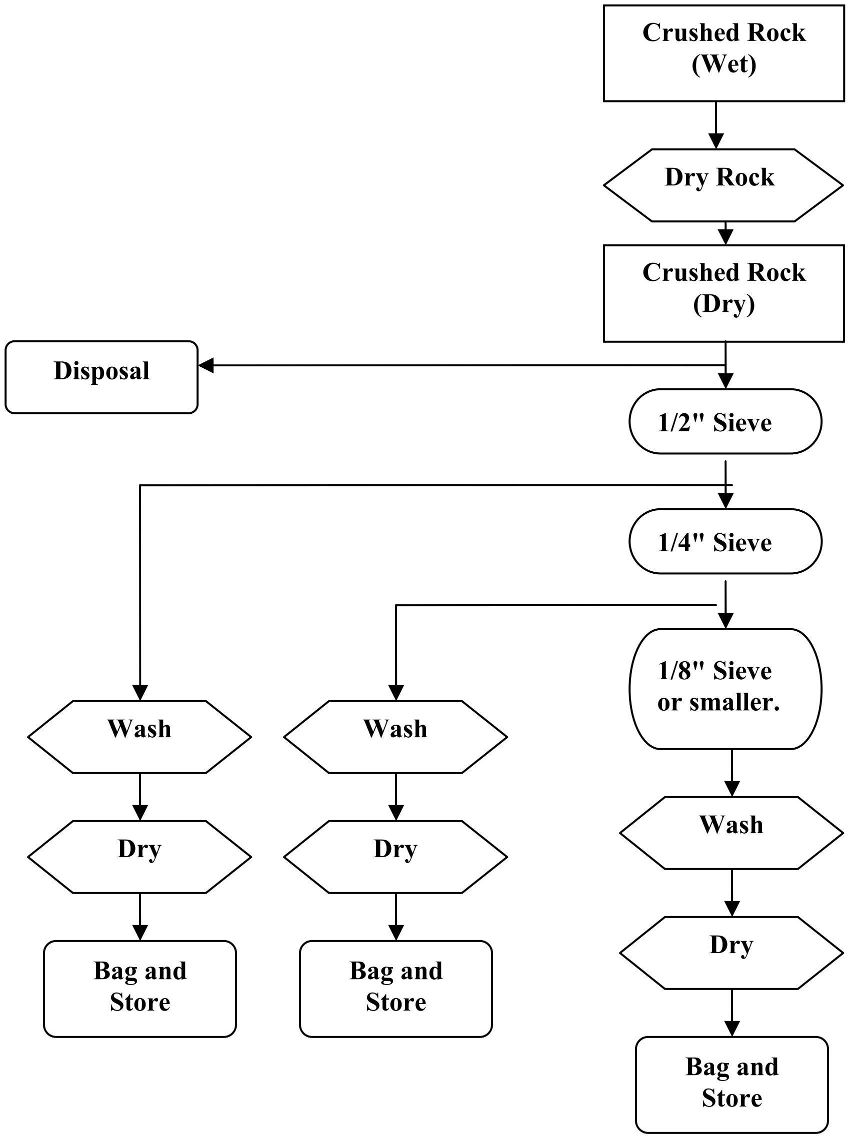

Figure 2. Media preparation flow chart when one crushed rock supply is used to produce media used in the three layer system.

outlet (using the disinfection tube). If this fails then all media must be removed from the filter, the construction of the filter checked and if OK the media is reinstalled. If the flow is still too low the filtering media has not been prepared correctly.

2. If the flow rate is too **high** the filtering media has not been prepared correctly. However, it may be possible to adjust this flow rate by removing 5 cm of the filtering media and replacing it with some 'super slow' filtering media prepared for this purpose. Super slow media may be unwashed filtering material or it may be produced using sieves with openings less than one half the diameter of the openings in mosquito netting. The flow rate through the super slow media should be 20 per cent or less than the flow through the filtering media. Experience will determine how this material is used. Keep in mind that the top of the filtering media can be 1 cm deeper than specified without impairing filter performance.

Effect of Variation in Crushed Rock Supply on Media Preparation

Three media systems developed using one type of material may be quite different from other three media systems developed using other types of material. Crushed granite, gneiss, quartzite, limestone, dolomite, sandstone, etc. can be expected to require quite different preparation procedures. As a rule the more similar the material and shape of the crushed particles (closely examined using a magnifying glass) the more similar the preparation procedure will be. Development of media preparation procedures using a completely unique material will be greatly facilitated by starting with any known procedure that is working successfully and modifying it as required.

Final Comments

The three layer media system has been used around the world to produce many thousands of BioSand Water Filters and is being used many individuals and organizations to produce many thousands more. The three layer media system has clearly been a success due to the conscientious and consistent attention paid to the guidelines presented. I acknowledge and congratulate all those responsible.