Water for the World

Designing a Slow Sand Filter
Technical Note No. RWS. 3.D.3

A slow sand filter is a very useful water treatment process. Slow sand filtration effectively removes organic matter, pathogenic organisms, color and mild turbidity to provide clean and safe water. No other single treatment process can improve the physical and biological quality of water as well as sand filtration.

Slow sand filters offer other advantages which make them useful in rural areas. They can be constructed with local materials and labor at a low cost. Operation and maintenance requirements are few and local labor can be trained to carry them out.

Even though sand filters are not difficult to design and operate, special care must be taken to ensure their efficient operation. This technical note describes the basic design features of a slow sand filter. Before attempting to design such a system, consult an engineer whenever possible.

The design process should result in the following three items which should be given to the construction supervisor.

1. A map of the area marked with the locations of the slow sand filter, other treatment systems planned, the water source, and any important landmarks. See Figure 1. Whenever possible, the filter should be located close to the water source.

2. A list of all labor and materials needed for the project. A sample list appears in Table 1.

3. A plan of the slow sand filter showing the design dimensions as shown in Figure 2.

Useful Definitions

BUTTERFLY VALVE - A valve used to accurately regulate the flow of water through a pipeline; a butterfly valve can be opened and closed slightly to regulate flow.

CREST - The top of a weir or spillway to which water must rise before passing over the structure.

DESIGN PERIOD - The length of the useful life of a structure or system during which no extension or expansion is required.

FREEBOARD - The height of the filter box above the water level.

GATE VALVE - A type of cut-off valve in a pipeline; when completely open, it provides a low resistance to straight line water flow.

SCHMUTZDECKE - A layer of biologically active microorganisms that forms on the top of the filter bed; the microorganisms break down organic matter and kill the bacteria in the water.

WEIR - A barrier placed in moving water to either measure, stop or control flow.

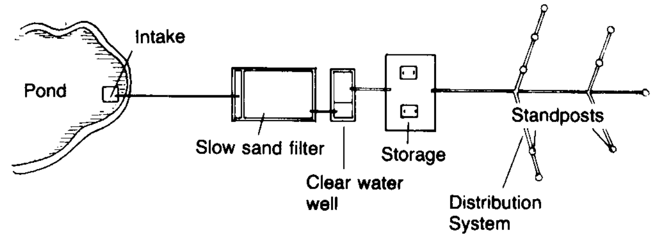

Figure 1. Location Map

Design Information

The basic parts of a slow sand filter are:

- the water reservoir above the layer of filter sand,
- the filter bed,
- the filter bottom and water drainage system,
- the filter box containing the three items above,
- the filter control system,
- the effluent system.

Each part plays an important role in the overall design. Before beginning to design the filter, it is necessary to determine the following:

- the amount of water that must be provided to the community and the capacity of the filter,
- the number of filter beds desired.

Table 1. Materials List for Slow Sand Filters

Item	Description	Quantity	Estimated Cost
Labor	Foreman	___	___
	Laborers	___	___
Supplies	Bricks	___	___
	Cement	___	___
	Gravel, 60-100mm	___	___
	Sand, 0.15-0.35mm	___	___
	Gate valves	___	___
	Butterfly valve	___	___
	PVC pipes	___	___
	Wooden stakes	___	___
	Rope	___	___
	Pipe glue	___	___
Tools	Digging tools	___	___
	Small saw	___	___
	Sieve	___	___
	Hammers	___	___
	Nails	___	___
	Measuring tape	___	___
	Trowels	___	___
	Wheelbarrow	___	___
	Mortar box	___	___
	Total Estimated Cost =		

The slow sand filter should be designed to meet a community's needs for about 7-10 years. Some systems can be designed for up to 20 years. In designing for the capacity of a slow

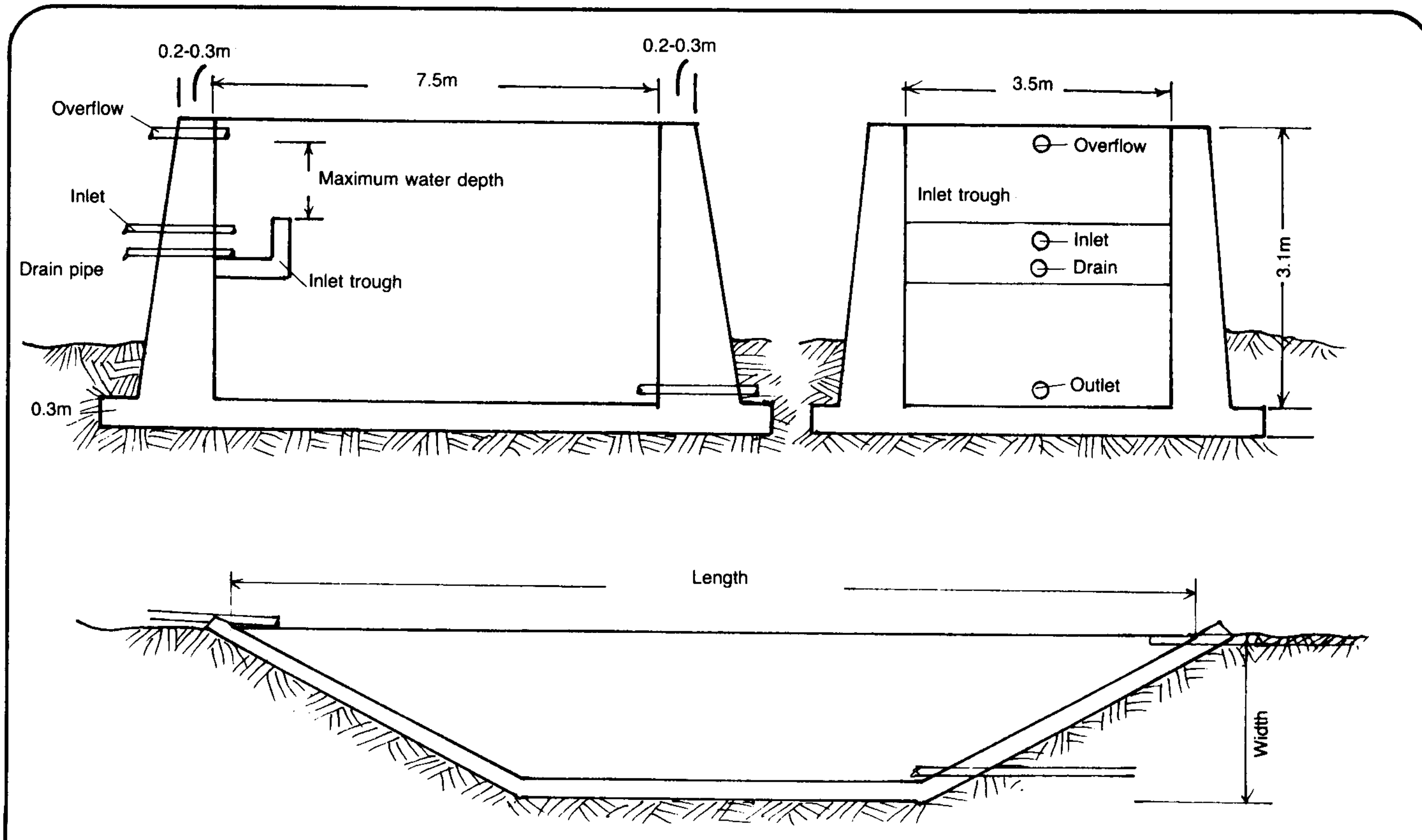

Figure 2. Design of Slow Sand Filter

sand filter, make an estimate of the community's population 10 years in the future. Although accurate information on population growth may not be available, gather any available data from local sources and make an estimate. Table 2 shows the population growth factors that can be used to estimate the future population of a community.

Table 2. Population Growth Factors

Design Period Years	Yearly Growth Rate (%) 1.5	2	2.5	3	3.5	4
7	1.1	1.15	1.19	1.23	1.27	1.32
10	1.16	1.22	1.28	1.34	1.41	1.48
15	1.25	1.35	1.45	1.56	1.68	1.80
20	1.35	1.49	1.64	1.81	1.99	2.19

For example, if the population of a certain town is 1000 and the yearly growth rate is 2.5 percent, the population in 10 years can easily be determined in the following way. First, look in Table 2 under the column 2.5 percent and find the number in the row for a 10-year design period. The number is 1.28. Multiply the present population (1000) by 1.28 to determine the population in 10 years:

1000 people x 1.28 = 1280

Therefore, the sand filter should be designed for a population of 1280 people.

Calculate the daily demand for water. When determining demand, assume a level of consumption of 40 liters per person per day. Total daily demand is:

1280 people x 40 liters/person/day = 51200 liters/day or approximately $52m^3$/day.

For design of the clean water storage tank and the distribution system, the hourly water demand must be calculated. The hourly water demand takes into consideration daily peak flows to ensure that water is provided to the users without interruption. Determine the hourly water demand by taking 20 percent of the daily demand. For example: $52m^3$/day x .20 = $10.4m^3/h$

Next determine the total filter area. The filter bed area can easily be calculatd using the following formula: $A = \frac{Q}{V}$. The area equals the quantity of water per hour divided by the velocity of water through the filter bed. Velocity should range between 0.1m/h and 0.2m/h. In this example, the quantity of water is $10.4m^3/h$. Assume a filtration rate of 0.2m/h. Therefore, the total filter area equation is:

$$\text{Area} = \frac{10.4m^3/h}{0.2m/h} = 52m^2$$

A minimum of two filters should be constructed. Each should have a filtration rate of 0.1m/h if they operate together. If one filter is shut down for cleaning, the other filter can be used. With one filter closed down, the filtration rate for the filter in operation would be no more than 0.2m/h. Since the total area of the filter beds is $52m^2$, two filters of $26m^2$ can be constructed ($52m^2 \div 2 = 26m^2$). Space for a third filter with the same area should be reserved for future expansion. Design the filters so that the ratio of length to width is between one and four. For example, each filter could have a width of 3.5m and a length of 7.5m ($7.5 \div 3.5 = 2.1$).

For filters with loads of $6m^3/h$ or less, a circular ferrocement filter can be constructed. A circular ferrocement filter is easier and cheaper to build than a rectangular concrete or masonry filter. Ferrocement filters are built using chicken wire, wire strips and a mixture of one part cement and two parts sand. The wire mesh is usually 20mm thick and the walls are between 60 and 120mm thick. See Figure 3 for more detail. Ferrocement filters should not be more than 5m in diameter and should have a filtration rate of 0.1m/h. They are especially useful in small villages.

The greater the capacity needed, the greater the number of filter units which should be built. Filter units should not be too large in order to simplify cleaning. To determine the number of filter units needed for a system, use the following formula:

$n = 1/4\sqrt{Q}$ (the number of filters is equal to one-fourth the square root of the infiltration flow rate) where:

n = number of filters (where n must be 2 or greater)

Q = the water flow rate in m^3/h.

In the above example, the flow rate, Q, is equal to $10.4m^3/h$.

Therefore, $n = 1/4\sqrt{10.4m^3}$
$n = 1/4\ (3.2)$
$n = 0.8$, or approximately one filter. Since two filters should be provided, an adequate supply of water will be available for the community from two small sand filters.

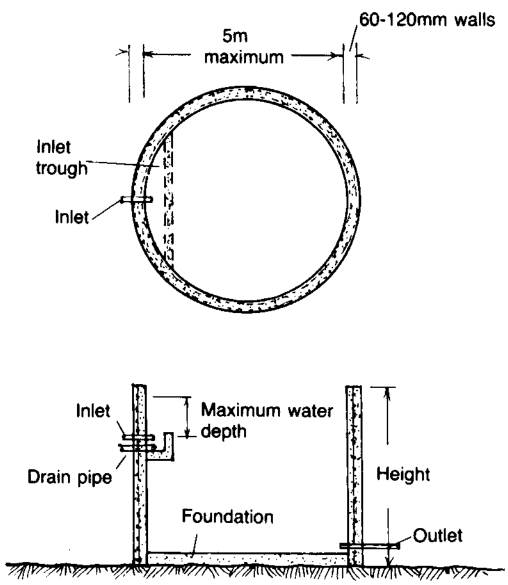

Figure 3. Ferrocement Sand Filter

Filter Box

The filter box consists of four parts:

- the water reservoir above the filter bed,
- the filter bed,
- the underdrain system, and
- the filter control system.

The water reservoir above the sand level provides a waiting period for the water in which sedimentation can take place and produces a head of water greater than the resistance of the filter bed. A head of between 1.0-1.5m above the filter bed is an acceptable water depth. The walls of the reservoir should extend 0.2-0.3m above the water level as shown in Figure 4. This extension is called the freeboard.

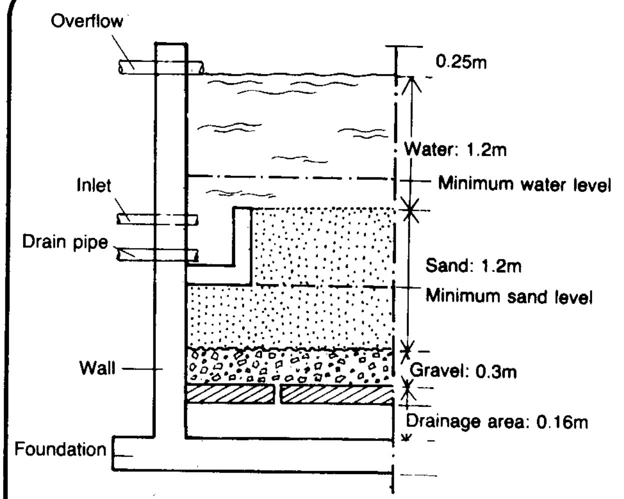

Figure 4. Filter Bed Construction

The filter bed is where the purification process takes place. The filter material is usually a fine grain sand and should be free from clay loam and organic matter. The diameter of the sand should be just small enough to ensure that the filter produces good quality water and to prevent the entry of clogging material into the filter bed.

Sand size is described by two measurements, the effective size and the uniformity coefficient. The effective size of the sand is the size of the sieve opening through which 10 percent of the filter bed material will pass. For the sand filter, use sand with an effective size between 0.15-0.35mm.

The coefficient of uniformity of the sand used in the filter should be less than 3. The coefficient of uniformity is a ratio between the sieve size through which 60 percent of the filter material passes (d_{60}) and the size through which 10 percent of the sand passes (d_{10}). The coefficient of uniformity can be determined as follows:

$$\text{coefficient of uniformity} = \frac{d_{60}}{d_{10}} = \frac{\text{diameter through which 60 percent of material passes}}{\text{diameter through which 10 percent of material passes}}$$

For example, if 60 percent of the material passes through a sieve of 0.61mm and 10 percent through a sieve of 0.21mm, the coefficiency of uniformity is:

$$\frac{d_{60}}{d_{10}} = \frac{0.61\text{mm}}{0.21\text{mm}} = 2.9$$

To determine the effective size and the uniformity coefficient of sand requires a set of standard sieves and good scales. Equipment for making these measurements is used in soil laboratories. Other places that can do sand analyses are public works departments, concrete mixing plants and cement factories. Check with local people to see whether sized sand can be obtained. If sized sand is unavailable, choose coarser sands for the filter bed. Try to avoid using fine sands.

Design the filter box to provide space for a filter bed 1.0-1.4m thick. This thickness permits the filter bed to last several years before new sand must be added. New sand must not be added until the filter bed thickness falls to 0.7m. For information on the care of the filter bed see "Operating and Maintaining a Slow Sand Filter," RWS.3.O.3.

Next, determine the amount of sand needed for the filter. To determine this amount, the volume occupied by the sand must be calculated using the following formula:

Volume of sand = the area of the filter bed times its height

Filter bed area = length x width of filter

Area = 3.5m x 7.5m

Area = $26.25m^2$

Volume = area x height

Volume = $26.25m^2$ x 1.2m

Volume $31.5m^3$

The volume of sand needed for each filter bed is $31.5m^3$ or a total of $63m^3$ of sand for the two filters.

Below the filter bed is the underdrain system. The purpose of the underdrains is to support the filter bed, ensure a uniform filtration rate and collect the filtered water.

The support for the filter bed consists of several gravel layers of different sizes. Use four layers of gravel sized as shown in Figure 5. Each layer should be between 60mm and 120mm thick.

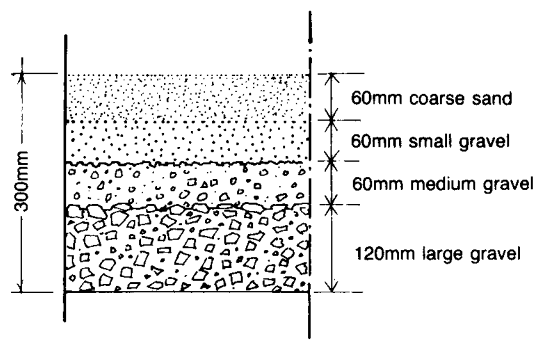

Figure 5. Filter Support System

The collection system is located below the gravel layers. The underdrain system can be built with bricks and porous concrete or prefabricated concrete slabs as shown in Figure 6. The distance between the lateral drains must be between 1-2m, with 2m the maximum allowable distance. Lay the brick drain tile so that the space between the bricks is 2-4mm and the distance between the spaces is approximately 0.15m. See Table 3 for more specific information.

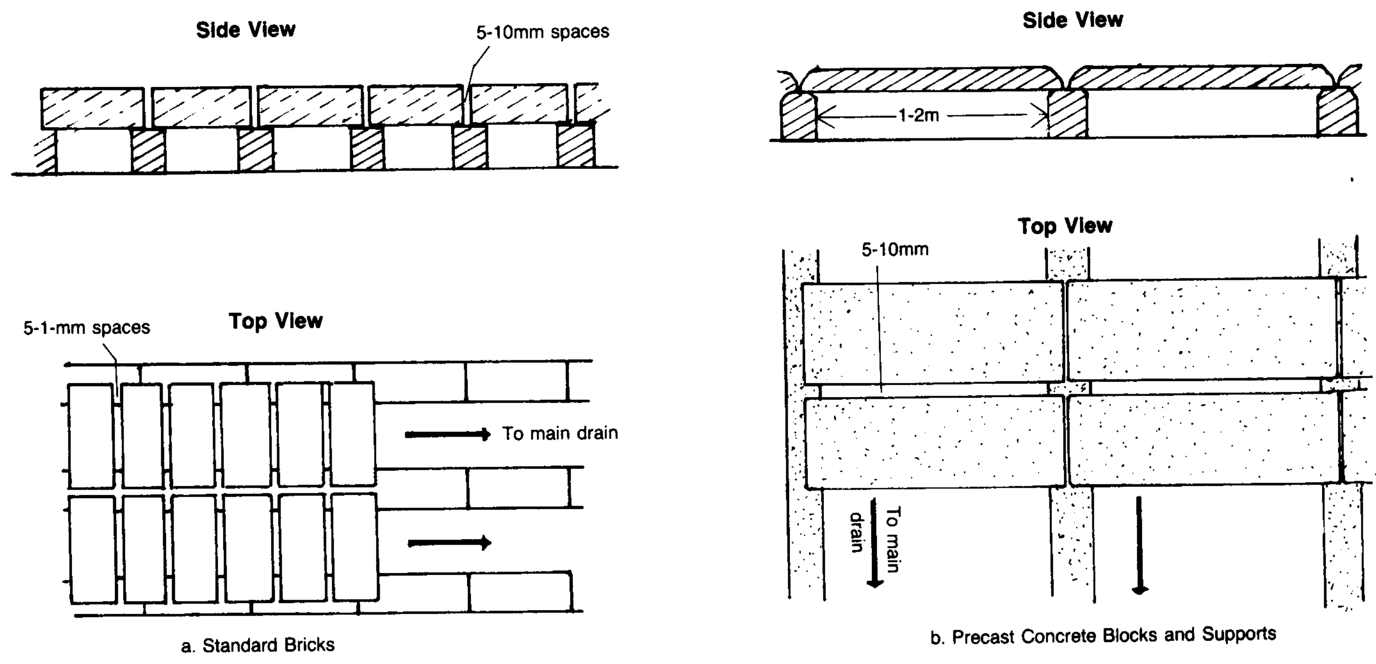

Figure 6. Underdrain System

By adding the dimensions of the filter box parts, it is possible to calculate the total depth of the filter. The dimensions below are averages.

Freeboard above water level in tank	0.25m
Water level	1.20m
Filter bed	1.20m
Four layer gravel support	0.30m
Brick filter bottom	0.16m
Total	3.11m

The total depth is 3.11m.

Table 3 gives a complete list of the design dimensions of a typical slow sand filter.

The rate of filtration should be controlled in order to ensure effective operation of the slow sand filter. The control basically consists of an inlet, a drain and an effluent regulation system. Refer to Figure 7 while reading this section.

Table 3. Slow Sand Filter Design

Description	Design Limits	Technical Note Example
Area per filter bed	10-100m^2	26m^2
Number of filter beds	Minimum 2	2
Water level height in filter	1-1.5m	1.2m
Depth of filter bed	1-1.4m	1.2m
Depth of under-drain system	0.3-0.5m	0.46m
Spacing of laterals in drain	1-2m	1.5m
Size of spaces in laterals	2-4mm	3mm
Distance between spaces in laterals	0.1-0.3m	0.15m
Filtration rate	0.1-0.2m/h	0.1m/h
Filter box height	2.5-4m	3.11m

The inlet structure must ensure an even flow of water onto the filter so that the sand bed is not disturbed by falling water. If falling water displaces or destroys the schmutz-decke, the filtration process will not work properly. For best results, the flow of water into the filter should be low (0.1m/second). A small trough located under the inlet to catch the

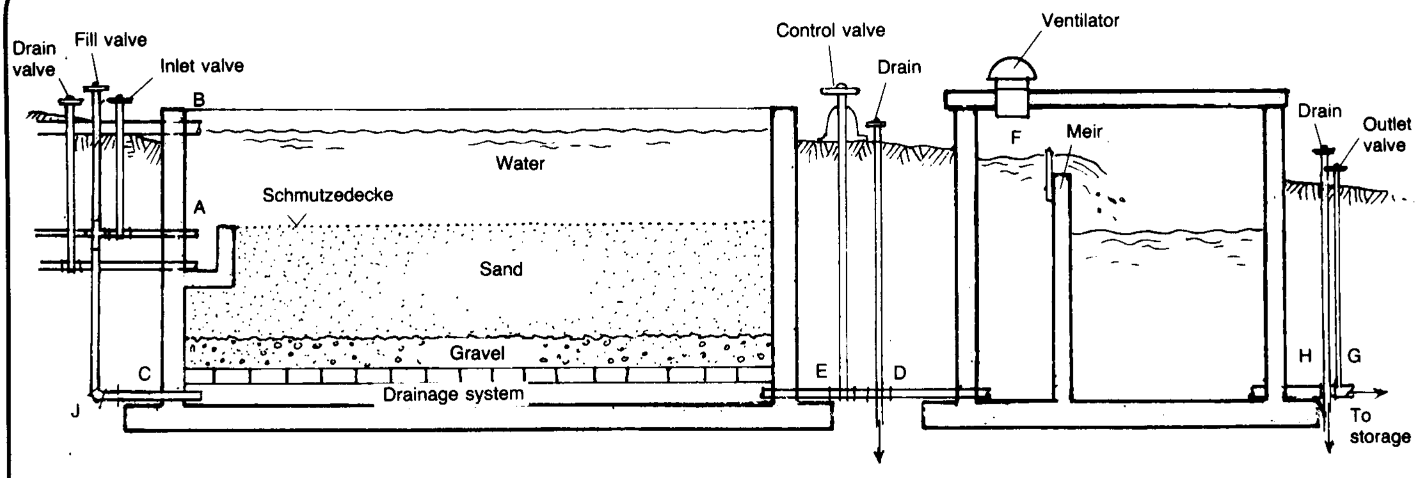

Figure 7. Slow Sand Filter with Valve System and Clear Water Well

inflow can be constructed. This catchment is useful in evenly distributing the incoming water. A control valve should be located at the filter inlet to adjust the water level in the tank. A float controlled butterfly valve or a manually operated gate valve can be used for this purpose. The valve is needed to shut down the system for cleaning. See valve A in Figure 7. An overflow weir should be installed above the water level in the filter box as shown by outlet B in Figure 7.

Install a drain, Figure 7, controlled by valve C, to remove water from the filter when cleaning is necessary. Locate the drain near the bottom of the inlet trough. There should also be a drain to remove the water in the top layers of the filter bed. See the valve marked D in Figure 7.

The most important control in the filter system is the effluent control valve E. This valve can be either a gate or butterfly valve. The butterfly valve provides better control as it can respond to small changes in pressure and adjust the filtration rate by opening more fully as resistance in the filter bed increases. This adjustment allows the total resistance in the bed and valve to remain uniform.

As the filter becomes increasingly loaded, resistance to flow increases. By opening valve E, the total resistance decreases so that the flow in the filter continues over the weir. Open the control valve wide enough to keep an even flow of water over the weir, F. One valve is generally sufficient to provide a uniform flow in the filter. When the flow rate drops below the level of resistance, the sand bed should be cleaned by skimming and raking it. If cleaning does not renew good flow, a sand change may be necessary. This should not be needed for a year or more. Another valve, H, should be installed to run water to waste before the filter bed is ready for operation. Valve G is installed to control the flow from the filter to the clear water well. The clear water well should have a capacity of 30-50 percent of daily water production from the filter.

An overflow weir forms part of the system to control the filtration rate. The crest of the overflow weir should be a little above the top of the sand bed shown by point F in Figure 7.

To refill the filter after cleaning, an inlet for backfilling is installed in the filter as shown by valve J. Refilling the filter from the bottom to the top pushes trapped air upward and out of the filter bed to provide for more efficient filtration.

Construction Materials

Most slow sand filters are rectangular shaped with vertical walls. Various materials can be used in the construction of slow sand filters. Large filters, which generally are built with reinforced concrete, require more advanced construction techniques and skilled labor. Small filters with a maximum length of 20m can be built using mass concrete or masonry. Most filters have concrete floors and vertical walls of concrete, masonry, or stonework. The choice depends upon which materials are available and the skills of the labor force working on the construction. Small rectangular filters with vertical walls can be built above ground for convenience. They should be above ground where the groundwater table is high or where solid rock makes excavation difficult. Larger filters should be built into the ground so that the ground provides support for the walls. When designing a rectangular slow sand filter with vertical walls, always keep in mind the following design criteria:

- Prepare a foundation with a minimum depth of 0.3m to provide support for the walls.

- Plan the depth of the foundation so that there is a minimum distance of 0.5m between the top of the filter and the ground level to prevent the entrance of children or animals. Generally a distance between 0.5-1.0m is adequate.

- Use a raft design for the foundation. See Figure 8. The raft foundation gives the filter structure extra strength and prevents leaking at the joints.

Once the basic design is set, the amount of materials needed should be determined. If bricks are used for construction, determine the volume in cubic meters of the construction and the number of bricks needed per cubic meter. Add a 10 percent error factor to the calculation to prevent falling short of materials. Check with local masons or brick-makers who generally know the number of bricks needed per cubic meter.

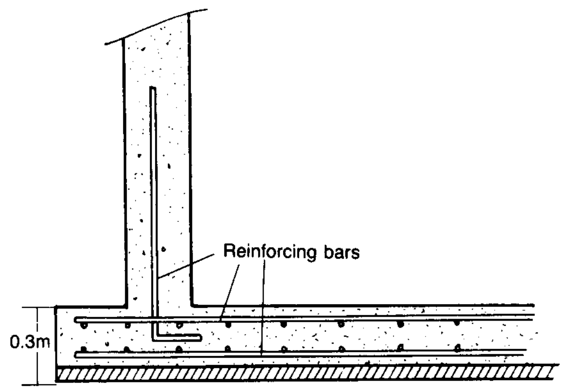

Figure 8. Raft Foundation for Filter Walls

When using mass concrete, determine the amount of materials needed by doing the calculations shown in Worksheet A. Make all walls 0.2-0.3m thick. The dimensions given are those used in the earlier example.

Excavated sloping wall structures can also be designed. They are the simplest and most inexpensive filters to install but they are not as sound structurally as rectangular filters. Do not design a sloping wall structure where the groundwater table is high or where there is doubt about whether the structure will be watertight.

If a sloping wall structure is used, the tank will be completely below ground level. The slope of the walls should be approximately 1:2, 1m of slope for every 2m of height. This slope will increase the length of the filter basin and require that a larger land area be used. Piping and valves to control flow must be carefully worked out beforehand as flow is by gravity.

Suitable lining materials for the walls are masonry, mass concrete, puddled clay or a sand/cement mixture with chicken wire reinforcing. Wall thickness will vary with material used. Make sand/cement and mass concrete walls .08m thick, impervious clay walls .05m and brickwork 0.1m. Other design features are similar to filters with vertical walls. The area around the filter should be fenced to keep animals away.

Worksheet A. Calculating Material Quantities for a Concrete Slow Sand Filter

Total volume of each rectangle = length (l) x width (w) height (h)

1. Volume of two sides = 1.75 m x 0.25 m x 3.1 m x 2 = 11.625 m^3
2. Volume of two ends = 3.5 m x 0.25 m x 3.1 m x 2 = 5.245 m^3
3. Volume of foundation = 8.0 m x 3.5 m x 0.25 m = 7.0 m^3
4. Total volume from steps 1, 2, 3 = 24.0 m^3
5. Add 10% for safety factor = 2.5 m^3
6. Total volume of structure from steps 4 and 5 = 26.56 m^3
7. Unmixed volume of materials needed = total volume, from step 6 x 1.5 = 26.5 x 1.5 = 39.75 m^3
8. Volume of each material (cement, sand, gravel, 1:2:3)

   Cement: 0.167 x volume from line 7 39.75 = 6.7 m^3

   Sand: 0.33 x volume from line 7 39.75 = 13.15 m^3

   Gravel: 0.5 x volume from line 7 39.75 = 19.9 m^3
9. Number of 50kg bags of cement = $\frac{\text{volume of cement}}{\text{volume per bag}}$

   $\frac{\text{volume of cement} = 6.7\ m^3}{\text{volume per bag} = .033\ m^3/\text{bag}}$ = 203 bags
10. Use about 28 liters of water for every bag of cement. Amount of water = 28 liters x 203 bags = 5684 liters

Note: To save cement, a 1:2:4 mixture can be used with no loss of strength.

Summary

A slow sand filter is an effective method of treatment for a rural water supply system. The filter is easy to operate and maintain with local skills and labor. However, a skilled technician should be available to design and construct the filter to ensure that it works correctly. Slow sand filters are useful in most areas where there is sufficient good quality sand and where land is available. The site should provide gravity flow to the users.

The filters mentioned in this technical note are examples of design suggestions. The choice of sand filter design will depend on the site available, materials and local skills. Follow the directions in this technical note as a basic guide.