


GREYWATER TREATMENT IN SAND AND GRAVEL FILTERS

Low Tech Solution for Sustainable Wastewater Management

MANUAL FOR DESIGN, CONSTRUCTION OPERATION AND MAINTENANCE

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CONTENT:

BACKGROUND

Environmental pollution is a global concern because of the harmful effects on public health and the environment. The irresponsible disposal of untreated wastewater into surface waters, soil and groundwater results in polluted water resources and environmental damages such as eutrophication.

Pollution prevention is most successful through the reduction or elimination of pollution at source instead of the common end-of-the-pipe approach. The treatment at source is the most efficient environmental protection by avoiding the generation of mixed waste streams and harmful emissions.

Figure 1: Disposal of untreated wastewater to the landscape in Western Georgia.

In the framework of the project "Reducing the pollution of the Black Sea by introducing sustainable wastewater and nutrient management in rural Georgian communities“ funded by UNEP, a number of community based actions to prevent further pollution of the water bodies have been implemented in the villages located along the Black Sea coast. In Western Georgia, the international NGO WECF (Women in Europe for a Common Future) and the local NGO RCDA (Rural Communities Development Agency) are undertaking measures for waste management systems improvement, including wastewater management through provision of simple, low cost and ecologically safe sanitary concepts applicable for the region.

There are adequate and appropriate solutions for integrated wastewater treatment available, both on community and household level. This project entails the application of Urine Diverting Dry Toilets (UDDT) - as ecological sanitation solution in the area without reliable water supply - and sand or gravel filters for the treatment of the greywater.

This manual provides the background of greywater characteristics and gives guidance how to construct and operate a low-tech sand filter for onsite greywater treatment. It describes all aspects to be considered in the process of planning, construction and maintenance of greywater filters on the household level in rural areas.
This manual is made for practitioners, technicians and interested households who want to design, construct and operate a low-tech greywater filter.

GREYWATER

Greywater is a wastewater fraction which is not heavily polluted. It includes wastewater from hand wash basins, showers, kitchen sinks and household appliances like washing machines or dishwashers and excludes toilet wastewater. The major pollutants are thus derived from soaps, shampoos, detergents, sweat, dead skin, hairs, oil and grease (from kitchen wastewater) and might include bacteria and pathogens. However the contamination by pathogens in greywater is considered to be very low due to the absence of toilet wastewater.

The amount of greywater is directly related to the water consumption of the residents and to the appliances used in the household. The average greywater production per person varies between 30 to 120 liter depending on access to piped water and people´s habits and their culture. In practice, the greywater flows can be roughly estimated based on surveys with the target population. If water meters are installed the greywater amount can be approximated as 75% of the total water consumption of the household (25% is estimated to be used for toilet flushing). A more detailed calculation of the greywater volumes and flows from the number of residents and the connected appliances is possible and should be conducted by trained professionals; using reliable data (see Annex 4).

The composition of greywater strongly depends on the behavior of the inhabitants and the individual choice of soaps and detergents in the household. Therefore, the overdosing of shampoos and detergents as well as the use of strong detergents (e.g. with high sodium content, phosphate content or chlorine) should be avoided.

Prevention at source is the best way to avoid environmental pollution and related health risks. Avoid overdosing of cleaning agents. Use only environmentally safe detergents.

SAND AND GRAVEL FILTERS

In low-tech greywater filters, the wastewater flows through a filter medium - sand or gravel. The main treatment process encompasses the retention of particles by the filter material and cleaning processes due to biological activity in the biofilm on the sand or gravel.

After passing the filter media, the treated greywater can be used for irrigation according to WHO guidelines (2006) or may be discharged into the surface waters. It can be infiltrated into the soil in case of a low groundwater level. For a better treatment and to avoid clogging, the planting of reeds or other suitable plants on the filter is recommended although the efficiency is not determined by the plants.

The WHO guidelines for the safe use of wastewater, excreta and greywater (Volume 4: Excreta and greywater use in agriculture) from 2006 give indications how to manage greywater use for irrigation based on a health risk assessment. It is recommended to apply restricted irrigation for treated greywater (e.g. not on crops to be eaten raw).
http://www.who.int/water_sanitation_health/wastewater/gsuweg4/en/

The filter systems presented here are characterized by:

- applicable for greywater from wash basins, bath tubs, showers, dishwashers and washing machines. For greywater from kitchen sinks, it is recommended to apply a pre-treatment such as settling tank or a biofilter, see section *Pretreatment,* because the kitchen greywater contains oil and grease which can cause clogging of the distribution pipe and smelling from the sand filter
- has a good treatment performance and allows the use for restricted irrigation of the treated wastewater
- work only with gravity, thus without pump, and do not need any electricity
- water level inside the filter is subsurface, so there is no open water surface. That is why there is no risk of mosquito breeding or snakes
- the planting of suitable plants like reed is recommended in order to improve aeration and avoid clogging
- construction, operation and maintenance are low-cost and low-tech

There are generally two different types of greywater filters:

(a) Vertical flow system and (b) Horizontal flow system.

The selection of the type of filter system depends on a number of criteria such as ground water level and the height at which the greywater pipe goes out. The different schemes can be seen in Figure 2.

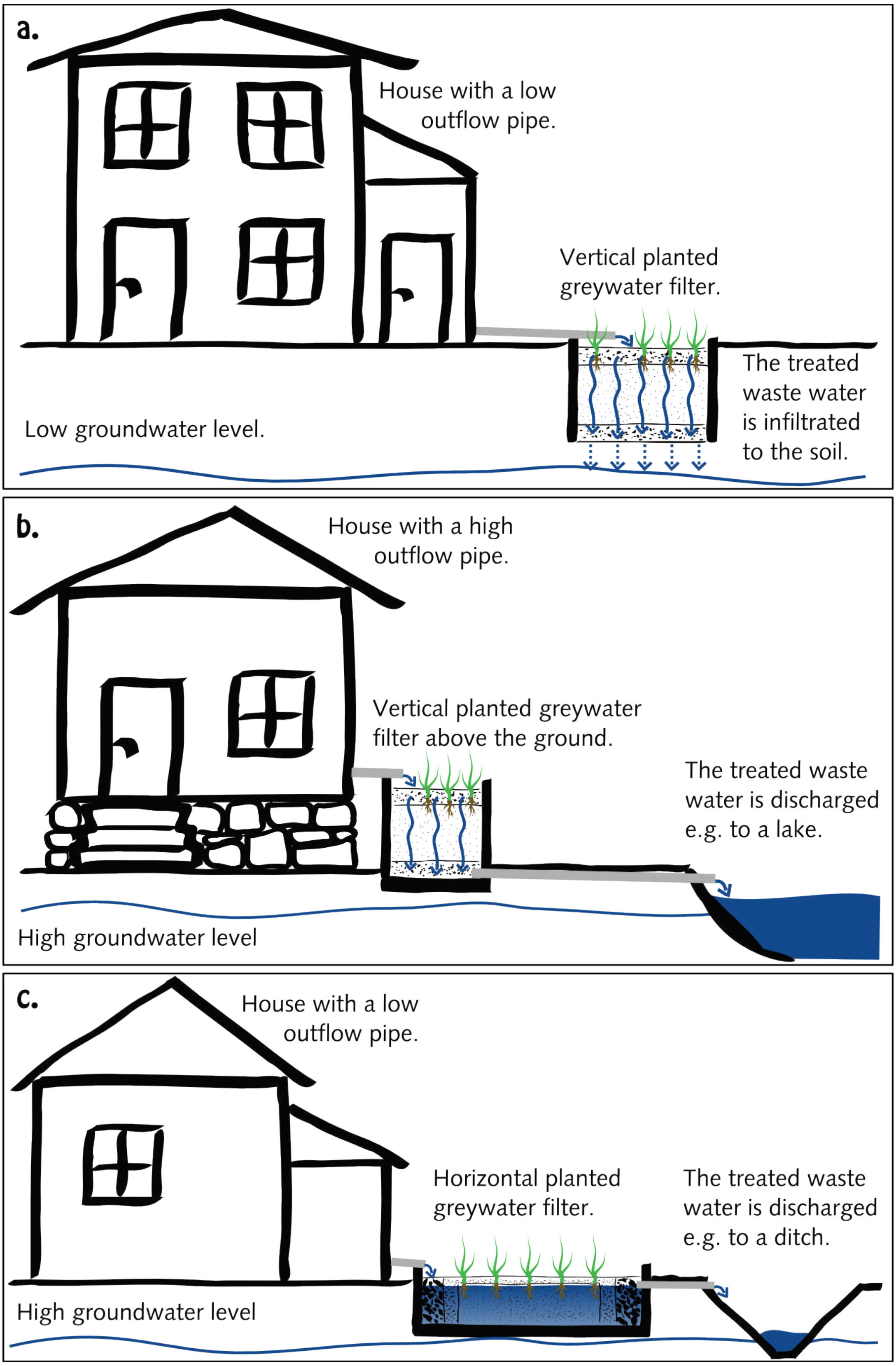

Figure 2: Schemes showing the different types of filter systems.

The simple decision support scheme in Figure 3 helps the reader to decide which system is best suitable for his or her situation.

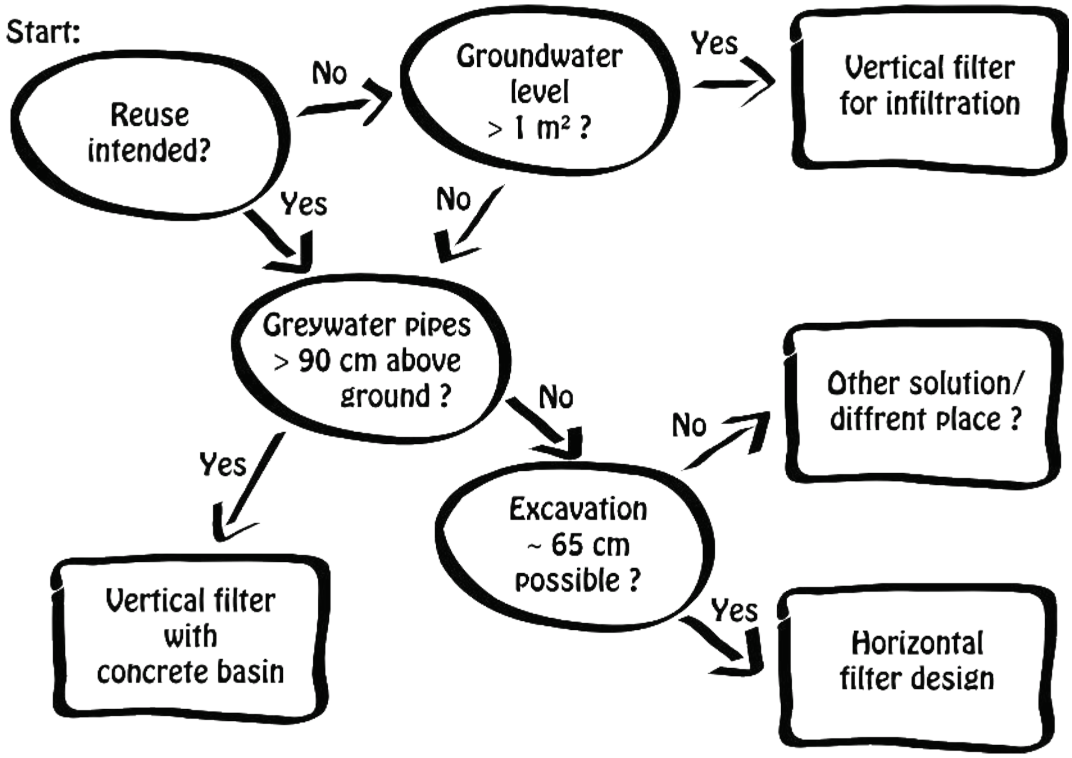

Figure 3: Simple decision support scheme to identify the right filter design

VERTICAL GREYWATER FILTER

The simplest greywater filter is a vertical sand filter where the wastewater is distributed to a basin filled with sand and gravel.

There are basic differences of vertical filter design depending on how the effluent is dealt with: The treated effluent can be infiltrated to the soil or it can be discharged to surface water. At a high groundwater level (< 1 m), it is recommended to construct the filter above the ground and discharge the treated water to surface water, such as a lake, river and channel. If the groundwater level is lower than 1 m, the outflow water can be infiltrated into the soil.

In case the treated greywater is supposed to be used for irrigation, a storage tank has to be installed where the water can be taken or an irrigation channel can be connected.

For a proper functioning of the filter the application of sand and gravel with the appropriate grain size is mandatory. An instruction for the analysis of the sand with a simple test is given in the Appendix (Annex 3). In general only washed sand and gravel should be used in greywater filters.

A vertical filter with subsequent infiltration is constructed from concrete or brick walls, framing layers of sand and gravel. Depending on the groundwater level, the filter is constructed in the ground, which allows easy construction and prevents it from freezing. Figure 4 shows a scheme of a vertical filter for infiltration purposes with the required layer structure.

The sand and the gravel have to be arranged in layers as follows:

1. *A 20 cm distribution layer of gravel (grain size 8 – 20 mm).*
2. *The filter layer of minimum 60 cm of sand (0 – 4 mm).*
3. *A 20 cm drainage layer of gravel (grain size 8 – 20 mm)*

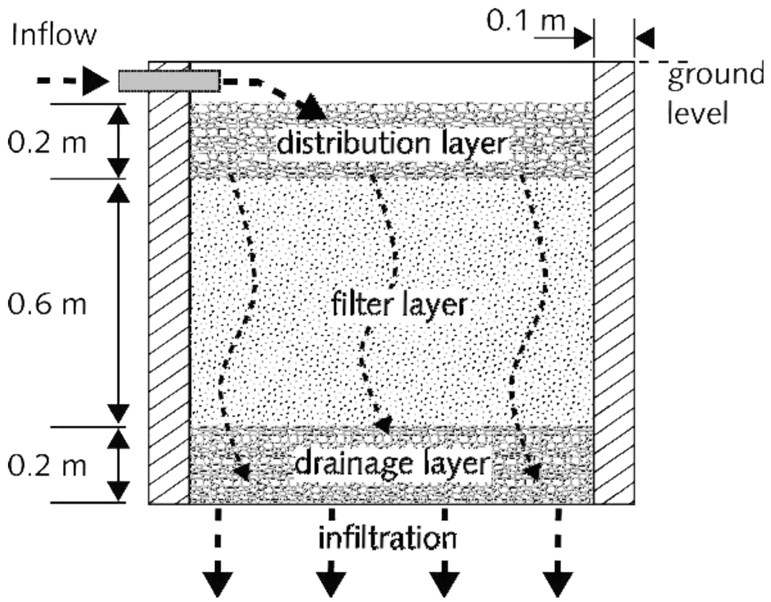

Figure 4: Cross section of a vertical filter for cold climates with subsequent infiltration.

The operational principle of a vertical filter for subsequent discharge to surface waters is given in Figure 5. For the construction of such a filter the greywater pipe from the house needs to have a minimum height of 90 cm from the ground (in case this is not possible the horizontal filter design is applied, *see below*). In order to prevent the gravel from entering the outflow pipe, it is recommended to build an area of stones (5 to 15 cm diameter) in the drainage layer in front of the outflow pipe. The basin can be constructed from concrete with 10 cm wall thickness and a proper foundation of at least 15 cm. Before applying the filter material, the basin has to be checked for leakages. The check can be done by filling it with water at least overnight and measure if the water level goes down due to leakages.

Above ground filter designs are only applicable in warm climates as the filter will not work during longer periods of frost. In general, the infiltration design is cheaper and easier to construct. Therefore it should be preferred in case the groundwater level is appropriate.

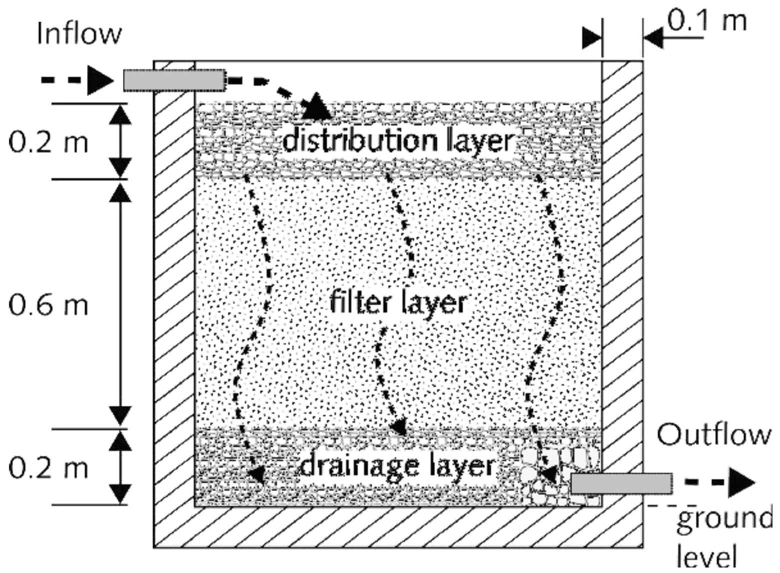

Figure 5: Cross section of a vertical greywater filter from sand and gravel with a concrete basin.

Vertical filter design

The size of the filter depends on the greywater quantity to be treated.

As general rule, the required area is 1.25 m² of filter surface per 100 L of greywater a day. To ensure proper functioning of the filter the surface should be at least 1 m² and should not exceed 2.5 m².

> *The surface of a vertical greywater filter should not exceed 2.5 m². If the expected amount of greywater requires a bigger area the implementation of multiple filters for independent greywater sources is recommended.*

HORIZONTAL GREYWATER FILTER

The function of the horizontal greywater filter design is in principle the same as in the vertical sand filter but gravel is used as filter material. However, in this case the water is not flowing vertically through the filter but horizontally across vertical gravel and stone layers. In contrast to the vertical filter, the horizontal filter is filled with water up to the outlet.

The horizontal flow allows a flat construction but requires more space compared to the vertical greywater filter. The basin can be built in the soil as long as the outflow pipe ends up above the ground. The height difference required between inflow pipe and outflow pipe of the filter is minimum 5 cm. Within this construction, even pipes from greywater sources that are low above the ground, can be handled if the groundwater level allows an excavation. Figure 6 is showing a cross section of the horizontal, planted greywater filter design.

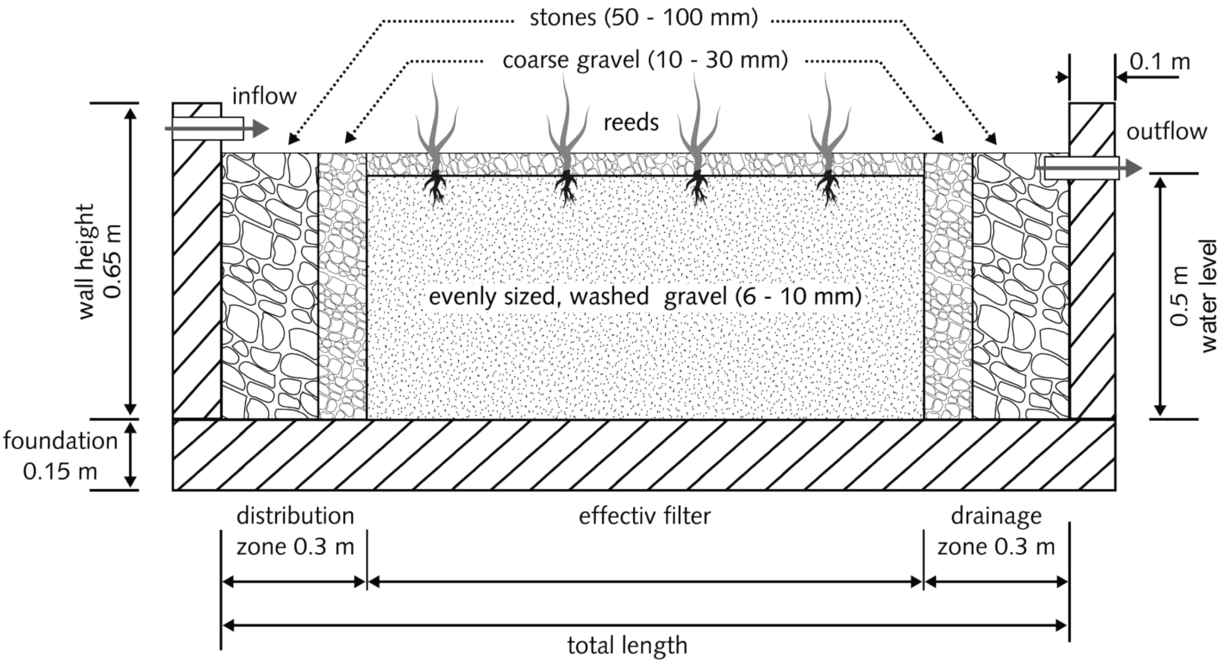

Figure 6: Cross section of the horizontal, planted greywater filter design.

The horizontal filter design is based on a concrete basin with an inner height of 0.65 m. The filter body has a height of 0.55 m and consists of three vertical layers.

The gravel and stones have to be arranged in vertical layers:

1. *Distribution layer from 0.2 m of stones (50 - 100 mm grain size) and 0.1 m of coarse gravel (10 - 30 mm grain size).*
2. *Filter media from evenly sized, washed Gravel (6 – 10 mm) with a length relative to the number of people and sinks connected to the filter.*
3. *Drainage layer from 0.1 m of the coarse gravel and 0.2 m of the stones.*

The filter media is covered by a 5 cm layer of the coarse gravel. The inflow pipe is installed at a minimum height of 0.55 m and the outflow pipe at 0.5 m.

Figure 7: A horizontal greywater filter in the project region, between construction and planting.

Horizontal filter design

The total size of the system depends on the required area of the filter zone which is again coherent with the amount of greywater and derives from a minimum area of 2 m² per 100 L greywater a day. Since this is a minimum value the horizontal filter should be designed bigger if possible. The length of the filter should be at least 1.5 times the width. The consequential effective filter length plus the 0.6 m of the drainage and the distribution zone sums up to the total length of the filter body (*see Annex 4*).

The inlet and outlet pipes should have a slope of at least 2 %, which equals to 2 cm decline per one meter of pipe. They can be installed in flow direction or on the edge of the distribution and drainage zone. This allows to adapt the filter to the individual set-up. A top view scheme of the horizontal filter showing the principle options for inlet and outlet positions is shown in Figure 8.

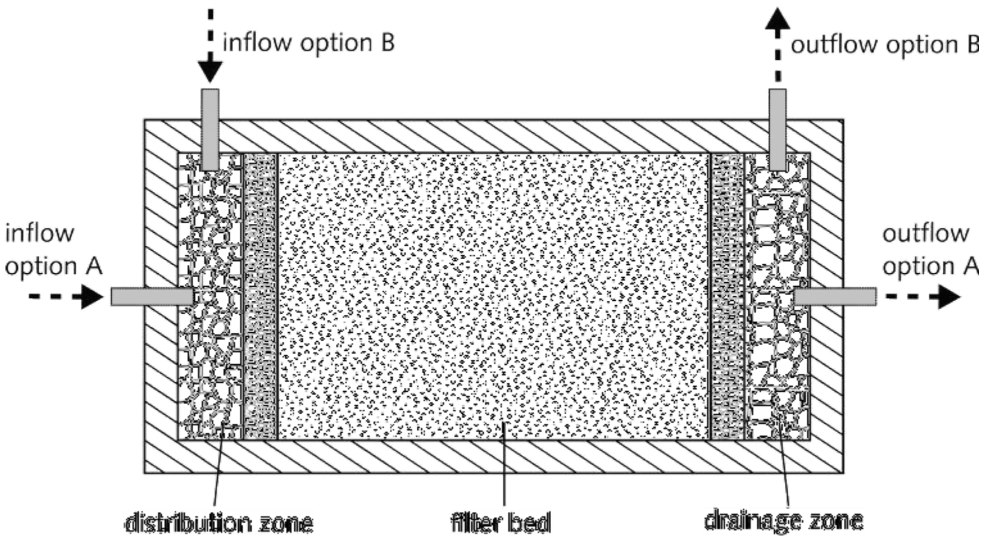

Figure 8: Top view on the horizontal filter design with different options.

STARTING THE GREY WATER FILTER OPERATION

After the leakage test and the filling of the filter layers the filter has to be settled. This is done by repetitive flooding and settling for some hours or even over night. Eventually occurring holes due to settling of the material should be refilled before the cover layer is distributed to the filter. Basically, planted soil filters have a startup phase of 2 weeks during which the bio film develops, whereas the reeds need 1 or 2 vegetation periods to spread over the whole surface area.

The filter should not be compacted by stamping since this leads to a higher risk of clogging. Therefore, avoid walking on the filter during construction and operation (see also "Maintenance").

PLANTING

Sand and gravel filters can be planted with swamp plants. They have no major treatment performance in the process but they support aeration and avoid clogging. Proper and effective aeration of the filter is reached through use of common reed (*phragmites australis*) that has demonstrated good performance in practice. The long roots, up to 2 m can burrow through the whole filter material, thus improving the functioning of the filter and preventing clogging.

a b c d

Figure 9: Swamp plants used for planting in filters.

a. Common Reed b. Hardstem Bulrush c. Broadleaf Cattail d. Yellow Iris[1]

Other alternatives are the planting of hard-stem bulrush (*schoenoplectus lacustris*) or broadleaf cattail (*typha latifolia*). Visible sides of the filter can be embellished with yellow iris (*iris pseudacorus*). Usually, the reeds are able to occupy the area without assistance but the filter bed should be freed from rambling weeds and other external plants particularly, during the first vegetation period.

[1] For picture credits see page 25.

The reeds should be planted early during the vegetation period (from April till September). If the filter is constructed in autumn it can be simply operated without plants till the next spring.

The best results are achieved if the reeds are planted as seedlings baled in some topsoil. 4 to 8 seedlings should be planted per m² of the filter. The seedlings have to be planted into the filter sand in case of vertical filter, respectively into the washed gravel in case of horizontal filter.

The seedlings can be planted into the filter layer by means of a piece of a big pipe (15 – 20 cm diameter). The pipe is put into the top layer until it reaches the filter layer. The gravel inside the pipe is removed and the seedling is planted into the lower layer.

PRETREATMENT

In general the greywater can be applied directly to the sand filter. However kitchen wastewater contains a lot of fat, oil and grease which is likely to cause clogging problems. Therefore it is advisable to filter these constituents in a pretreatment step. The pretreatment unit can be applied directly under the sink or outside on the way of the wastewater flow to the filter.

Bio Filter

A very easy and effective pretreatment is a simple bio filter with a decomposition bag. It is built-up from a permeable bag filled with a natural structure material like bark mulch, straw, wood chips or even the dead reeds of a planted greywater filter. The structure material retains the fats, oils and grease and the filtered water is passed to the greywater filter. From time to time the structure material has to be refreshed and the residues can be applied to the compost site. Since the old material should rest for a while before it is distributed to the compost it is recommended to use a system with 2 bags in alternating operation. This can simply be constructed as a 2 chamber system with an adjustable inlet pipe as shown in Figure 10.

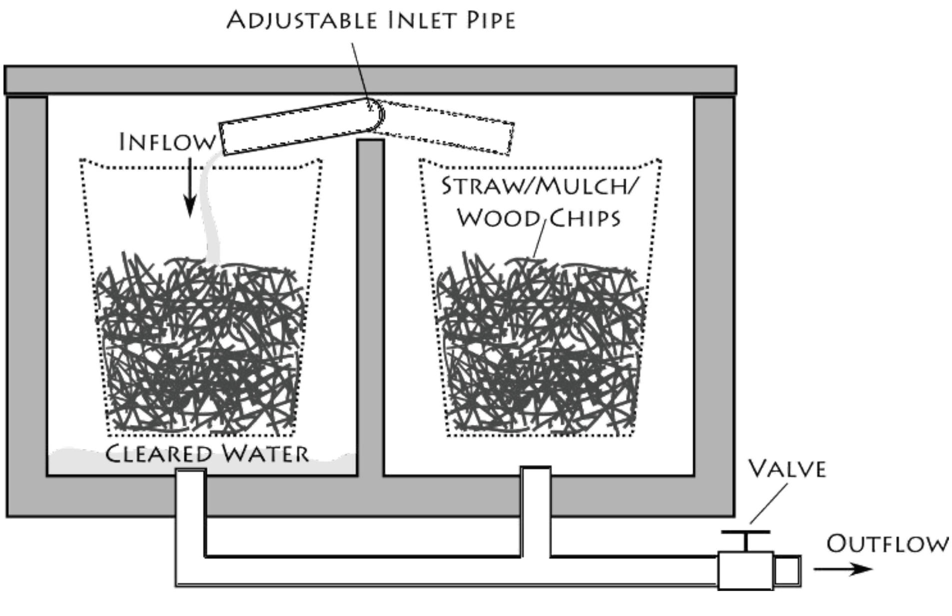

Figure 10: Principle of a bio filter system with 2 decomposition bags.

The size of the decomposition bag depends on the size of the kitchen basin and should capacitate at least 1.5 - 2 times more water than the amount fitting into the sink basin. The bags can be of any permeable material but compostable textiles should be preferred as they can be composted with the residues.

MAINTENANCE

Regular maintenance is required for a proper functioning of the greywater filters.

A common problem with sand and gravel filters is clogging, that may occur due to particles and other greywater constituents, as well as any matter falling on the filter. The clogging can be handled by careful removing of the cover layer(s) and mixing of the filter media.

If the filter blocks frequently or keeps being blocked, the application of improper sand/gravel might be the reason: either not washed or not the right grain size. Greywater constituents like particles and organic matter might be also the cause of clogging. In this case, the use of a pretreatment like settling tank or bio filter is recommended. Nevertheless, the filter media has to be replaced every 5 – 10 years depending on the conditions.

The pipes should be checked regularly to assure a good flow. Pour a defined volume of water into the sink and examine if the same volume of water comes out at the filter inflow steadily. If not all water is reaching the filter, check the pipes for leakages and clean the pipes. Use environmental friendly detergents and clean the pipes with a plumber's snake or a metal wire in case of blockages. The cleansing with strong detergents must be avoided since their negative effects on the bio activity can lead to a complete destruction of the filter.

Foreign matter like leaves, animal manure and the dead reeds should be displaced regularly to prevent blocking of the filter.

Cattle and poultry should be kept away from stamping and defecating on the filter by means of a fence.

The planted reed on the filter can be harvested and used as natural insulation material for houses and stables or as bio filter material in the pretreatment step. The reed however must not be harvested and can stay on the filter which is beneficial during the cold season to protect the filter from freezing.

ANNEXES

Annex 1. Material List for Greywater Filter

	Vertical filter	Horizontal filter
Basin	Concrete (1 part cement, 3 parts sand + water proofing admixture)	Concrete (1 part cement, 3 parts sand + water proofing admixture)
Distribution zone	Gravel (grain size 8 – 20 mm)	Stones (size 50 - 100 mm) Coarse gravel (grain size 10 - 30 mm)
Filter	Washed sand (grain size 0 – 4 mm)	Evenly sized, washed gravel (grain size 6 – 10 mm)
Drainage zone	Gravel (grain size 8 – 20 mm)	Stones (size 50 - 100 mm) Coarse gravel (grain size 10 - 30 mm)
Cover layer	No additional cover	Coarse gravel (grain size 10 - 30 mm)
Pipes	(Ø > 70 mm)	(Ø > 70 mm)

See materials calculated for one household in Annex 4

Annex 2. Prices of Materials

ITEMS	UNIT	Price per UNIT in different countries	
		Georgia GEL	**Germany EUR**
Washed Gravel (grain size 6 – 10 mm)	m^3	**25**	**44**
Coarse Gravel (grain size 8- 20 mm)	m^3	**15**	**44**
Coarse Gravel (grain size 10 – 30 mm)	m^3	**15**	**44**
Stones (50 - 100 mm)	m^3	**12**	**80**
Washed Sand (grain size 0 – 4 mm)	m^3	**40**	**43**
Cement -400	ton	**220**	**145**
Pipes (Ø > 70 mm)	m	**6**	**4**

See materials calculated for one household in Annex 4

Annex 3. Defining the proper sand characteristic

1) Check if the sand/gravel is washed

The grain size of the sand and gravel is the major factor for a proper functioning of greywater filters. Only washed sand and gravel should be used as filter material.

Picture A: Sand layers of different grain size in a water bottle.

Picture A shows a simple way of checking the quality of the sand: Fill 2 - 4 handfuls of sand into a bottle of water and shake it well. After some time (depending on the composition of the sand) the sand is settled in layers at the bottom of the bottle. The layer of fine and clayey matter on the sand (yellowish in the picture) is the fraction that is likely to block the filter and cause malfunction. These particles should be less than 10 % of the total amount of sand. The clayey matter is simply washed away with water before the sand is applied to the filter basin.

2) Check the grain size of the sand

To check the washed sand for its applicability on greywater filters the following simple test (adapted from *Lack 2006*) is performed:

Materials needed: 1 ruler, 1 marker, 1 pipe (10 cm inner diameter and 40 cm length), a piece of fly screen, 2 buckets (1 x 10 L, 1 x 5 L), 2 short beams, a stop watch.

The time that 1 liter of water needs to infiltrate into the sand is measured by the following steps:

1. Measure **12.7 cm** inside of the pipe and **mark** the spot.
2. Cover the **bottom** with the **screen**.
3. Fill the pipe with **25 cm** of the **sand**
4. Fill the 10 L bucket with water and put the **pipe into** the **water**.
5. Take out the pipe **after 1 night** and place it on the beams so the water can flow out.
6. Fill in water with the 5 L bucket **exactly** until the water starts to overflow.
7. As soon as the pipe is full **start the stop watch**.

Stop the time when the water reaches the mark **at 12.7 cm**. With **proper sand** the measured infiltration time should be around **~ 1.5 minutes.**


Pictures B and C: Checking the proper sand composition with the kf Test.

Annex 4. Filter design for one household

Greywater filters have to be designed according to the raw greywater from the household and the appliances. Depending on the ground water level the decision whether vertical or horizontal design is more applicable should be made (*see chapter "Sand and Gravel Filters"*). In case the greywater flow is not known from measurements, an assumption by the connected appliances according to Table A can be conducted.

Table A: Specific water consumption by different household appliances, per person (Friedler 2004).

Specific water consumption of household appliances.		
Appliance	Water consumption	Unit
Hand wash basin	15	L / person / day
Bathtub	20	L / person / day
Shower	20	L / person / day
Kitchen sink	25	L / person / day
Dishwasher	5	L / person / day
Washing machine	20	L / person / day

Based on these assumptions the dimensions of the appropriate filter are defined. For vertical filters an area of 1.25 m² per 100 liter a day should be considered. For the horizontal filter design an area of 2 m² per 100 liter a day plus the distribution and drainage area is needed.

Sample calculation for a bathroom for 4 persons with shower and hand wash basin for both types of filter is given below:

The resultant greywater, Q derives from the water consumption per person of a hand wash basin and a shower:

$$Q = (15 + 20) = 35$$

The needed area A is calculated by multiplication of Q to the number of persons, P and the factor for the type of filter, F and subsequent division by 100:

$$A = \frac{Q * P * F}{100}$$

Therefore the needed area for the vertical filter design appears to be:

$$A_{vert} = \frac{35 * 4 * 1.25}{100} = 1.8\, m^2$$

With a length and width of:

$$\sqrt{1.8} \approx 1.4\,m.$$

The calculation of the dimensions of a horizontal filter is a bit more demanding. The needed filter area is calculated as before:

$$A_{hor} = \frac{35 * 4 * 2}{100} = 2.8\,m^2$$

As the length of the filter should be 1.5 times the width, the dimensions derive from:

$$length = 1.5 * width \text{ and } length * width = A_{hor}$$

Indicating that: $length = 2.1\,m;$ $width = 1.4\,m$

After addition of the 30 cm of distribution zone and 30 cm drainage zone the dimensions of the horizontal filter design are: $width = 1.4\,m$; $total\ length = 2.7\,m$

With a total area of: $A_{total} = total\ length * width = 2.7 * 1.4 = 3.6\,m^2$

In Table B and Table C the resulting material costs are given referring to the material prices above. The pipes and the transport costs are not shown as they are depending on the individual location still they are important for planning of a greywater filter.

Table B: Material needed and expectable costs for a vertical filter for 4 people with hand wash basin and shower in Georgia and Germany.

Vertical filter for 4 people with hand wash basin and shower			
Material	**Volume [m³]**	**Price GEL**	**Price EUR**
gravel (8 - 20 mm)	0.75	11.3	33.0
sand (0 - 4 mm)	1.10	44.0	47.3
sand for concrete	0.79	31.5	33.9
cement	0.26	92.4	60.9
Total costs	-	**179.2**	**175.1**

Table C: Material needed and expectable costs for a horizontal filter for 4 people with hand wash basin and shower in Georgia and Germany.

Horizontal filter for 4 people with hand wash basin and shower			
Material	**Volume [m³]**	**Price GEL**	**Price EUR**
stones (50 - 100 mm)	0.35	4.2	28.0
gravel (10 - 30 mm)	0.20	3.0	8.8
gravel for cover 0.05 cm (10 - 30 mm)	0.15	2.3	6.6
evenly sized, washed gravel (6 - 10 mm)	1.50	37.5	66.0
sand for concrete	0.98	39.0	41.9
cement	0.33	114.4	75.4
Total costs	**-**	**200.4**	**226.7**

Annex 5. References and further literature

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Annex 6. Picture credits

Figure 9:

a. - "Schwielowsee-Schilfrohrguertel-01" by Botaurus stellaris
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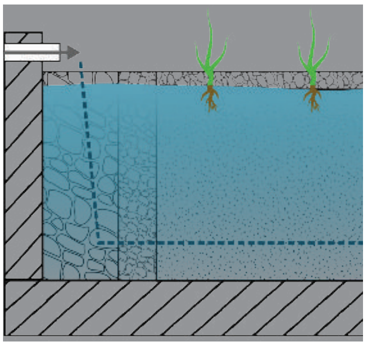

Only 20% of the global wastewater is currently being treated which is not only a risk to public health but results in a serious damage for ecosystems and water resources. Greywater is a major part of the domestic wastewater and as it excludes toilet wastewater, greywater causes less hygienic risks and is easier to manage. Greywater can be a valuable resource for water reuse, for example in agriculture.

Greywater management is complementing sustainable onsite sanitations solution such as an Ecosan toilet. This manual explains how greywater can be treated in a sand or gravel filter before being re-used. Different greywater filter designs have been demonstrated in Georgia in two villages close to the Black Sea coast by the Georgian NGO RCDA with guidance by a student from Hamburg University of Technology. The technology is very efficient, relatively simple, low-cost and can be realized by practitioners in rural and peri-urban areas of most settings.

WECF is member of the Global Wastewater Initiative (GW^{2}I) which has been launched by UNEP as a multiple stakeholder platform in order to address wastewater management, prompt coordinated action and encourage new investments in the sector. The GW^{2}I aims to increase priorities for wastewater management in world water politics, to prevent further pollution and damage and emphasize that wastewater is a valuable resource for future water security. More information: http://unep.org/gpa/gwi/

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