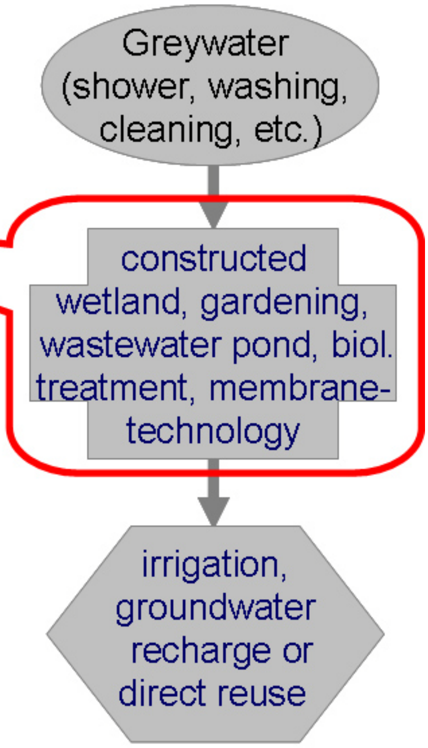
4.7 Greywater treatment

Learning objectives: Get familiar with various treatment options and with the application of various processes



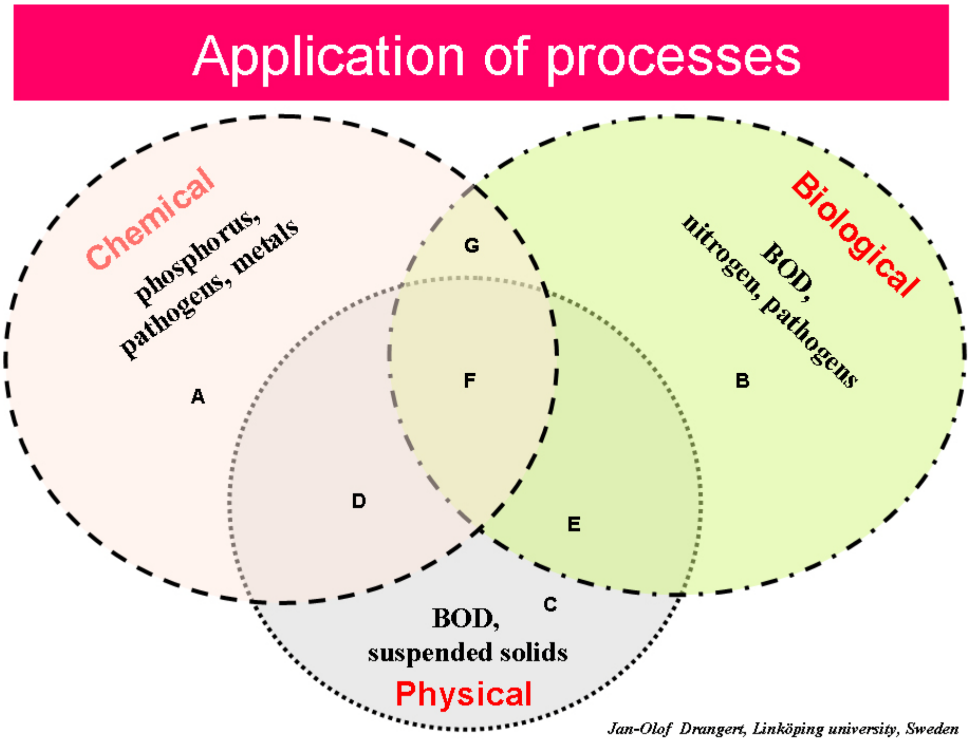
Can we remove all the pathogens and heavy metals?

What is in the sludge?

An outcome-based strategy initially outlines what levels of pollutants – after treatment – are acceptable for the intended use. The next step is to find out the origin of any pollutants that are present at excessive levels. Is it possible to reduce or prevent these pollutants from entering the water flow? How can unnecessary pollution of the water be avoided? There is a host of source-control measures that can be used (see Module 4.5). If source control measures cannot solve the problem, the pollutant has to be captured in a treatment process. A range of processes are explained in Module 4.6. This “start from the end” approach is helpful in developing a treatment strategy.

Before selecting technology or method to treat the wastewater to the desired standard, a lot of issues have to be thought through. Is the solution intended for a single household or a small community? The management options stretch from own-key to turn-key arrangements (see Section 2.3- 5). The local physical conditions also play a role and a holistic sanitation selection algorithm can be helpful to decide what technology may be appropriate (see Section 2.5-11).

4.7- 2



Jan-Olof Drangert, Linköping university, Sweden

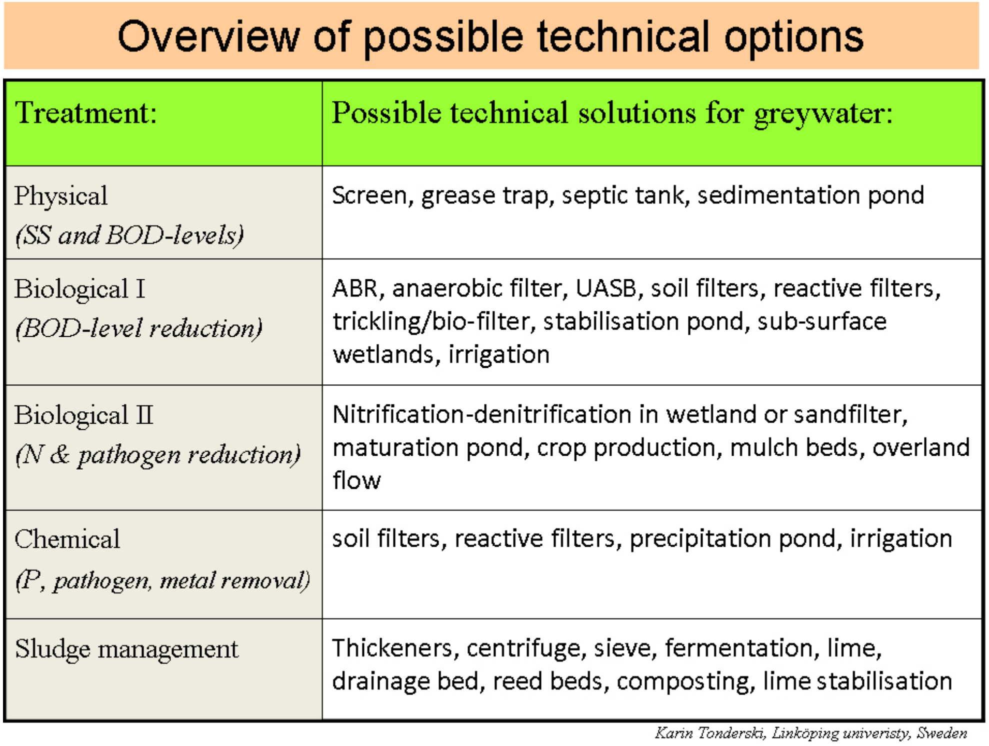
The picture shows how various treatment processes, i.e. physical, chemical and biological, can be combined. The first example is a combination of measures to prevent eutrophication of a water body. The amounts of nitrogen and phosphorus (N and P) in the effluent need to be reduced. It is well known that most P and N originate from excreta (mainly urine) and an effective source-control measure would be to introduce urine-diverting toilets and use the urine to fertilise farmland. If this long-term solution is not possible, the wastewater has to be stripped of N and P in a treatment process. There are a number of possible ways to do that at the end-of-pipe by combining physical, chemical and biological processes (F in the picture):

- Some N and P are found in larger organic particles, fat and grease. These can be caught in a grease trap through screening and flotation (C). The collected scum can be composted and returned to the soil.
- A further reduction of nutrient-rich particles can be obtained through settling in a septic tank or baffled anaerobic reactor where anaerobic decomposition also takes place (E).
- N and P from urine are dissolved in the wastewater. N can be partly reduced by biological processes such as microbiological nitrification-denitrification in a wetland or pond (B). P can be reduced by treating the water in filters made up of reactive materials rich in iron, aluminium and/or calcium compounds to which P is adsorbed (A and D).
- Reduction of both N and P can be attained by using the pre-treated, particle-free, greywater for irrigation, where the crops will absorb nutrients and some P will be adsorbed to the soil particles (G).

The second example demonstrates that a treatment process for drinking water may act on two or more metals simultaneously. Assume that the groundwater contains iron and arsenic. When the groundwater is aerated (D), the iron is precipitated as Fe(III) hydroxide. It is positively charged and a good adsorbent for the negatively charged arsenate ions. The flocs that are formed have a high density and sink to the sediment at the bottom. The single process of aeration solves both problems.

The above example indicates how effluent and sludge can be made useful.

4.7- 3



Overview of possible technical options

Treatment:	Possible technical solutions for greywater:
Physical *(SS and BOD-levels)*	Screen, grease trap, septic tank, sedimentation pond
Biological I *(BOD-level reduction)*	ABR, anaerobic filter, UASB, soil filters, reactive filters, trickling/bio-filter, stabilisation pond, sub-surface wetlands, irrigation
Biological II *(N & pathogen reduction)*	Nitrification-denitrification in wetland or sandfilter, maturation pond, crop production, mulch beds, overland flow
Chemical *(P, pathogen, metal removal)*	soil filters, reactive filters, precipitation pond, irrigation
Sludge management	Thickeners, centrifuge, sieve, fermentation, lime, drainage bed, reed beds, composting, lime stabilisation

Karin Tonderski, Linköping univeristy, Sweden

The table above lists how the different processes shown in the preceding diagram translate into a number of different technical solutions available for treatment of wastewater in general. All wastewater treatment methods generate sludge to varying extents, and hence we have also included methods to manage the sludge in a safe way. This is a crucial component of the entire wastewater management system.

In the first column, we list in italics the prime purpose of the respective treatment process in terms of which substance in the wastewater it is primarily designed to reduce. SS (Suspended Solids) refers to particles in the wastewater. BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand) and TOC (Total Organic Carbon) are three different analytical methods for measuring the concentrations of organic matter in wastewater.

In this module, we present in more detail the techniques that are most relevant for greywater treatment and their pros and cons. As will be seen, it is common to combine two or more of the techniques to achieve a certain treatment goal. The desired maximum levels of pollutants should preferably be determined based on the intended use of the treated water and related sludge. This requires knowledge about the content of the greywater.

The second column lists both high-tech techniques (such as UASB and centrifuges) requiring a lot of operational skills and electrical energy input, and more low-tech techniques such as stabilization ponds, wetlands and sandfilters. It is thought to be implicit that high-tech techniques are more suitable for larger, centralized systems where the management costs can be shared among many connected households, whereas for small villages or individual households, robust simple easily managed techniques are more suitable. However, there are low-tech solutions fit for large system (e.g. polishing effluent in wetlands) and recent technical developments have produced advanced technical solutions for individual households. The various techniques are therefore rather neutral as for the number of users.

Screens and grease traps

4.7- 4

Organics from kitchen pipe sorted out in a plastic screen

Jan-Olof Drangert, Linköping university, Sweden

Fat, oil and grease (FOG) are usually rinsed with hot water and/or detergent in the sink. However, when the greywater cools down, the FOG becomes solid again and separates itself from the liquid. The left-hand picture shows a simple grease trap serving a single household. The warm greasy water passes a plastic sieve or screen where larger particles are trapped. The greywater collects in the compartment underneath, and slowly cools and overflows to the bigger compartment in front. The grease floats to the surface and has to be removed. A pipe next to the bottom leads the effluent to a soil filter or other treatment. The grease trap must be large enough to provide a long enough retention time for the FOG to solidify and float up to the surface. Information about designs and dimensions of grease traps can be found in Crites and Tchobanoglous (1998), Sasse (1998), and Tchobanoglous (1991).

If allowed to enter wastewater pipes, FOG readily adheres to the inner surface of the piping material. Many states in the US therefore require grease traps for kitchens in institutions and restaurants to control the solidification where it can be taken care of before it reaches the sewers and eventually the treatment plant.

Similarly, an individual household benefits from having a grease trap to reduce the amount of FOG before treating and reusing the greywater. Householders can also wipe off and dispose of organics on cooking utensils and plates together with other organic waste instead of flushing them away in the sink. Such a source-control measure is easier than emptying the sieve. The picture on the right shows an ordinary plastic collander (red colour) being used to catch solid particles before the greywater flushes down through a kind of a trickling filter which contains material such as coconut fibres with lots of microorganisms and worms that feed on FOG and other organic matter (Section 2.7- 4). The floating FOG is regularly removed and can be put on a compost heap, in a biogas reactor or in an incinerator.

Sedimentation pond

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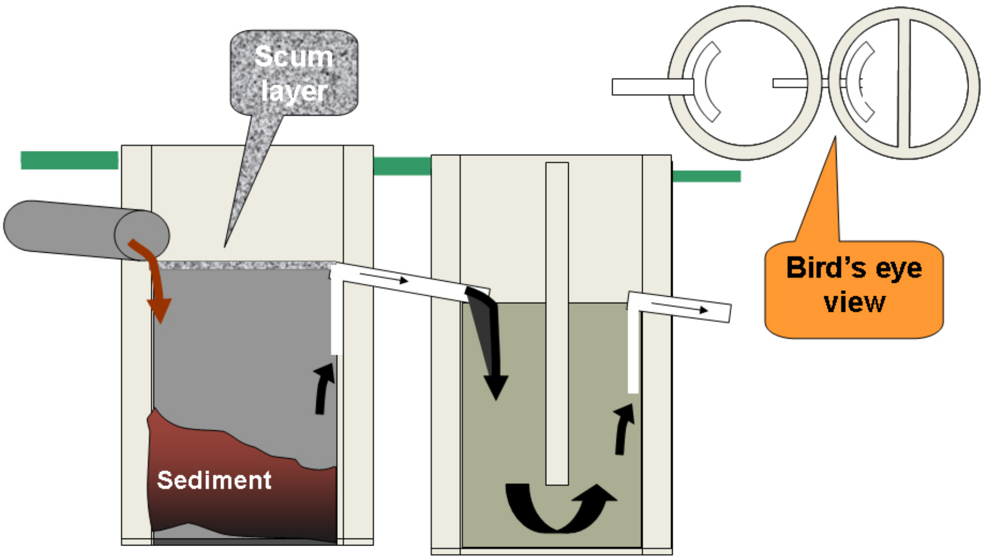
4.7- 5

Sedimentation of particles and flotation of grease in greywater can also be achieved in a pond. In warm climates, so-called stabilisation ponds for wastewater treatment are commonly used as a cheap method to treat mixed wastewater (e.g. Mara, 2004). Typically, a series of ponds ranging from anaerobic, facultative, and maturation ponds (shallow ponds densely populated with algae, see Section 4.6–13) ensures a considerable reduction in the levels of pathogenic organisms and solids (due to sedimentation), organic matter (decomposition) and chemicals (adsorption and precipitation). Heavy metals, if present, may be precipitated as sulphides in the first anaerobic pond (see Section 4.6–19). Organic chemicals are to a large extent decomposed as the retention time in a pond system is quite long (5–20 days in each pond); however more persistent organic chemicals will most likely remain a problem. Stabilisation ponds can also achieve significant removal of microorganisms, and cyst and helminth eggs (Jimenez et al., 2010). These remain in the pond sediment and may be viable for several years in the sludge. Viruses are removed through adsorption onto solids, including algae, and remain in the pond sludge as these solids settle. Bacteria are removed in the same way and in addition they can be inactivated by several mechanisms including UV light (see Section 4.6- 12) and a pH value above 9.4.

If a pond is used as the first step in greywater treatment without first going through a grease trap and screen, it may develop into an aesthetic problem with an unpleasant smell and appearance. An alternative is a covered sedimentation unit, i.e. a septic tank.

Simple septic tank

4.7- 6



Jan-Olof Drangert, Linköping university, Sweden

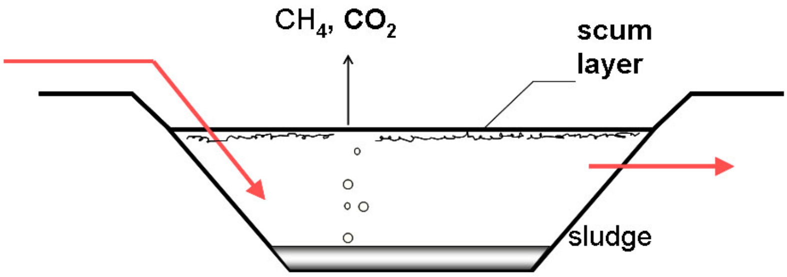
A septic tank is an anaerobic system consisting of one or two interlinked watertight tanks of concrete, plastic or fibreglass buried in the ground. The greywater should ideally flow with as little turbulence as possible, since this can disturb both the settling and the flotation of suspended solid material. Perforated wide inlet pipes (see bird's eye view) entering just below the water surface (main picture) reduce turbulence and prevent floks and scum from entering the drainage or subsequent stages in the treatment. Many countries provide national standards for septic tank design and dimensions. The permeability of soil and the groundwater level are important restrictions for siting septic tanks (British Geological Survey, 2003).

A properly designed and maintained septic tank is odour-free and has a long life. It removes FOG and solids, which either float to the surface or sink to the bottom. It removes 30–75 % of the biodegradable solids from the greywater and thus 25–70 % remains in the effluent. The efficiency is higher when the flow rate is low, and the designed retention time should be at least 24 hours. If the tank is divided into 2–3 chambers, or if a second tank is added, the fluid will be forced to move down and up an extra time and the treatment will further improve (see the tank to the right in the picture). Pathogen removal in septic tanks is always poor and, like metal removal, depends on the efficiency of particle removal (WHO, 2006). Thus, both effluent and sludge need further treatment.

A person contributes the equivalent of about 70 kg of dewatered sludge annually to the wastewater. Removal of sludge (desludging) is vital for a well-functioning septic tank, and should be done every year depending on the dimensions. If the sediment is allowed to fill a large section of the tank the raw greywater will simply pass over the surface of the sludge directly to the exit pipe, so quickly that no or very little sedimentation, flotation and decomposition takes place. There is no reason not to empty the sludge since the anaerobic process rapidly re-starts – provided some sludge is left in the tank.

Septic tank effluent is the most frequently reported cause of groundwater contamination (USEPA, 1977) and it is estimated that in the USA only 40% of existing septic tank systems function correctly. Since every part of the tank is buried in the ground, owners are less likely to worry about the functioning unless there is a blockage pushing the effluent back to the bathroom or up through the inspection hole. Therefore, municipalities often stipulate annual compulsory emptying of tanks.

Anaerobic pond



Karin Tonderski, Linköping university, Sweden

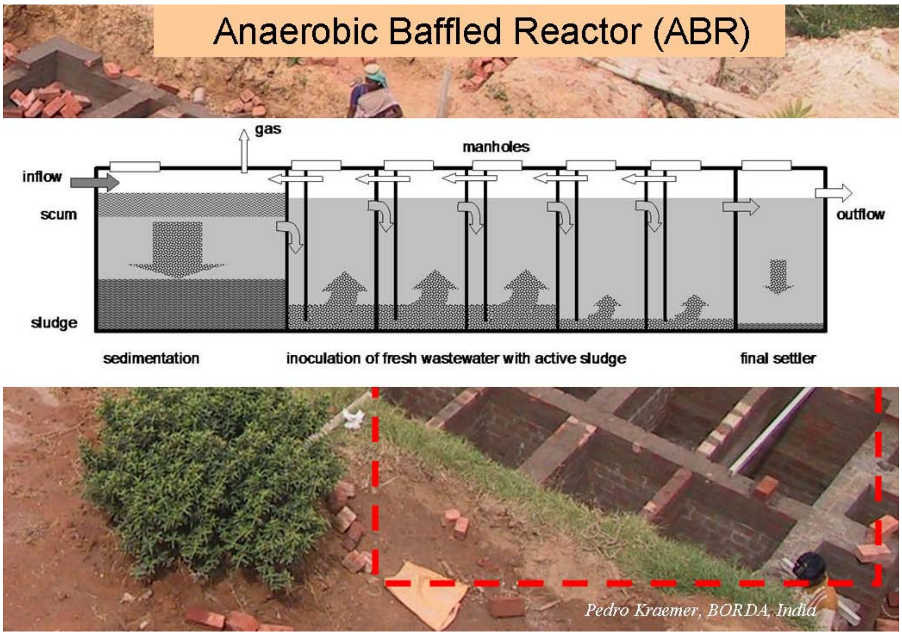
If the wastewater is rich in organic matter (high BOD concentration), an anaerobic pond can be used for pre-treatment (picture above). Such a pond is usually 2–4 m deep depending on the local soil and groundwater conditions. The dominant treatment processes are sedimentation of particles and decomposition of organic matter with a copious production of ‘biogas’ (CO_2 and CH_4 bubbles in the picture). An anaerobic pond functions much like an open septic tank, with the same groups of bacteria involved. This means that the required environmental conditions for successful treatment are the same. However, an open pond will be more sensitive to cold temperatures than a buried septic tank, and the decomposition rate will decrease as the temperature drops below zero. Another important parameter is the pH of the wastewater, which should preferably be > 6.5. A high pH also minimises the risk of releasing the strongly smelling gas H_2S, since this gas is in equilibrium with the dissolved ions H^+ and S^{2-} and the proportion of H_2S gas decreases with an increasing pH. If the pond emits a bad odour, lime or soda ash can be added to raise the pH and get rid of the smell. However, experience has shown that odour problems are rare if the sulphate (SO_4^{2-}) concentration of the household water supply is below 500 mg/l. The sulphate concentration is one factor that limits how much S^{2-} can be formed (since one molecule of SO_4^{2-} yields one S^{2-} ion), and therefore the risk for smell drops at lower sulphate concentrations. Sulphate is part of naturally occurring minerals in some soils and rocks, and hence the sulphate concentration in ground water depends on the local geological conditions.

The organic loading, λ_V, of a pond is measured in g per m^3 per day, i.e. the BOD concentration (mg/l) multiplied by the retention time [daily wastewater flow (m^3/day) divided by the volume of the pond in m^3]. Typically, the load measured as BOD_5 in g/(m^3 day) should be in the range

$$\mathbf{100 \leq \lambda_V \leq 400}$$

If the loading is less than 100, the pond cannot be anaerobic, and if it is higher than 400 there is a risk of odour problems.

A properly designed and maintained anaerobic pond can remove around 70 % of the organic matter and suspended particles in the wastewater. However, for small-scale wastewater treatment, a septic tank is a preferred solution, since the risks of smell and fly breeding in the scum layer are lower in a covered septic tank than in an open anaerobic pond.



Pedro Kraemer, BORDA, India

4.7- 8

The Anaerobic Baffled Reactor (ABR) combines a septic tank with a series of baffled compartments. A baffle forces the wastewater to flow from the bottom upwards to the surface without additional energy being applied. This is a technology often used for housing complexes and institutions such as hospitals and schools where a competent operator is available (see Module 4.4).

ABRs remove organic and settleable matter from the greywater more efficiently than a conventional septic tank. The suspended solids settle primarily in the first sedimentation (septic) tank and less in the following compartments (drawing above). Each inlet is at the bottom so that the flow of wastewater disturbs the settled sludge and it whirls up in the water body (activated sludge). The greywater flow and gas bubbles bring the sludge particles towards the outlet at the top, while they try to settle because of their higher density. The flow velocity must be regulated so that the anaerobic sludge does not leave the reactor with the effluent (max upflow velocity is 0.6 m/h). According to the design the particles should stay as a floating blanket, where the bacteria attached to the particles have easy access to the surrounding wastewater and can degrade its organic content. As in other treatment systems involving sedimentation, the sludge has to be removed annually.

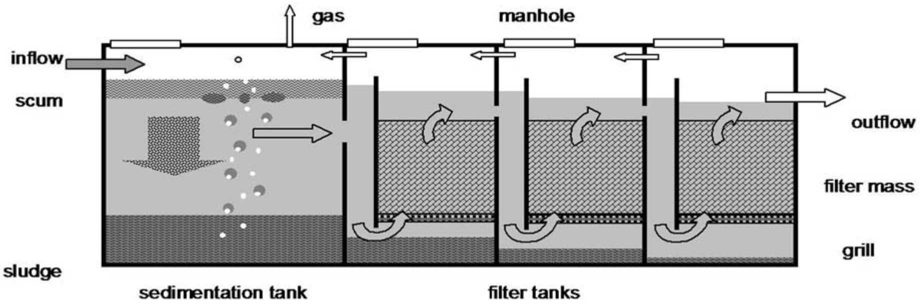
This treatment system is very resistant to hydraulic and organic shock loads, and is easy to operate. Unlike treatments based on filtering processes, ABRs are not at risk of clogging,. Even difficult-to-degrade organic matter is affected, thanks to the long retention time (48–72 hrs). Such organic matter may be hydrolysed after some time and then further degraded (4.4-12). The result is that 50–90% of the organic matter is removed. Gases are generated in the ABR, including carbon dioxide, methane, hydrogen sulphide and nitrogeneous gases, and they dissipate into the atmosphere unless collected.

The treated effluent is clear but not hygienically safe. The reactor is not designed to reduce pathogens or metals and chemicals in the wastewater, although there is some reduction since ions and microorganisms may be attached to the settled sludge particles. Hence, the operator is exposed to health risks when desludging, but they can protect themselves easily.

If only greywater is treated, the effluent is not rich in plant nutrients and may be connected to a sewer or drain. If the wastewater also contains human urine and faeces, a large proportion of the nutrients remain in solution and will be in the effluent when it leaves the ABR. In any case, the effluent water may be good for irrigation and some fertilisation, with more health precautions required when the greywater is mixed with blackwater (WHO, 2006).

Anaerobic Filter (off-plot biogas system)

4.7- 9



Courtesy of Pedro Kraemer, BORDA, India

Anaerobic filters consist of a sedimentation tank followed by one or a series of tanks with fixed filters made of gravel, slag or plastic elements. One system may serve a single or many households, as well as treat wastewater from institutions and public conveniences. The aim is to trap particles, reduce BOD levels and catch the gases released from the tanks. The influent must contain enough organic matter in dissolved form to produce gas, but too high concentrations of suspended particles will cause clogging of the filters. In practice a volumetric load (measured as COD) varying between 1 and 3 kg/(m^3 day) is used (Henze et al., 2002: pp. 311–317). This is different from a biogas digester which requires a dry matter content of 10%.

The filters require a continuous flow. Both upstream and downstream flow modes are possible. However, an upstream flow (picture above) is preferable since it reduces the risk of fixed biomass being washed out from the tank. The efficiency in reducing the BOD level is influenced by retention time, and up to 80 or 90 per cent reductions can be achieved if the water is processed for 1–1.5 days.

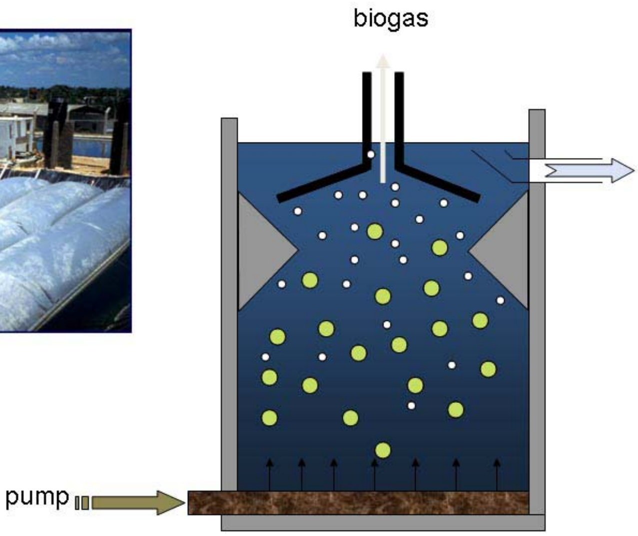
Microorganisms grow on the filter material and make up a so-called biofilm. The surface area of the filter material may be 90–300 m^2 per m^3 of filter material. The smaller the pores, the larger the area of contact with microorganisms and wastewater. However, there has to be a balance between filter material size (typically 12 to 55 mm) and organic load since small pores have a tendency to clog when receiving high loads of organic matter. Clogging means that dissolved and non-settleable solids adhere to the filter material or simply physically block passage ways. Both situations diminish the permeability of the filter. The water flow in the remaining open pores increases and tends to wash away the bacteria. Also, high local speeds provide little time for the bacteria to degrade organics and poor effluent quality may result.

The filter material has to be washed regularly to keep the pores open. This can be done by back-flushing or by physically removing the sand/gravel/plastic, washing it and putting it back. If operated correctly, anaerobic filters are reliable and robust. However, the start-up time is more than half a year because that is how long it takes for the biofilm to develop fully. It has been suggested that anaerobic microorganisms can be added to improve the decomposition of organic matter in the filter.

'Biogas' (mainly CO_2, CH_4, H_2O and H_2S) is produced in all tanks and collected in a gas storage tank. Therefore, all the tanks have to be airtight to prevent gas from escaping. However, the gas pressure fluctuates and therefore it is not ideal for household appliances. An alternative is to have a flame burning to prevent the methane from reaching the atmosphere.

UASB Reactor

4.7- 10



Jan-Olof Drangert, Linköping university

The upflow anaerobic sludge blanket (UASB) reactor is an advanced treatment method invented in the 1980s. It comprises a single tank (right picture) into which wastewater is pumped from the bottom and flows through an anaerobic sludge bed where the microorganisms degrade the organic material and release biogas (methane and carbondioxide; white spots). The sludge bed is composed of microorganisms that form small granules (yellow spots) with a high sedimentation velocity, which makes them resist wash-out from the tank. The upward motion of the gas bubbles provides a self-sustained mixing mechanism.

The process works on the assumption that the speed of the upstream flow is high enough to prevent sludge from settling but low enough to keep the sludge granules in the reactor. The tank has deflectors in the upper part (see right-hand picture) which prevent granules and flocs from escaping. The operator controls the electric pump to maintain a flow velocity of 0.6 to 0.9 m/h to optimise the contact with microorganisms. This is a delicate task that requires the support of monitoring equipment. The UASB technology is therefore developed and used in industrial and communal wastewater treatment plants (left-hand picture).

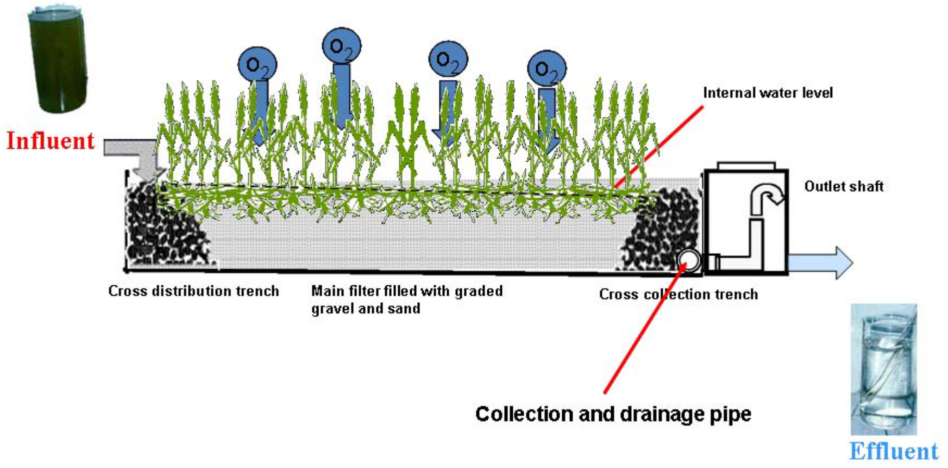
The reactor can produce a better effluent than a septic tank despite a smaller reactor volume, and can remove 85 to 90 per cent of the organic matter measured as chemical oxygen demand (COD).

Biogas is generated and collected in a storage tank, and hence the construction must be airtight. The gas pressure fluctuates and is therefore not ideal for household appliances.

At the start-up phase anaerobic granules of floating organic matter must be formed. When in operation, the UASB is stable because the granules grow heavier and their settling speed increases. The aim is to retain the maximum possible amount of sludge in the reactor to affirm a high Solid Retention Time (SRT) of about 50 to 100 days or more, while at the same time having a short Hydraulic Retention Time (HRT). Basic design principles are given by Ghangrekar, at: www.waterandwastewater.com/www_services/ask_tom_archive/design_of_an_uasb_reactor.htm

Horizontal subsurface flow wetland

4.7- 11



Courtesy of Roshan Shrestha, UN-Habitat, Nepal

Another predominantly anaerobic treatment system is the subsurface horizontal flow wetland shown in the picture above. Subsurface flow wetlands are low-maintenance systems suitable for treatment of small flows of wastewater, and the simplest type to operate is the horizontal flow wetland with gravity flow. The pre-treated wastewater (grease and particle reduced) is spread evenly with a perforated cross-distribution pipe along one edge of the wetland bed. Depending on the local soil and groundwater conditions, the bed may be sealed with clay, concrete or a rubber sheet to prevent seepage. The effluent flows horizontally through the bed composed of gravel and/or sand and planted with a wetland plant species tolerant of anaerobic conditions. Microorganisms grow on the gravel/sand grains and feed on organic matter in the wastewater. Plants modify the physiochemical environment in the rhizosphere in different ways that stimulate the microbial communities (see Section 4.6–21). One example is that some oxygen is transported from the leaves to the roots and leaches out to the surrounding bed material, thus stimulating some aerobic decomposition of organic matter in the otherwise mainly anaerobic bed. The plants also take up some of the nutrients in the wastewater, though this process is usually of minor importance for the overall nutrient removal. Plants also increase the water losses, particularly in warm climates where the plant evapotranspiration rate may sometimes be higher than the inflow rates, resulting in zero effluent discharge.

Another advantage with a subsurface flow wetland, in contrast to ponds and open-water wetlands, is that mosquito breeding is not an issue, since no flooding of the sand/gravel occurs in a well functioning system. A reliable performance also in harsh winter conditions has been demonstrated as long as freezing of the distribution system is prevented, though cold weather may cause the nitrogen removal efficiency to drop. One of the most important design aspects is that the hydraulic load must be adapted to the hydraulic conductivity of the bed material.

Experience shows that such systems effectively reduce concentrations of organic matter (BOD/COD) and particles (80–90%), but the N removal is lower due to the predominantly anaerobic conditions that prevent nitrification (Vymazal, 2005a). Generally, a better treatment is achieved with a finer grain size, but there is a trade-off between grain size and the amount of water that can flow through the bed. Hence, the size of the bed depends on the grain size of the material versus the amount of water that needs to be treated per day.

If the bed is filled with a material with a high P sorption capacity, phosphorus can also be removed. However, eventually the material will be saturated with P and will need to be replaced to maintain the removal capacity. Such P saturated material may be a good source of phosphorus for fertiliser, provided that no toxic compounds are discharged from the household. If toxic metals are discharged into the wastewater, they may be adsorbed to the material and hence make it less suitable for use in agriculture.

Although the effluent from such treatment systems is clear, it may still contain potentially pathogenic organisms. The reduction of common indicator bacteria is relatively low, around 1–2 log units (Vymazal, 2005a and b).

The advantage of a horizontal subsurface flow constructed wetland is that it provides a high treatment level (of organic matter and suspended particles) of effluents compared to a septic tank alone, and can do so with minimal management. Increasingly, such wetlands are also used for treating stormwater prior to discharge into groundwater or surface waters. However, the very variable water flow may become a problem as each subsurface flow wetland has a definite upper limit to how much water that can pass through the bed per hour, depending on the permeability of the material.

Some guidance how to design and construct a subsurface wetland is given in 4.7-12.

4.7- 12

Construction of horizontal flow wetlands

Karin Tonderski, Linköping university, Sweden

The left-hand picture above shows a horizontal flow wetland where the unit is constructed from concrete with a sealed bottom. A common alternative is to use a rubber sheet to protect the groundwater from any infiltrating wastewater. The inflow part (top right) is filled with coarse gravel or stones followed by a finer sand as the main treatment material in which wetland plants are planted. Planting is usually done manually by digging up pieces of roots and rhizomes with intact shoots from natural wetlands and transferring these to the upper layer of the constructed wetland. It is important to keep the upper bed layer wet without flooding the new shoots completely during the first weeks after planting. This is done by regulating the level of the outflow pipe. *Diluted* wastewater from the source to be treated can be discharged into the wetlands immediately after planting, but it is important to maintain relatively aerobic conditions in the bed material until the plants are successfully established.

Useful information on the design of horizontal flow, vertical flow and surface flow (see Sections 4.7- 15 and 4.7- 21) for constructed wetlands is available from the US EPA at:

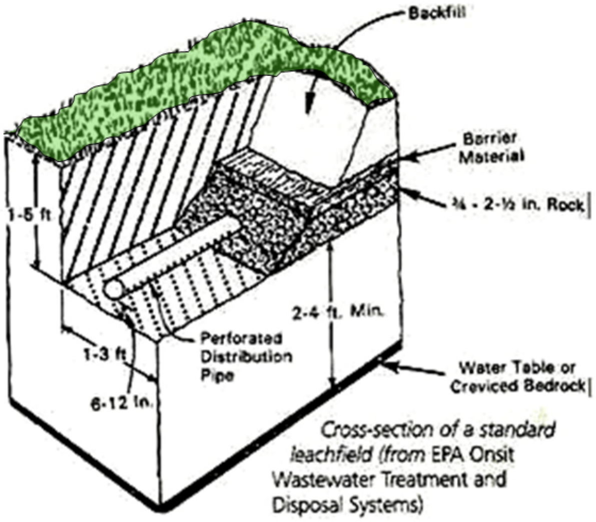
http://www.epa.gov/owow/wetlands/pdf/Design_Manual2000.pdf

The UNEP Division on Technology, Industry and Economics also provides a design manual for subsurface flow wetlands and stabilisation ponds based on experiences from East Africa at:

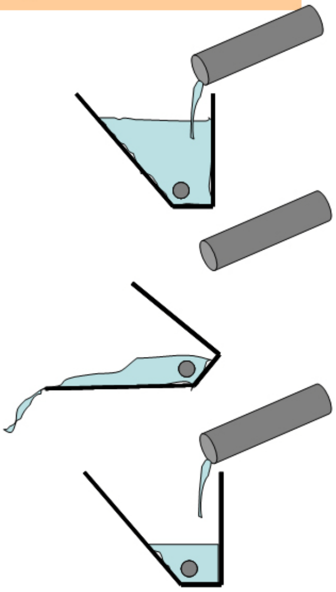
http://www.unep.or.jp/ietc/Publications/Water_Sanitation/ponds_and_wetlands/index.asp

This site also contains a mathematical design model.

Soil filters – leachfield or mound systems



Cross-section of a standard leachfield (from EPA Onsit Wastewater Treatment and Disposal Systems)



Jan-Olof Drangert, Linköping university, Sweden

Soil filters, or leach fields, are common in many parts of the world. They are similar to the subsurface horizontal flow wetlands presented earlier. However, unlike horizontal flow wetlands they are aerobic treatment systems as the wastewater is applied on top of the soil (or filter sand) via a perforated distribution pipe. The water then percolates vertically to a deep groundwater table. A well functioning soil filter depends on a good distribution of the water to maintain the soil in an unsaturated state. That is, the load of water should be low enough to ensure that the distribution pipe and soil layer are not completely flooded.

The cross-section of a leachfield (left picture), shows a perforated distribution pipe (with a slight downward slope) embedded in a layer of coarse gravel or stones. The 40–60 cm deep trench is backfilled with soil on which grass can grow. The gravel layer is covered with a barrier material such as geotextile that keeps the backfilled soil separated from the gravel and also prevents infiltration of stormwater to some extent. The pipe distributes the pre-treated greywater evenly over a subsoil surface (bottom of the trench), which allows the greywater to infiltrate and percolate further down in the soil profile. If the greywater is not pre-treated in a septic tank or other system, the leachfield will soon clog. Should the local soil be unsuitable for wastewater treatment (e.g. if the grain size is too small), a sand filter can be constructed with a collector pipe at the bottom. In many countries, percolation to groundwater is not allowed, and instead the treated effluent is collected in a perforated pipe deeper down in the soil and discharged to a ditch or other surface water body (the appropriate method depends on the topography).

Several treatment processes are at work in a leachfield. The greywater enters in batches, preferably by gravity, from a septic tank or other treatment process. This allows for some drying and aeration between the batches .The vertical flow of the water allows for some aeration of the gravel layer and a rich microbial flora and fauna zone develops in the subsoil layer just below the pipe. Here, micro-organisms feed on the organic matter in the greywater and decompose it into carbon dioxide, water and inorganic ions of nutrients and metals (aerobic decomposition). Due to the predominantly aerobic conditions, the treatment of suspended solids and reduction rates of organic matter (BOD/COD) are very high, and oxidation of some ammonium to nitrate is also commonly observed. As in all wet soils, anaerobic micro-sites will also develop, where the decomposition may result in some production of hydrogen sulphide gas and even methane (anaerobic decomposition).

A tipping device can supply the wastewater in intervals. It is made of an open “bucket” with a rod fixed onto it from both sides (round grey in the right picture). The position of the rod is such that when water reaches a certain height, the bucket becomes heavier on the left-hand side and flips over and empty into the leachfield. A spring turn the bucket back to the original position, and water fills again.

If the dimensions of the leachfield are appropriate, the subsoil beneath the distribution pipe and gravel layer does not clog. If the application rate of wastewater and/or organic matter content is too high, the soil infiltration capacity may decrease due to the growth of microorganisms and the accumulation of organic matter in the soil pores. Hence, the life expectancy of the leachfield depends on the greywater composition and the load. A rule of thumb is that sieved subsoils can manage a daily load of about 30–60 litres per m^2 depending on the sand content, whereas lower loads have to be applied in finer soils. Similarly, the recommended hydraulic load on a sand filter depends on the grain size of the sand (see US EPA 2002, pp. 4–12) and on the concentration of organic matter in the wastewater. Leachfields for greywater only (without excreta) are usually 35–40 % smaller than fields for ordinary wastewater. The money saved by installing a wastewater-only leachfield can pay for the installation of a compost toilet.

The removal of phosphorus depends on the physical and chemical composition of the material in the bed (e.g. local soil, a filter sand or a material designed for high P removal). If a soil or sand layer with high P sorption capacity is used, the phosphorus concentration in the effluent can initially be less than 1 mg per litre, but will increase as the soil gets saturated with phosphorus. Metals will also largely be adsorbed to the soil particles in the filter, as discussed in Sections 4.6–9 and 4.6–10.

For information about the siting and design, the reader is referred to Siegrist, Tyler and Jenssen (2000) and USEPA (2002). Information can also be found in Chapter 5 of the WHO guidelines.

Trickling filter

4.7- 14

Jan-Olof Drangert, Linköping university, Sweden

A trickling filter comprises a medium of rocks, gravel or shredded PVC bottles on which microorganisms can attach. The pre-treated wastewater is sprayed over the medium. A trickling filter is often part of the treatment processes in a wastewater treatment plant, typically with a rotating distribution pipe (left-hand picture). The jet can be directed a bit sideways so that the pipe moves around without other energy input. A household unit which requires no electricity can be constructed in which the water is spread over the media with a perforated immobile pipe (right-hand picture).

The upper part of the medium is wetted and wastewater percolates through the aerobic lower part. Thus, aerobic microorganisms are active in decomposing organic matter into water and carbon dioxide (see Section 4.6–16). The microbial biofilm on the medium gradually grows thicker until the outer part eventually sloughs off and flows away in the treated effluent. Typically, a trickling filter is followed by a clarifier or sedimentation tank to separate and remove this microbial biomass, i.e. sludge. Further treatment and use of the sludge is discussed in Section 4.7

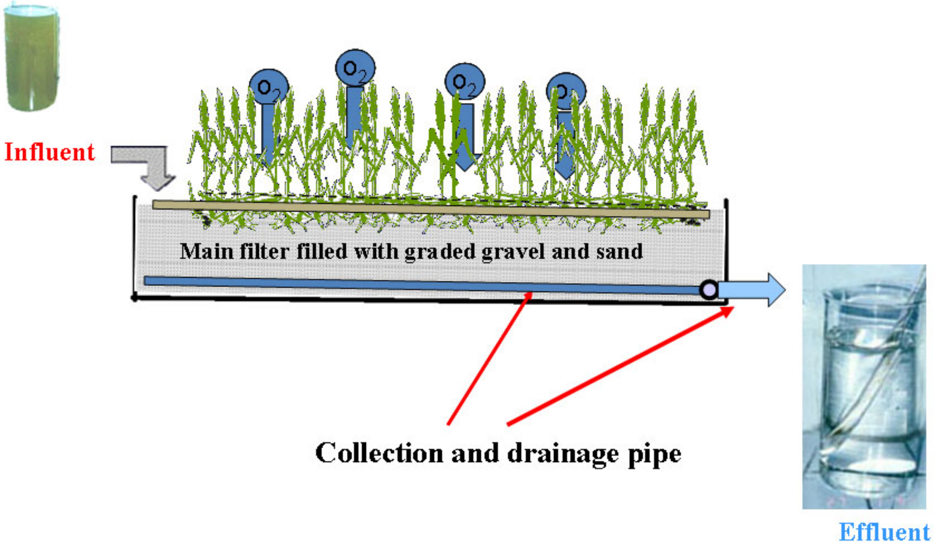
The capacity to reduce the level of organic matter (BOD, COD) is good, and with an even distribution of the wastewater on the media, some nitrification of ammonium to nitrate can also be achieved. With respect to reduction of pathogens, the US EPA states that there is a 1–2 log unit reduction of faecal coliforms, and that the reduction is lower than with activated sludge treatment. Studies of parasite removal suggest 75–90 % removal of protozoa. In general the removal increases at lower filtration rates (i.e. lower loads).

Trickling filters are not designed to trap heavy metals but they are partly adsorbed on particles and microbial biomass and may settle in the clarifier.

Large trickling filters require trained staff to monitor the distribution pipe and the accumulation of sludge and check the growth of filter flies (alternatively drain flies).

Vertical flow subsurface wetland

4.7- 15



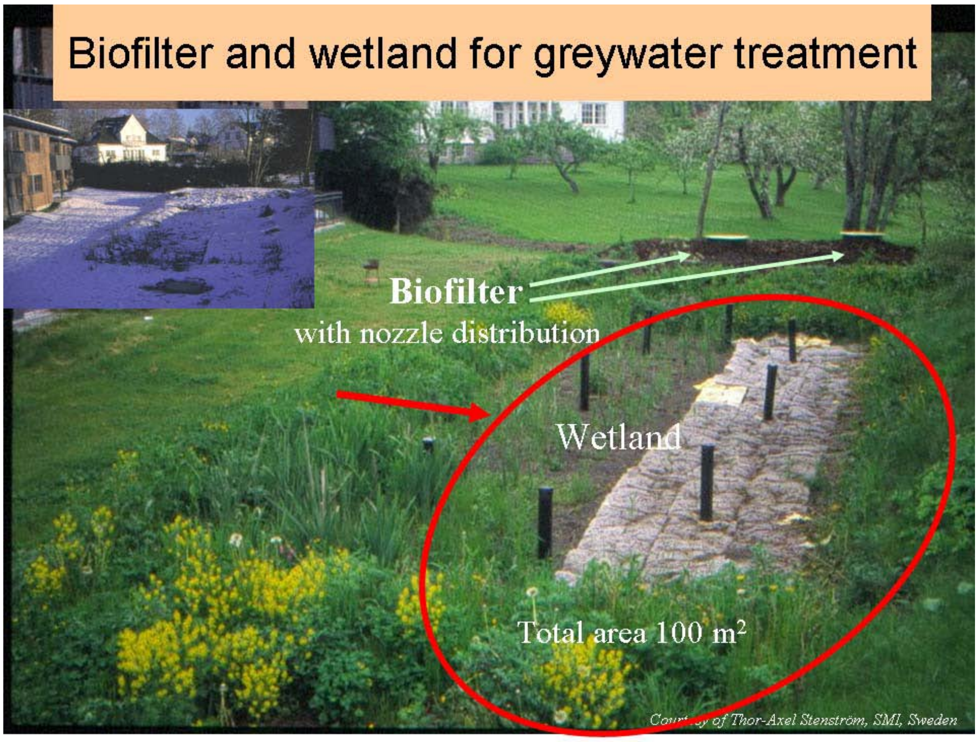
Courtesy of Roshan Shrestha, UN-Habitat, Nepal (revised)

Vertical flow subsurface wetlands might be viewed as a soil filter planted with wetland plants. Pre-treated greywater (e.g. in a pond or septic tank) is evenly distributed on, or just below, the coarse sand at the top of the filter (upper brown pipe in picture above). The greywater percolates by gravity down through the sand and gravel filter material, where aerobic and anaerobic microorganisms feed on its organic content. Usually, the unit is sealed with clay, concrete or a rubber sheet at the bottom, and the treated effluent is collected in a perforated drainage pipe (blue pipe).

The processes in operation are the same as in soil filters (see Section 4.7–13), but in addition the root zone of the plants contributes to the treatment. The evapotranspiration by plants may be quite high in warm climates, and this turns the system into a low or zero discharge unit. In colder climates, the dead plant biomass serves as an insulating layer during the cold months of the year. Also, some plants have an efficient gas transfer system, and leach some oxygen to the microorganisms in the root zone.

The treatment results are similar to those of a sand filter, with very high removal of particles and organic matter, and with some oxidation of ammonium to nitrate. The log reduction of bacteria is usually 2–3 units, which means that the treated effluent is not hygienically safe and some care is needed when reusing it. With a proper sizing, the filter will not clog, but as for soil filters, a high load of wastewater or organic matter may result in flooding of the filter. If this happens, a resting period needs to be observed, or even an exchange of the upper layer of sand that has clogged. There is no need to remove sludge, but as the functioning of the wetland depends on the removal of particles and grease in a pretreatment unit such as a septic tank, regular maintenance of the sedimentation unit is an integrated part of its operation.

The rule of thumb for a sieved soil is that about 30–60 litres of wastewater can be applied per m^2 per day. With a suitable sand, even higher application rates have been used without problems. To achieve a high nitrogen removal, sand filters, trickling filters and vertical flow constructed wetlands need to be combined with a more anaerobic unit. This could be a horizontal flow wetland (see Sections 4.7–11 and 4.7–12) or a surface flow wetland with a lot of plant biomass (4.7–22). In such combined systems, a very high removal (3–6 log units) of indicator bacteria has also been recorded, (Vymazal, 2005a, b).



Courtesy of Thor-Axel Stenström, SMI, Sweden

4.7- 16

Student dormitories at an agricultural university outside Oslo, Norway are connected to a greywater treatment wetland serving 48 students. The system consists of a pre-treatment and pump unit, a so- called biofilter for further pre-treatment and a subsurface horizontal wetland with an area of 100 m^2. The treated water finally percolates down to the deep groundwater..

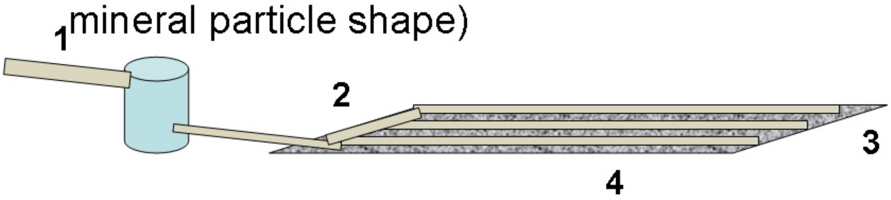
The biofilter consists of two domes with nozzles spreading untreated greywater uniformly over a filter surface area of 6 m^2 (like the trickling filter described in Section 4.7–15). The filter material is grains of lightweight aggregate 2–10 mm in size, but other materials such as shredded plastic bottles, or crushed coconut shell could be used to house the (aerobic) microorganisms. If there is a favourable topographical gradient, the pump and nozzles could be replaced by a siphon or a tipping bucket (4.7-13). This part of the treatment system is designed for aeration, decomposition of organic matter and bacteria. Loading rates up to 1 m per day on a biofilter can achieve treatment results of more than 70% reduction of the BOD level and a 5-log reduction of indicator bacteria – that is, a 99.999 % reduction (Jenssen & Vråle, 2004).

The resulting low concentration of BOD allows a higher load to be injected in the subsequent wetland or infiltration system. Here, the breakdown of contaminants in the pre-treated water is done mainly by aerobic bacteria and fungi that receive oxygen through the black aeration pipes (see picture). Nitrate formed in the biofilter is denitrified to nitrogen gas. The final effluent has very low counts of bacteria (WHO, 2006), and the level of nitrogen is of drinking water quality. If a material with a high P sorption capacity is used in the wetland bed, the phosphorus concentrations in the effluent can be <1 mg/l, but the concentrations will gradually increase as the sorption capacity of the bed is exhausted. When that happens it has to be replaced with new material. Any metal contained in the wastewater is also subject to adsorption to the bed materials.

The treatment unit works in the wintertime with temperatures well below zero degrees (small picture, top left). However, the biological treatment of nitrogen compounds is less efficient in winter time.

Common problems in soil filters

1. **Overloading** (suspended solids, high BOD, water)
2. **Uneven distribution** (over surface, over clay)
3. **Failure in drainage** (waterlogging, roots)
4. **Wrong choice of sand and gravel** (texture, mineral particle shape)



Jan-Olof Drangert, Linkoping university, Sweden

The picture above indicates where problems commonly occur in soil filters and subsurface flow wetlands. By overloading the system (1) with wastewater and/or suspended material and/or organic matter the subsequent treatment steps become less efficient or non-functional. The system design must therefore be correct, or else the application rates must be lowered or the pre-treatment improved.

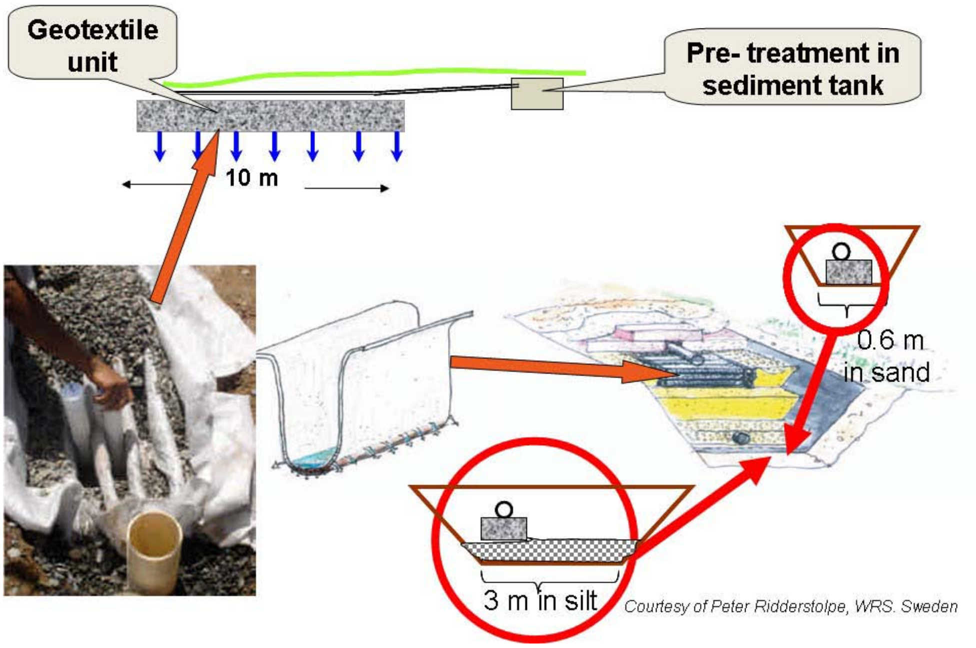
In order to make use of the whole treatment unit, the greywater should be evenly distributed over the soil or filter bed (2). If not, it is likely that the active parts will be overloaded and clogged and/or anaerobic conditions will develop, thus reducing the treatment capacity.

Even if the first two steps function well, problems may arise due to drainage failure (3). Such failure can be caused by waterlogging from below or due to very heavy rains, which prevent a continuous flow of wastewater. Another common problem is that roots grow into the pipes and eventually block them. In such cases, the pipes have to be taken up and cleaned or replaced.

The fourth common problem arises from rapid clogging due to an inappropriate choice of sand and gravel in the filter bed (4). The remedy is to change the sand or to extend the pre-treatment and the size of the bed.

Improved distribution using controlled clogging

4.7- 18



Courtesy of Peter Ridderstolpe, WRS, Sweden

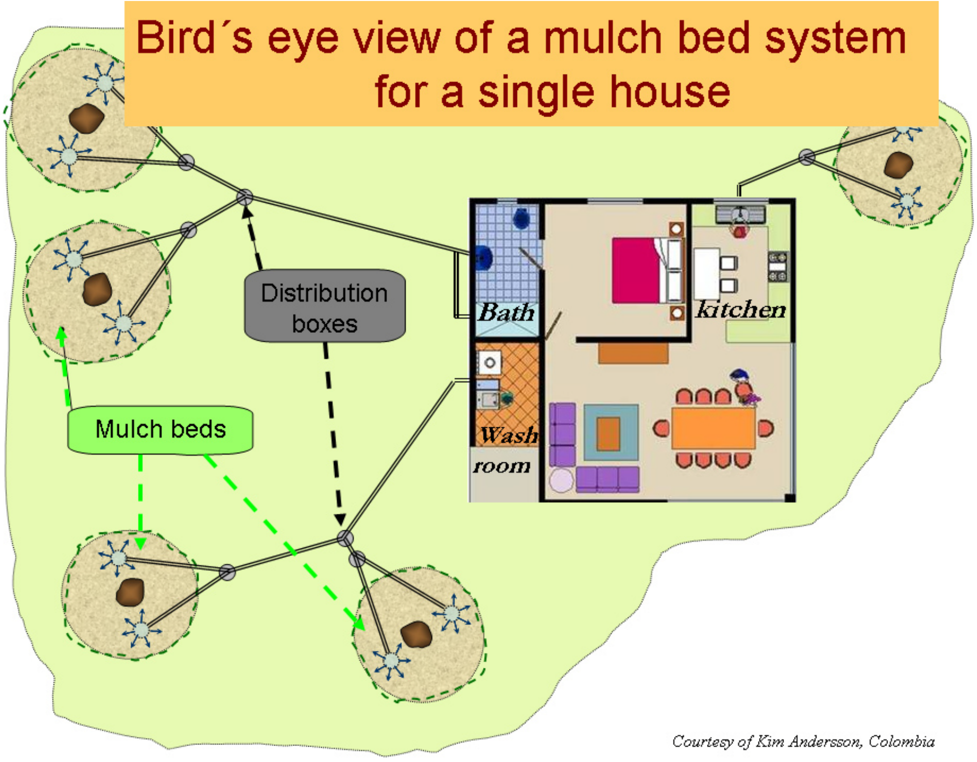
It is possible to control the clogging problem common to filter systems by introducing an artificial geotextile filter. The left part of the picture shows the principle of this technique using a folded geotextile to create a structure containing ‘valleys’ and ‘ridges’. As the bottom of a ‘valley’ becomes clogged with biofilm, the pre-treated wastewater level increases. Infiltration continues along the sides of the ‘valleys’ and the filtered water percolates through the underlying filter media. In addition, this distribution system helps buffering against large flow variations, and a rising water level during high flows will not negatively impact the infiltration of water into the underlying soil/sand.

The active, predominantly aerobic, microflora and fauna on the geotextile and in the upper soil/sand layer decompose the organic matter in the pre-treated wastewater.

A perforated pipe on top of the geotextile filter unit distributes the pre-treated water (top picture). A prefab geotextile unit with a typical dimension of 0.2m x 0.6 m x 1.25 m has a capacity of about 125 litres per 24 hours (e.g. EKOTREAT Compact Filter; Ridderstolpe, 2004). Eight units in a row can form a 10 metre-long filter with a total capacity of 1 m^3 per day. This is what a household of some 10 persons will need. Evaluation results for treatment of greywater in Sweden show that the removal of organic matter (measured as BOD) and suspended solids was > 97% and >73%, respectively (Table 1 in Gustafsson, 2005). The concentrations of indicator bacteria were below the limits for swimming water quality (< 1000/100 ml for faecal coliforms, and < 300/100 ml for faecal streptococci) at most of the sampling occasions.

The wastewater percolates through the geotextile down to the bottom of the trench. The infiltration capacity of the underlying natural soil determines how large the trench area must be. In sandy soils (right-hand picture) a 0.6 m wide trench is enough to infiltrate the percolating water. In all other soil types one has to add a 0.3 m gravel bed between the geotextile unit and the bottom of the trench to help spread the effluent and simultaneously treat it a bit more. For instance, in a silty soil the trench needs to be 3 m wide, and in clayey soils 5 m wide to have enough capacity to infiltrate all effluent from the geotextile. The infiltrated soil pores will not become clogged since the wastewater contains very little solid material after leaving the geotextile. Also, the water is evenly distributed over the soil which is very beneficial for the infiltration. Compared to a gravel bed the infiltration area can be reduced by a factor 2 to 5!

4.7- 19


Bird´s eye view of a mulch bed system for a single house

Courtesy of Kim Andersson, Colombia

A garden can be used as a treatment unit for greywater in a system which irrigates and fertilises at the same time. Small mulch beds around trees and bushes serve as the treatment units (see next section). A grid of plastic pipes distributes the greywater to the mulch beds (picture above). A mulch bed system is flexible in the sense that one can add or reduce the number of beds fed by the distribution boxes according to the greywater flow rate and available space. For instance, if the household has a clothes washing day, they can open the pipes to all the mulch beds to manage the extra load of greywater efficiently.

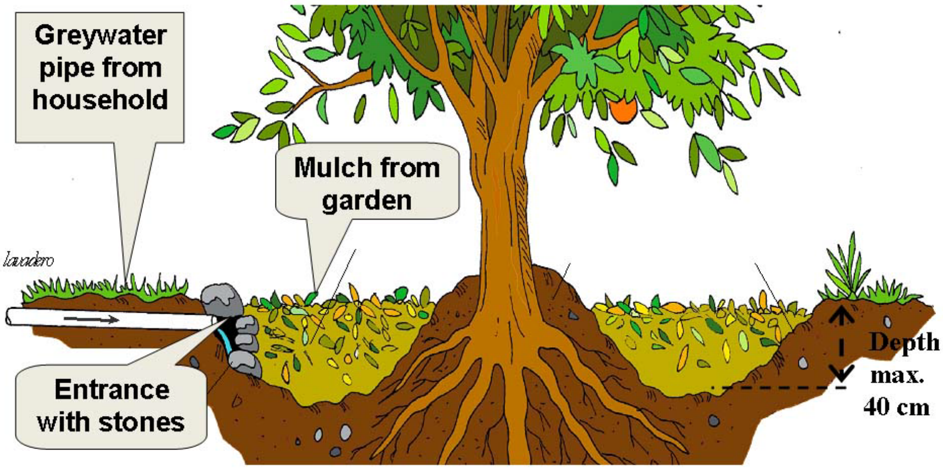
With such a system, there is no need to pre-treat greywater from bathrooms and washing rooms. However, if a lot of fat or oil is used for cooking, the risk of clogging can be avoided with a small grease trap attached to the kitchen pipe. The source-control alternative for the homeowner is to be careful and throw FOG in the solid waste bin. Residents are likely to be careful with what they add to the greywater simply because they know that certain substances will clog or harm their garden or cause extra work.

The plant roots may act as an efficient barrier against the uptake of non-essential metals. However, one important exception is cadmium, which is a non-essential metal that can pass through the root barrier due to its resemblance to zinc. Cadmium is toxic to humans and needs to be limited in wastewater going onto agricultural land (WHO, 2006).

Most other metals will not be taken up by plants unless they have reached a threshold concentration in the soil and the metal is in a mobile form – that is, dissolved in the soil solution and not adsorbed to soil particles. The interaction between heavy metals and crops is complex due to antagonistic interactions that affect their uptake by plants (Drakator el al., 2002). Typically, metals are bound to soil at pH levels above 6.5 and/or if the soil has a high organic matter content (see Section 4.6–10). If the pH is below this value, and all organic matter in soil is saturated with ions, metals become mobile and can be absorbed by crops and can also contaminate water bodies.

Mulch bed filter

4.7- 20



3-10 litres of greywater per m^2 per day

Courtesy of Kim Andersson, Colombia

A mulch bed consists of mulch from garden refuse (twigs, leaves and woodchips) which is placed in a shallow (< 40 cm) dug trench around a tree (see picture) or berry bush. The untreated greywater enters through a filter of stones to prevent larger particles from entering the mulch bed. Greywater usually enters intermittently because of the use pattern of household water and is spread around the circular trench. This means that both aerobic and anaerobic conditions are present in the bed and this provides environments suitable for different species of bacteria, fungi and worms. The surface area of leaves and other organic material is very large and can host huge numbers of microorganisms (see Section 4.6–24). They oxidise the organic matter into water and carbon dioxide which dissipates to the air, and some of the CO_2 is taken up by the tree leaves (see Section 4.6–21). When a gush of greywater enters the bed, the oxygen is rapidly depleted due to the intensive decomposition, turning part of the bed into an anaerobic system where even nitrogen gas and hydrogen sulphide may be formed. Such reduced chemical compounds are likely to be oxidized when oxygen diffuses into the bed during the resting periods between inputs of greywater, thus minimizing the risk of bad smells.

The effluent infiltrates down to the root zone where additional decomposition takes place. Much of the water, nutrients and other particles are taken up by the plants. The system can be designed in such a way that the amount of effluent which infiltrates further down into the soil is minimal.

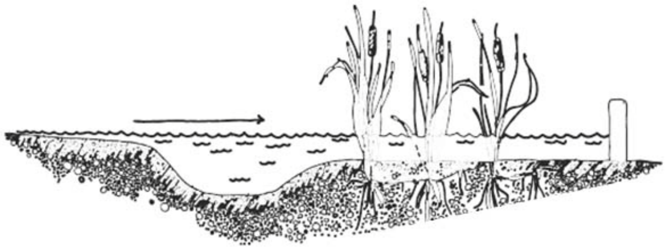
The problem of clogging is managed by adding or replacing the mulch regularly when it has decomposed enough. If necessary, rainwater can be diverted by a circular mound around the mulch bed to make sure aeration is sufficient in the mulch bed material.

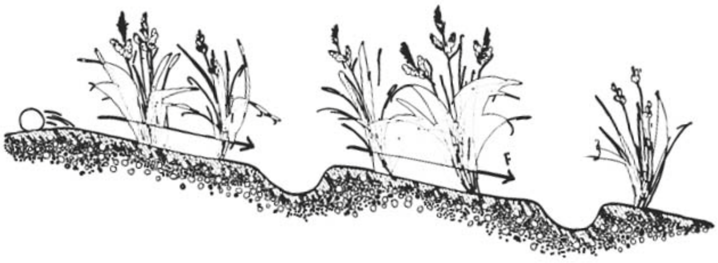
The capacity of a mulch bed around a tree ranges from 3–10 litres of greywater per m^2 per day depending on the tree’s water demand and the porosity of the soil. As in all other soil and sand systems discussed, organic chemicals will be degraded in the soil, if they are degradable, and most metals and phosphorus will be retained in the soil through adsorption until the sorption capacity is exhausted. The reduction of potentially pathogenic organisms in the wastewater is comparable to the levels achieved in the soil infiltration systems discussed above (see Section 4.7- 13), or better if the amount of water distributed per surface area is kept low.

The removed mulch is composted before being applied as a soil conditioner in the garden.

Wetland irrigation and overland flow

4.7- 21





Karin Tonderski, Linköping university, Sweden

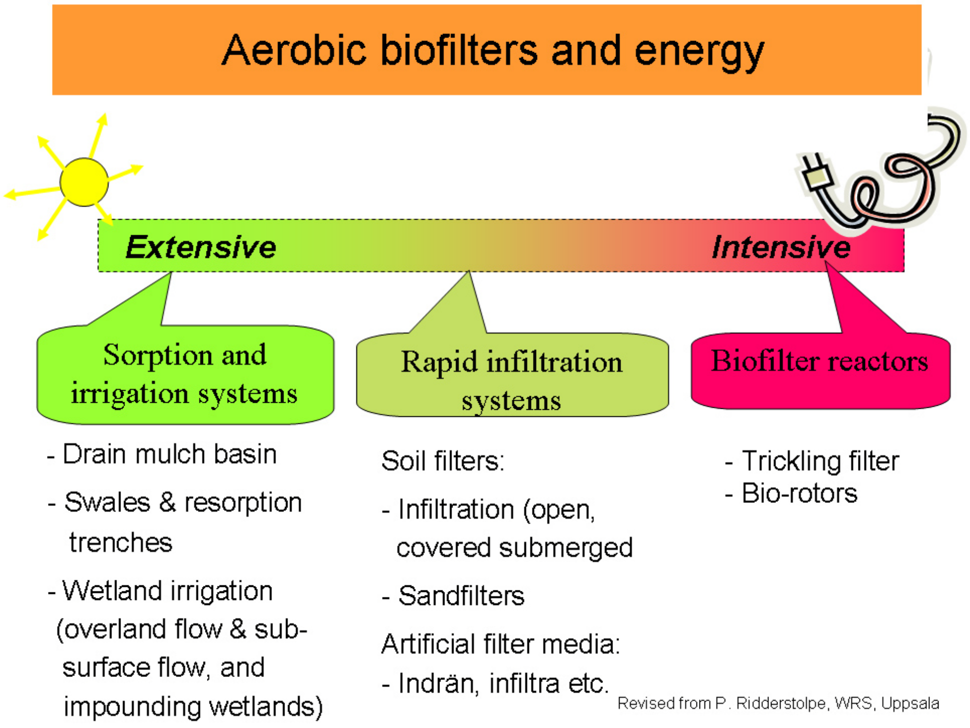
In some cases, a surface flow wetland can be a suitable system for the treatment of greywater. A surface flow wetland consists of a shallow pond with wetland plants, commonly with a variable depth profile (0.2–1 m deep) to support both submerged and emergent plants (top picture). Submerged plants contribute oxygen to the water because photosynthesis takes place in the water. This is also promotes colonization by invertebrates (e.g. water insects) that act as predators on mosquito larvae, and thus help to control a potential problem. In tropical areas where malaria is a problem, care must be taken not to create a breeding ground for mosquitoes by using improperly designed ponds or surface flow wetlands for greywater treatment. A suitable pre-treatment is sedimentation and grease removal. If not removed, grease may form a film on the water surface that prevents oxygen diffusion.

The advantages of a surface flow wetland are that it is easy to construct, can be constructed in areas with heavy soils unsuitable for infiltration, there is no need to purchase filter sand, there is no risk of clogging, and it requires little maintenance. A disadvantage is that a large surface area is needed. A typical load is 20–70 litres per m^2 per day in wetlands used for polishing wastewater from conventional treatment works. Loads in the lower range are suggested for greywater treatment to create a longer retention time. The main challenge is to ensure that the water flows over the entire wetland area to prevent short-circuiting and a drop in the water retention time. It has been observed that the removal of indicator bacteria increases with higher retention times, and removal of 1–2 log units for faecal coliforms and streptococci has been observed with retention times of 5–10 days (Vymazal 2005b).

In some areas of the world, a paddy field could serve to treat greywater and at the same time reuse both the water and nutrient resources. However, as mentioned above, proper pre-treatment involving sedimentation and a grease trap is a prerequisite, as is awareness that the effluent is not hygienically safe.

Sometimes, an overland flow system is used as part of a system to treat wastewater (bottom picture). This is a lightly sloping vegetated field where the water flows as a shallow “film”. The effluent is applied along the entire width of the field, for example through perforated pipes or a ditch, and is collected beneath the field for further treatment or reuse. Particles are filtered out in the dense vegetation. As the water flows relatively quickly over the soil surface, intensive oxygenation takes place and this promotes decomposition of organic matter and nitrification of ammonium, as well as some removal of bacteria. Overland flow systems have commonly been used to promote oxygenation and in combination with other methods, such as surface flow wetlands. In such cases, the loads have varied between 100 and 200 litres per m^2 per day.

4.7- 22



Aerobic biofilters and energy

Extensive — **Intensive**

Sorption and irrigation systems

- Drain mulch basin
- Swales & resorption trenches
- Wetland irrigation (overland flow & sub-surface flow, and impounding wetlands)

Rapid infiltration systems

Soil filters:

- Infiltration (open, covered submerged
- Sandfilters

Artificial filter media:

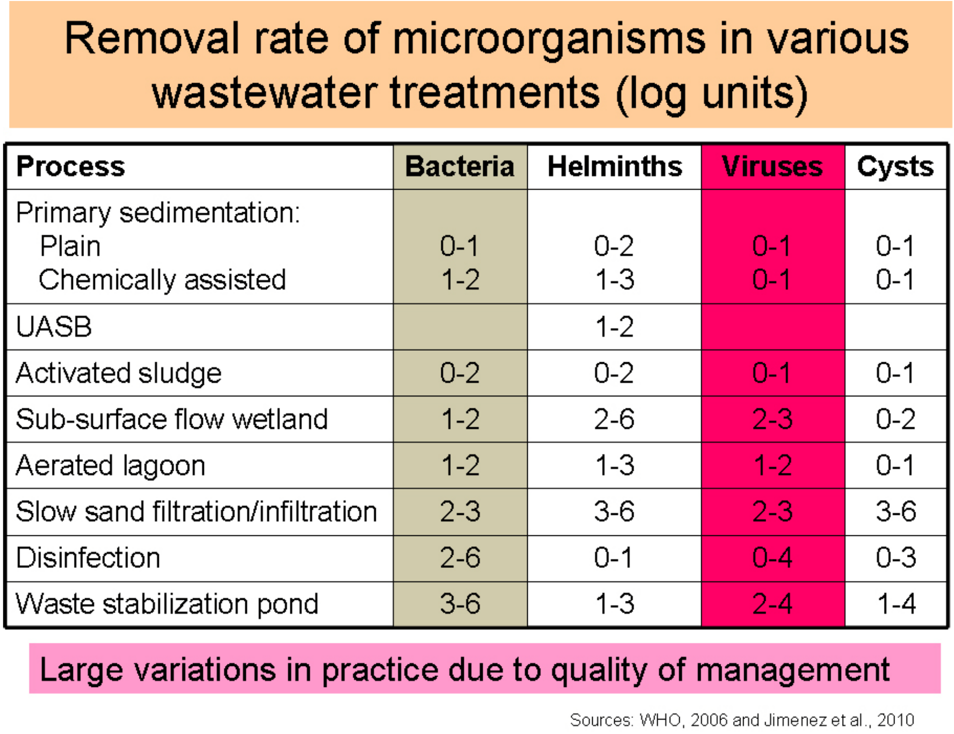
- Indrän, infiltra etc.

Biofilter reactors

- Trickling filter
- Bio-rotors

Revised from P. Ridderstolpe, WRS, Uppsala

This picture is a summary of the treatment systems that have been discussed so far, illustrating their dependence on energy input other than the sun. Mulch basins and surface flow wetlands are usually constructed without any external energy input, with gravity distribution of the effluent. At the other end, bio-rotors and rotating trickling filters require electrical energy to circulate the water and the rotors. It is also implicit in this picture that the land area requirement to treat a certain volume of wastewater increases as we move to the left in the figure.



4.7- 23

Removal rate of microorganisms in various wastewater treatments (log units)

Process	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation: Plain Chemically assisted	 0-1 1-2	 0-2 1-3	 0-1 0-1	 0-1 0-1
UASB		1-2		
Activated sludge	0-2	0-2	0-1	0-1
Sub-surface flow wetland	1-2	2-6	2-3	0-2
Aerated lagoon	1-2	1-3	1-2	0-1
Slow sand filtration/infiltration	2-3	3-6	2-3	3-6
Disinfection	2-6	0-1	0-4	0-3
Waste stabilization pond	3-6	1-3	2-4	1-4

Large variations in practice due to quality of management

Sources: WHO, 2006 and Jimenez et al., 2010

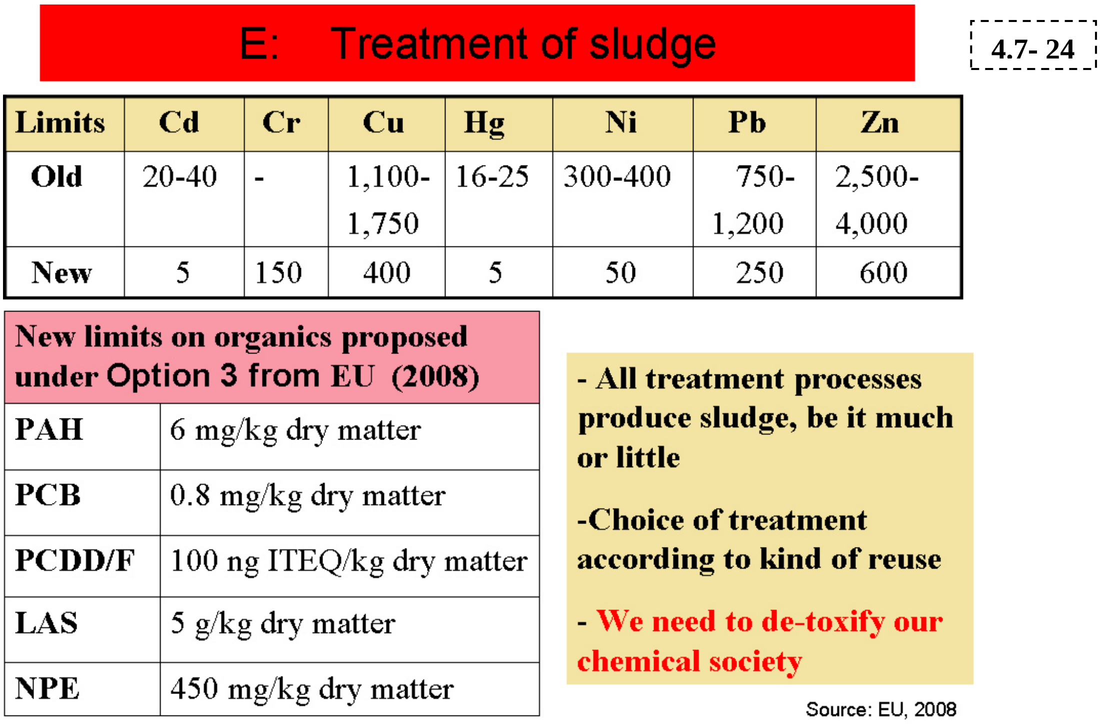
A long-standing aim of treatment of wastewater is to get rid of pathogens which can cause health problems for staff, farmers, and families reusing greywater. The table above shows the ranges of expected reductions of various microorganisms in different wastewater treatment units. If the treatments units are in a sequence the corresponding reductions add up to the total reduction. From a groundwater quality perspective, it may be mentioned that the eventual soil infiltration also has a high efficiency and bacteria and viruses are reduced by more than 2 logs and parasitic protozoa more than 3 logs, which is similar to the reduction in a traditional wastewater treatment plant (Siegrist, Tyler, Jenssen, 2000).

The various treatment processes reduce the number of microorganisms in the wastewater in a variety of ways: die-off, photooxidation, predation, suffocation, and poisoning. A 1-log reduction means a 90% reduction and a 6-log reduction is 99.9999% reduction. This may look impressive, but if there are millions of pathogens and a species is infectious to humans in very small doses, not even 6-log reduction may be enough to prevent disease from occurring (see Chapter 3).

A tolerable additional disease burden of $<10^6$ disability-adjusted life year (DALY) per person per year applies to drinking water quality (see Section 3.1). The same risk level is set for wastewater use in agriculture. This translates into the following reduction levels of excessive risks of viral, bacterial and protozoan infections:

- a 3–4 log unit pathogen reduction by the wastewater treatment system is required to protect the health of those working in wastewater-irrigated fields
- a 6–7 log unit pathogen reduction is required to protect the health of those consuming wastewater-irrigated food crops.

These levels can be achieved by a combination of 3–4 log unit reductions by wastewater treatment and an additional 2–4 log unit pathogen reduction by post-treatment health protection control measures such as those listed in Section 4.7–25 (crop washing, peeling, and cooking). Furthermore, the treated wastewater should contain < 1 human intestinal nematode egg per litre to protect workers, farmers and consumers from helminth infections (Mara and Bos, 2010).



E: Treatment of sludge

4.7- 24

Limits	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Old	20-40	-	1,100-1,750	16-25	300-400	750-1,200	2,500-4,000
New	5	150	400	5	50	250	600

New limits on organics proposed under Option 3 from EU (2008)	
PAH	6 mg/kg dry matter
PCB	0.8 mg/kg dry matter
PCDD/F	100 ng ITEQ/kg dry matter
LAS	5 g/kg dry matter
NPE	450 mg/kg dry matter

- All treatment processes produce sludge, be it much or little

-Choice of treatment according to kind of reuse

- We need to de-toxify our chemical society

Source: EU, 2008

All wastewater treatment processes produce sludge and the amount depends on the treatment process employed. Sludge is composed of organic matter (i.e. dead and living microorganisms) and any non-decomposed solids that were in the wastewater to begin with and, if flocculent have been used as part of the treatment process they will appear in the sludge. A large proportion of any metals and potentially harmful organic molecules that have been discharged into household wastewater end up in the sludge either because they are adsorbed to the organic particles or are precipitated with the sulphides formed in an anaerobic sedimentation unit.

In large treatment units, some of the sludge composition is known but most is not, simply because the authorities and utilities only monitor a few substances. It is typical in today’s chemical society that the focus is on production of goods that are saleable, while little attention is paid to what happens to these products after use. The number of professional chemists employed by industry to develop new chemical products exceeds by a thousand times the number of chemists in environmental agencies and water utilities. The battle against polluting chemicals is therefore lost before it starts, but improvements can be achieved when industries produce non-toxic, rapidly degrading compounds (see Section 4.5–15).

So far, it is Nature which has rung the alarm bell in the form of dead birds or dolphins, or dying sea beds, coral reefs and fish. Only when confronted by such warnings is society motivated to make radical changes. With 9 billion rather well-off people expected to inhabit the globe by 2050, pollution problems will escalate. Nature will hit back more often and more fiercely at the output of the chemical society. This new situation requires tough new measures in order to implement the already existing good framework documents on zero emissions, the precautionary principle, the polluter pays principle, and outcome-based regulations (see 2.3–5).

The huge volume of sludge from cities and towns, where the wastewater is mixed from numerous different sources, makes it tempting for utilities and decision-makers to spread the sludge on farmland. It is well known that it is better to return it to the soil than to water bodies where it does not belong. However, even if the sludge is “certified” to be spread on soil, it may still contain too many unknowns that will accumulate in the soils. If nothing else, the precautionary principle should be applied to prohibit chemically polluted sludge to be used in agriculture. Incineration of sludge from large wastewater treatment utilities is becoming a more common solution but this requires very well designed and operated incineration plants with advanced systems for cleaning the exhaust fumes.

Today, “new” substances are regularly discovered in the sludge, but the manufacturers of the products which contain them are certainly aware of them. For instance, nano-particles from diesel engines and from wear and tear of linings of car breaks can be detected today with measuring instruments. Nano-particles of silver originating from stockings and other clothes are found in sludge. The silver has been added to kill off bacteria and reduce bad odours. Silver particles easily spread through the environment, and are accumulated in the soil and water bodies.

The main remedy has to come from improved source-control measures which reduce the chemical content of **all** household products. Manufacturers should be obliged to prove that their new products are not harmful but easy to handle after use. Furthermore, separating different horizontal water flows (see Section 4.5–3) from each other also facilitates source control. In the long term there are options for source-separating systems which enable the recovery of valuable compounds at the source (urine-diverting toilets etc.). Households must sort hazardous waste and not discharge it in their greywater.

The European Union is engaged in lowering the permissible levels of various compounds (see top table above). This is a complex task due to a genuine lack of knowledge, and the fundamentally different priorities of governments and industry. For example, a background report to the EU on the use of sludge in agriculture states that it is:

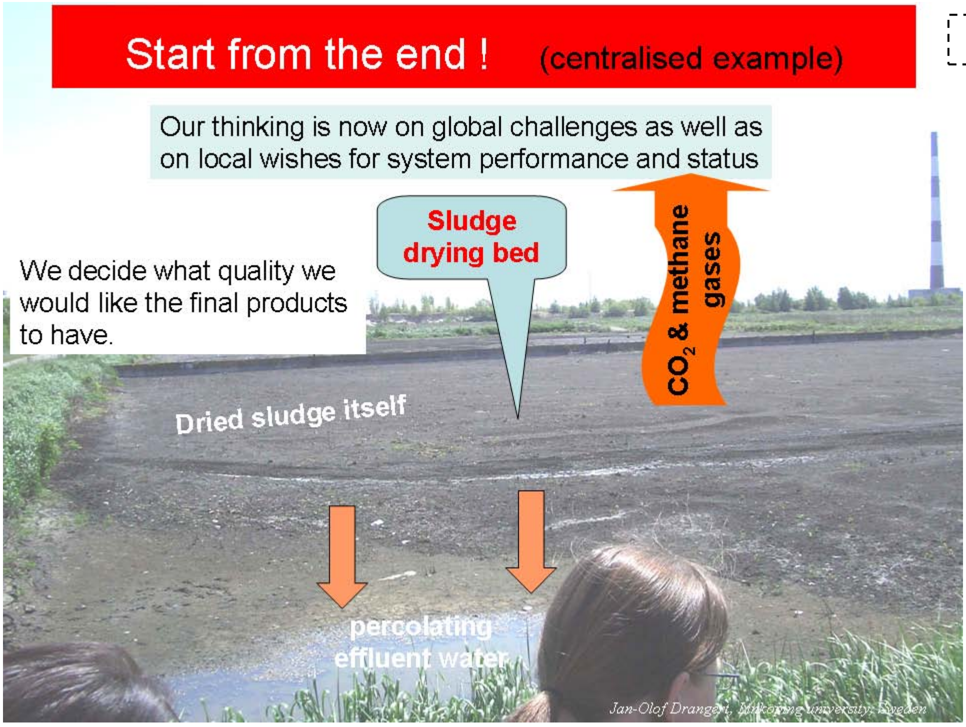
> important to recognise that the potential environmental and health benefits resulting from more stringent sludge standards in Options 2 and 3 (as well as the total ban of land use in Option 4) are not quantified here, nor will they be in the final CBA unless respondents can provide relevant data (EU, 2008).

This demonstrates the limitation of basic data on which decisions are based. The precautionary principle could fill this gap by prohibiting the production or sale of products (see 2.3-5). However, the report states – without supporting evidence – that “the Sewage Sludge Directive (1986/278/EEC) could be said to have stood the test of time in that sludge recycling has expanded since its adoption **without** environmental problems.” This sweeping statement is made at a time when many new hazardous compounds are being developed and put in consumer products. Most chemical compounds are new and it may take a generation or two to reach concentrations where human health and the environment will be affected (Qadir and Scott, 2010). The rapid expansion of our chemical society will aggravate the problem of lack of data and the regulatory system is likely to slip out of public control.

If the new lower limits for ***heavy metals*** are enforced (see upper table above), all EU member states except Denmark will have to lower their legislative limits. The case of Denmark shows that the new limits are achievable, though they may not be adhered to in reality. No limits were imposed on ***organics*** in the 1986 legislation, and the proposed limits in the table (lower table) include PCBs (sum of the polychlorinated byphenols component numbers 28, 52, 101, 118, 138, 153, 180), PAHs (sum of polycyclic aromatic hydrocarbons: acenapthene, phenanthrene, fluorene, flouranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1, 2, 3-c, d)pyrene), PCDD/F (Polychlorinated dibenzodioxins/ dibenzofuranes), LAS (Linear alkylbenzene sulphonates) and NPE (comprises the substances nonylphenol and nonylphenolethoxylates with 1 or 2 ethoxy groups). About 50% of the present sludge is expected to be unacceptable under the new limits (EU, 2008).

Another new limit concerns methane emissions. Measures will require that sludge shall be stabilised (or pseudo-stabilised) to reduce degradability during field-site storage or after land spreading to reduce methane emissions, and to reduce odours.

The global society needs to de-toxify in order deal with the problem of toxic sludge.



Start from the end ! (centralised example)

Our thinking is now on global challenges as well as on local wishes for system performance and status

We decide what quality we would like the final products to have.

4.7- 25

This picture shows one of the end-products from a wastewater treatment plant – a drying bed for dewatering sludge. The purpose is to save on energy by this natural drying before the sludge is incinerated or transported elsewhere. What happens in the sludge bed? Aerobic and anaerobic processes are active and the former creates a lot of carbon dioxide which is emitted into the air and taken up by plants during the photosynthesis. Anaerobic digestion in the bottom part of the sludge layer produces methane gas which is an aggressive greenhouse gas. A productive way to take care of the methane would be to collect it in one way or another (see Module 4.4).

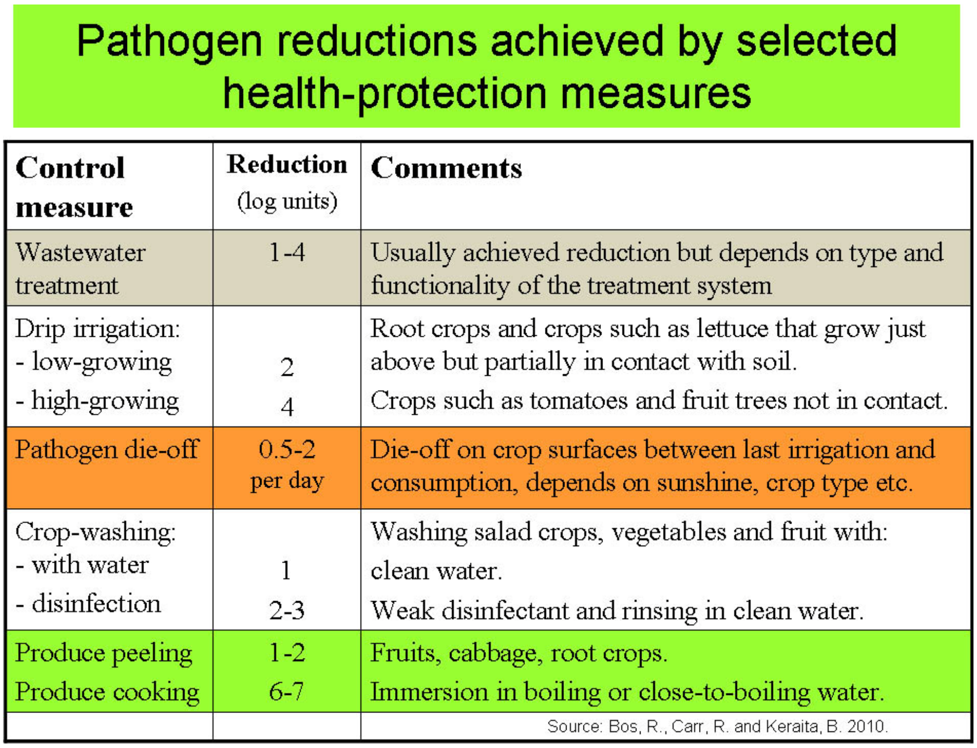
The damp sludge is not only evaporating water but also percolating leachate into the ground. The remedy is to place an impermeable sheet at the bottom of the excavation just as is done in well managed landfills. This will protect the groundwater, but the leachate has to be treated further to avoid the discharge of excess nutrients and other chemicals into the environment.

The dried sludge itself contains the remaining organic material and any number of chemicals including heavy metals and persistent organic compounds that were contained in the wastewater and not decomposed in the treatment. The presence of each of these tens of thousands of compounds should be at low levels before the sludge is returned to farmland. To ensure that no net accumulation of such compounds occurs in the soil, it is also important to control the *amount* of sludge used on each field.

Small decentralised sludge treatment units also release gases and leachate water. The sediment or sludge in a septic tank releases carbon dioxide and methane gases to the atmosphere as part of the degradation of organic material. If the greywater is not very polluted by potentially harmful substances, the sludge can be applied to farmland where microorganisms will degrade it mostly aerobically and less methane will be emitted.

A sustainable society must focus its actions on the sources of sludge and gas emissions. By not mixing urine, faeces and greywater, cross-contamination by metals and other hazardous substances can be avoided. Urine and faeces can be treated with negligible losses of nitrogen and methane (see Module 4.4), and the nutrients can be applied on farmland without causing health problems. With proper source control, the greywater can also be kept relatively free from unwanted and potentially toxic chemicals, thereby allowing reuse of a valuable water resource.

4.7-26



Pathogen reductions achieved by selected health-protection measures

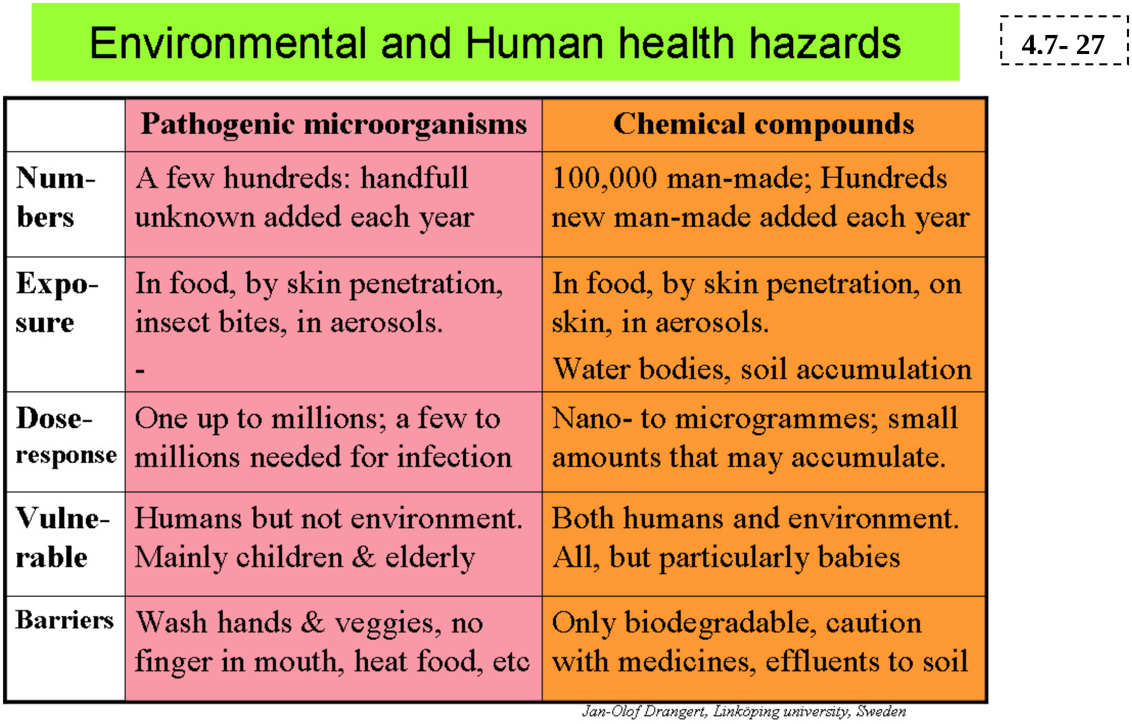
Control measure	Reduction (log units)	Comments
Wastewater treatment	1-4	Usually achieved reduction but depends on type and functionality of the treatment system
Drip irrigation: - low-growing - high-growing	 2 4	Root crops and crops such as lettuce that grow just above but partially in contact with soil. Crops such as tomatoes and fruit trees not in contact.
Pathogen die-off	0.5-2 per day	Die-off on crop surfaces between last irrigation and consumption, depends on sunshine, crop type etc.
Crop-washing: - with water - disinfection	 1 2-3	Washing salad crops, vegetables and fruit with: clean water. Weak disinfectant and rinsing in clean water.
Produce peeling Produce cooking	1-2 6-7	Fruits, cabbage, root crops. Immersion in boiling or close-to-boiling water.
		Source: Bos, R., Carr, R. and Keraita, B. 2010.

A major concern for backyard irrigation is the possible spread of pathogens from greywater to humans. Such health risks from pathogens should be considered before, during and after wastewater application. There is no need for advanced measuring of greywater quality; practising some basic safety measures is sufficient (WHO, 2006:41). For instance, if a household washes diapers in the sink or washing machine, the greywater will have a high load of pathogens, and if possible such water should be discharged in the ground in a secluded part of the garden.

There has to be a trade-off between the advantages and disadvantages of greywater use and the best solution for each situation should be sought. The WHO guidelines suggest a multiple-barrier approach for achieving the health-based targets. These include combinations of several measures such as safe irrigation practices and washing food as part of its preparation.

As mentioned in Section 4.7–23 various treatment processes reduce the number of microorganisms in the greywater in a variety of ways. These include die-off, predation, suffocation and poisoning. The table above shows reduction rates of bacteria, viruses, helminths, and cysts in irrigation systems and during food-handling activities. Remember, a 1-log unit reduction means a 90% reduction and a 6-log reduction means a 99,9999% reduction. The WHO guidelines use a pathogen reduction of 6–7 log units as the performance target for unrestricted irrigation to achieve the tolerable disease burden of $<10^{6}$ DALYs per person per year (see Module 3.1). The table demonstrates that combining minimal wastewater treatment, drip irrigation and washing vegetables after harvesting can easily achieve a 6 log unit reduction (Bos, Carr and Keraita, 2010). The ability to select different combinations also allows people living under varying conditions to choose the combination that suits their time, pocket and lifestyle.

Short fact sheets and policy briefs for different stakeholder groups can be found at: www.who.int/water_sanitation_health/wastewater/usinghumanwaste/en/index.html



Environmental and Human health hazards

4.7- 27

	Pathogenic microorganisms	Chemical compounds
Num-bers	A few hundreds: handfull unknown added each year	100,000 man-made; Hundreds new man-made added each year
Expo-sure	In food, by skin penetration, insect bites, in aerosols. -	In food, by skin penetration, on skin, in aerosols. Water bodies, soil accumulation
Dose-response	One up to millions; a few to millions needed for infection	Nano- to microgrammes; small amounts that may accumulate.
Vulne-rable	Humans but not environment. Mainly children & elderly	Both humans and environment. All, but particularly babies
Barriers	Wash hands & veggies, no finger in mouth, heat food, etc	Only biodegradable, caution with medicines, effluents to soil

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The picture summarises and compares the hazards that pathogens and chemical compounds pose to human health and the environment. It follows WHO's risk-assessment approach based on numbers or concentrations of each hazardous item, exposure, dose-response relationship, vulnerability, and barriers (WHO, 2006). A first observation is that pathogens are present in nature, while chemical compounds are manufactured and supplied by companies. Thus, chemical compounds become more sensitive to discuss, and a lot of lobbying is involved.

The health hazards caused by pathogenic organisms (viruses, bacteria, helminth and protozoa) and chemical compounds (heavy metals, persistent organic compounds, nutrients etc.) have different features. Microorganisms are present in nature and perhaps a handful of new strains or species are detected every year. Chemicals are present in nature, but almost all the ones that humans are exposed to are made by humans. Altogether there are some 100,000 compounds in our chemical society, out of which 30,000 are used by households. Industries add hundreds of new compounds to products every year. These new ones are known, but their harmful effects not necessarily known.

Human exposure to pathogens is mainly through ingested food and water, skin penetration (snails), bites (mosquitoes), and inhalation of aerosols. Humans are exposed to chemical compounds in the same way, and also on the skin (from chemicals in clothes, etc.). Chemical compounds can have negative impacts on the environment such as pollution of water bodies, and accumulation in the soil and in plants. Chemical compounds can enter the food chain and move upwards to humans.

The exposure varies widely from hundreds of viruses or helminths to hundreds of millions of bacteria. The infectious dose, however, varies from a few Ascari eggs to millions of enteric coliform bacteria and the effect is seen within a short period of time. Not all pathogens can multiply, and they may predate and die off. Chemical compounds are usually available in small doses, but some of them can accumulate in the human body and in the environment and eventually reach hazardous concentrations. The effects are only seen after long exposure. Some heavy metals (cadmium, lead etc.) can affect the human body functions and can persistent organic matter such as PCBs and some pesticides. The symptoms can be difficult to diagnose, however.

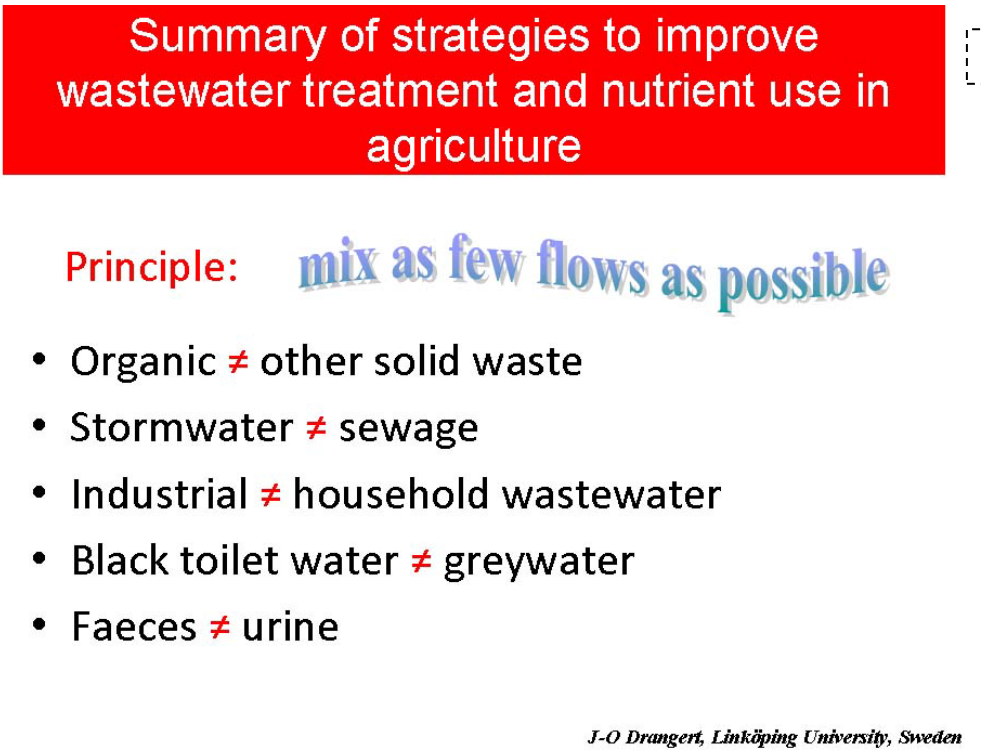
Pathogens cause disease and death among humans and other animals, but have little direct impact on the environment. Children, the elderly and the undernourished are the most vulnerable people. Chemical compounds, on the other hand, can have a negative impact on both animals and the environment. Babies are most vulnerable to acute or short-term toxic exposures (e.g. blue baby syndrome from excess nitrate) while carcinogenic and other disease-causing chemicals affect other age groups. Water bodies are sensitive in the short-term and the atmosphere and soils are affected over longer periods.

Protection against health hazards can be described as barriers, and they include washing hands and vegetables before eating, boiling food and water if necessary, heating left-over food before eating, no fingers in the nose or mouth, and using ORT to cure diarrhoea. Barriers against chemical hazards include being restrictive with medicines, avoiding breathing polluted air, washing new clothes before wearing them etc. However, most barriers against chemicals are long-term remedies which involve protecting the environment, such as only using biodegradable body care products and detergents, collecting and destroying expired medicine and left-over hazardous chemicals, and disposing of wastewater on soil rather than water bodies.

A stark difference between pathogens and chemicals emerges from this. The barriers for pathogens are controlled by the individual and the barriers do not require consumers to stop buying any products. Barriers to chemical compounds, on the other hand, require collective action to ban certain compounds and replace them with safe products to protect both our health and the environment. However, all of us also have an individual responsibility to change our consumption patterns. This involves decreasing our general consumption of status symbols, and restricting the purchase of products containing substances with unknown or negative health and environmental impacts.

The contrasting features of pathogens and chemical hazards call for radically different approaches to remedy the threats they pose.

4.7- 28



Summary of strategies to improve wastewater treatment and nutrient use in agriculture

Principle: mix as few flows as possible

- Organic ≠ other solid waste
- Stormwater ≠ sewage
- Industrial ≠ household wastewater
- Black toilet water ≠ greywater
- Faeces ≠ urine

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The best practice is to recirculate treated or untreated greywater. As an environmentalist put it: ‘*grow it away, don´t throw it away*!’ The new approach to wastewater treatment is to optimise the nutrient content in the effluent and outsource the treatment task to farmers and gardeners. A strong argument, apart from resource conservation, is that householders will only dispose of items in the sink which they know are beneficial to their garden and, more importantly, they will prefer to dispose of undesirable matter in the solid waste stream.

There are many ways to ‘grow away’ greywater and sludge. Sludge can be reduced and ideally avoided if water is mixed with environmentally friendly products only. Organic matter and oil, grease and fat should be disposed of as solid organic matter and composted. The microbial content of wastewater will decrease drastically if human faeces are not added to the water, and the die-off of microorganisms is quick if faecal matter is treated by storing it. The hygienised faecal matter is a good soil conditioner that improves soil properties and it contains plant-available nutrient ingredients. Irrigation with recycled greywater has to consider flow rates, soil conditions, and greywater characteristics (see Module 4.5). There are barriers and precautions to take to minimise the health hazards posed by recyled water. Stormwater typically contains large water volumes with low concentrations of heavy metals and should not be mixed with the greywater.

The strategy is simple – to treat each flow separately and return the hygienised products to the soil as a fertiliser and soil conditioner.

References/sources:

Bos, R., Carr, R. and B. Keraita, 2010. Assessing and mitigating wastewater-related health risks in low-income countries: An introduction. In Drechsel, P. et al. (eds). Wastewater irrigation and health. Assessing and mitigating risk in low-income countries. Earthscan with International Development Research Centre (IDRC) and the International Water Management Institute (IWMI). London.

British Geological Survey, 2003. Guidelines for assessing the risk to groundwater from on-site sanitation. British Geological Survey. Commissioned Rep CR/01/142:97.

Building Safety Journal, Jan-Feb 2008.

Carden, K., Armitage1, N., Sichone, O., Winter, K., and U. Rivett '*Management options for the safe use and disposal of greywater in the non-sewered areas of South Africa*.' Project K5/1524. WRC (Water Research Commission), Pretoria, South Africa.

Crites, R.W. and Tchobanoglous, G., 1998. Small and decentralized wastewater management systems. Water Resources and Environmental Engineering, 1. WCB/McGraw-Hill, Boston,1084 pp.

Drechsel, P., Scott, C., Rashild-Sally, L., Redwood, M., and Bahri, A. 2010. Wastewater irrigation and health. Assessing and mitigating risk in low-income countries. Earthscan with International Development Research Centre (IDRC) and the International Water Management Institute (IWMI). London.

DWAF 2001. "Managing the water quality effects of settlements: Planning to avoid pollution problems." Department of Water Affairs and Forestry. *Government Printer*, Pretoria, South Africa (October 2001).

EU 2008. Environmental, economic and social impacts of the use of sewage sludge on land. Consultation Report on Options and Impacts. Report prepared by RPA, Milieu Ltd and WRC for the European Commission, DG Environment under Study Contract DG ENV.G.4/ETU/2008/0076r

Ghangrekar, M. M. at: www.waterandwastewater.com/www_services/ask_tom_archive/design_of_an_uasb_reactor.htm

Gustafsson, K. 2005. INFILTRA compact filter for treatment of wastewater - experiences during 1993 – 2004. Report, Water Revival Systems Uppsala Ltd, Uppsala. In Swedish. Available at http://www.ekotreat.se/Pdf/Kompaktfilter rapport.pdf

Henze, M., Harremoes, P., Arvin, E. and J. la Cour Jansen. 2002. *Wastewater treatment. Biological and chemical processes*. 3rd ed. Springer-Verlag, Berlin. 428 pp.

Jimenez, B., Mara, D., Carr, R., and K. Brissau 2010. Wastewater treatment for pathogen removal and nutrient conservaion: Suitable systems for use in Developing countries. In Drechsel, P. et al. (eds). Wastewater irrigation and health. Assessing and mitigating risk in low-income countries. Earthscan with International Development Research Centre (IDRC) and the International Water Management Institute (IWMI). London.

Mara, D, 2004. *Domestic Wastewater Treatment in Developing* Countries. 310 pages, Earthscan Publications, Limited

Mara, D. and Bos, R. 2010. Rsik analysis and Epidemiology: The 2006 WHO Guidelines for the Safe Use of Wastewater in Agriculture. In Derchsel et al (eds). Wastewater irrigation and health. Assessing and mitigating risk in low-income countries. Earthscan with International Development Research Centre (IDRC) and the International Water Management Institute (IWMI). London.

Qadir, M. and C. A. Scott 2010. Non-pathogenic trade-offs of wastewater irrigation. In Drechsel, P. et al. *Wastewater irrigation and health. Assessing and mitigating risk in low-income countries*. Earthscan with International Development Research Centre (IDRC) and the International Water Management Institute (IWMI). London.

Ridderstolpe, P. 2004. Introduction to greywater management. Report 2004-4, EcoSanRes Publication Series. Stockholm, Environment Institute, Stockholm. www.ecosanres.org

Sasse, L. 1998. Decentralised wastewater treatment in developing countries. BORDA, Bremen, 160 pp

Siegrist, RL, Tyler, EJ, Jenssen, PD (2000). Design and performance of onsite wastewater soil absorption systems. Prepared for National Research Needs Conference, Risk-Based Decision Making for Onsite Wastewater Treatment. St. Louise, Missouri, 19-20 May, Sponsored by United States Environmental Protection Agency, Electric Power Research Institutes Community.

Tchobanoglous, G. 1991. Wastewater Engineering, Treatment, Disposal, and Reuse, Irwin/McGraw-Hill, 1334 pp.

US. EPA on http://www.epa.gov/owow/wetlands/pdf/Design_Manual2000.pdf

US EPA, 2002. On-site wastewater treatment systems manual. EPA/625/R-00/008, US Environmental Protection Agency, Washington, USA. Available at http://www.epa.gov/owm/septic/pubs/septic_2002_osdm_all.pdf

US EPA 1977. Report to Congress: *Waste disposal practices and their effect on groundwater*. Report No. EPA 570/9-77-001, Washington, USA.

VMK 2009. Risk assessment of contaminants in sewage sludge applied on Norwegian soils. Norwegian Scientific Committee for Food Safety. 2009.

WHO 2006. *WHO Guidelines for safe use of wastewater, excreta and greywater*. Volume 1. Policy and Regulation Aspects. WHO. Geneva, Switzerland.

Vinnerås, B., Palmquist, H., Balmér, P., and Jönsson, H. 2006. The characteristics of household wastewarer and biodegradable solid waste – A proposal for new Swedish design values. *Urban Water Journa*l, Vol. 3, No. 1, March 2006, 3-11.

Vymazal, J. 2005a. Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. *Ecol. Eng*. 25: 478–490

Vymazal, J. 2005b. Removal of enteric bacteria in constructed treatment wetlands with emergent macrophytes: A review. *Journal of Environmental Science and Health*, 40:1355–1367)