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Introduction to Greywater Management

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Foreword

The water from kitchen, bath and laundry is known as greywater. In ecological sanitation (ecosan) systems this greywater is not mixed with human excreta. This reduces the problems with environmental impact but still the greywater has to be handled carefully to avoid waterlogging, freezing and smell, and the uncontrolled release of chemicals and anthropogenic elements including micro-organisms into the environment.

In rural areas the handling of greywater is seldom a big problem. Greywater volumes are small and their content of environmentally hazardous or infectious substances is low. Greywater can be infiltrated into the ground or reused, for example in the irrigation of fruit trees.

In urban areas the situation is different. Consumption of water and the use of household chemicals normally start to increase. More people and houses per surface area limit the space for taking care of the greywater and thereby increase the risk for environmental problems and human contact with the non-healthy water conditions. Thus in the town, careful design and maintanence of technical systems for collecting, treating and discharging greywater is needed.

The aim of the report is to give a comprehensive description of the main components in successful greywater management. The system perspective is emphasized, i.e. to prevent pollution by measures at the point of origin as well as using appropriate techniques for purifying water with the endeavour to reuse it or return it to nature in a responsible way. Examples as well as recommendations are given for designing and dimensioning treatment systems. It should be stressed that there is still little knowledge and experience of greywater treatment in urban areas and in different climates. Most experiences are from cold climate regions, but the rapid ongoing development in ecosan throughout the world will probably bring about a lot of new insights in the field in the coming years.

The report is written for the Swedish Research and Development project EcoSanRes. Parts of the text have also been written to serve as a chapter in the SIDA commissioned book, Ecological Sanitation, now in a second edition by Uno Winblad.

Ebba af Petersens, WRS has provided assistance in the work and Håkan Jönsson, Swedish University of Agricultural Sciences – SLU, has given valuable comments. The responsibility for the content of the report is entirely mine.

Peter Ridderstolpe

April 2004, Uppsala, Sweden

What is greywater and what does it contain?

All waste produced in the home except toilet waste (urine and faeces) is called greywater. Greywater from washing dishes, showers, sinks and laundry comprises the largest part of residential wastewater.

WATER AMOUNT

The amount of greywater produced in a household can vary greatly. While the water consumption in poor areas is about 20- 30 litres per person per day, a person in a richer area may generate several hundreds of litres a day. When planning for water and sanitation it is essential to control water consumption. People should be provided with fresh water for basic needs while unnecessary consumption should be prevented. An efficient use of water is crucial wherever the water resource is scarce, but efficient use of water also gives more options for cost-efficient and volume- and space-saving solutions for greywater treatment.

Fees for water consumption and introduction of water-saving technique in households will control water use. The development in the industrialized countries in Europe show that this is possible without jeopardizing the supply or comfort for the residents. After the Second World War, the cities developed and were provided with water and sanitation. During a couple of decades with unlimited access to water and an improved standard of living, the water consumption increased dramatically. After introducing fees for water consumption and new water-saving techniques, the use in Sweden went down from about 220 litres mean water consumption per person per day in 1980 to about 190 litres today (SCB, 2000). This change was achieved without limiting behaviour or comfort, through water-saving techniques that have replaced more expensive old techniques and the added incentive of a reasonable water price.

In greywater systems where we do not need to flush toilets and transport faecal matters, a lot of water can be spared. New-built house areas in Germany, Norway and Sweden today demonstrate greywater production of less than 100 litres per person per day. In the eco-village Flintenbreite in Lubeck, where water-saving equipment is in use, the mean greywater production is measured to about 60 l/person/day (Oldenburg, OtterWasser Gmbh, 2003: pers. comm.).

SUSPENDED SOLIDS AND BIODEGRADABLE ORGANIC COMPOUNDS

The composition of greywater varies greatly and reflects the lifestyle of the residents and the choice of household chemicals for washing-up, laundry etc. Characteristic of greywater is that it often contains high concentrations of easily degradable organic material, i.e. fat, oil and other organic substances from cooking, residues from soap and tensides from detergents.

PATHOGENS

The proportion of pathogens in greywater is generally low. Pathogens are primarily added to wastewater with the faeces. The risk of infection is a function of the faecal contamination of the water. As greywater does not contain faeces, it is normally regarded as rather harmless (Stenström, 1996). Still, many public authorities around the world regard greywater as a health hazard. One explanation for this is that high numbers of indicator bacteria are usually found in greywater. Recent research has proved that growth of enteric bacteria such as the faecal indicators is favoured in greywater due to its content of easily degradable organic compounds. Thus a focus on bacterial indicator numbers leads to an overestimation of faecal loads and, thereby, the hygienic risk. Furthermore, the fact that greywater easily turns anaerobic and thus creates very bad odours, may have led to the wrong conclusion that greywater is a health hazard.

In recent years, other methods have been developed to assess the hygienic quality of water. By measuring chemical biomarkers in wastewater, such as faecal sterols, a more appropriate value of the faecal contamination is given. Investigation of a local treatment system at Vibyåsen, north of Stockholm, concluded that conventional measurements using traditional bacteria indicators overestimated the faecal load by 100–1000 fold compared with measurements using chemical biomarkers. Based on measured coprostanol, the faecal contamination to the greywater in Vibyåsen was estimated as 0.04 grams per person per day (Ottosson, 2003).

Since normal faecal load in mixed wastewater from households is about 150 grams per person per day, the treated greywater in Vibyåsen poses only a fraction of the risk of normal wastewater. If mixed wastewater is to be treated to this level of hygiene risk, then 99.97 % of pathogens must be removed. Such pathogen removal efficiency is, in practice, not achievable by conventional treatment. A well-functioning wastewater treatment plant including mechanical, chemical and biological steps should not be expected to remove more than 90–99% of incoming pathogens (SWEP, 1992).

One important conclusion from this discussion is that untreated greywater can be expected to contain far lower densities of pathogens than effluent water from an advanced wastewater treatment plant. Treated greywater can thus be expected to have a much better hygiene quality than any kind of mixed wastewater, as shown in figure 1.

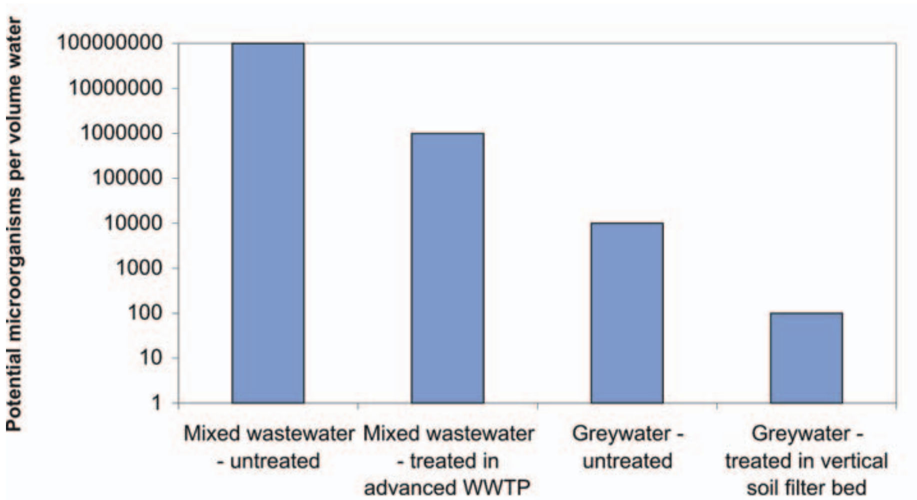

Figure 1. Comparing levels of potential pathogens in different waters. Levels of pathogens in the untreated waters are based on measured faecal load to greywater in Vibyåsen, Sweden, compared to the faecal contamination in normal mixed wastewater. Different empirical data is used for assessing the levels of pathogens in the treated waters (see text above).

NUTRIENTS

Greywater normally contains low levels of nutrients compared with normal wastewater from water-borne systems. Levels of nitrogen and other plant nutrients are always low, but in some greywater high concentrations of phosphorous can be found (Swedish EPA, 1995). This phosphorous originates from washing and dish-washing powder, where it is used for softening the water. Washing and dish-washing powders without phosphorous are available on the market. In general, these are as cheap and effective as those containing phosphorous, which makes choosing P-free detergents a sensible option. If people use only P-free detergents, the phosphorus content of the greywater should be reduced to levels lower than normally found in an advanced treated wastewater. Some progressive countries (e.g. Norway) and some cities in East Asia have banned washing powder containing phosphorous for water protection. This explains why the levels of phosphorous in greywater in Norway are only 10-20% of the levels normally found in Sweden (table 1).

Table 1. Specific loads and levels of oxygen-demanding compounds and nutrients in European greywater. Amounts of different compounds are compared to normal mixed wastewater in Sweden (Otterpohl, 2003; Ludwig, 1994; Jensson & Heistad, 2000).

Substance	Specific load	Concentration	Amount compared with mixed wastewater
BOD7	20-30 g/pd	150-400 mg/l	60-70%
Nitrogen (N)	0.8-1.2 g/pd	0.5-15 mg/l	5-10%
Phosphorous (P)	0.2-1 g/pd	1-10 mg/l	10-50%

METALS AND OTHER TOXIC POLLUTANTS

The content of metals and organic pollutants in greywater is generally low, but can increase due to addition of environmentally hazardous substances.

The levels of metals in greywater are for most substances approximately the same as in a mixed wastewater from a household, whereas for zinc and mercury the levels are lower (Vinnerås, 2001). Metals in greywater originate from the water itself, from corrosion of the pipe system and from dust, cutlery, dyes and shampoos etc. used in the household.

Most organic pollutants in the wastewater are found in the greywater fraction, hence the levels are in the same concentration range as in a mixed household wastewater. Organic pollutants are present in many of our ordinary household chemicals, e.g. shampoos, perfumes, preservatives, dyes and cleaners (Eriksson, 2002). They can also be found in furnishing fabrics, glue, detergents and floor coatings.

The content of metals and organic pollutants in greywater is heavily affected by human behaviour. By using environmentally-friendly household chemicals, and not pouring hazardous substances such as paint, solvents etc. into the washbasin, the levels of metals and organic pollutants in greywater can be kept low.

Main components to consider in greywater management

The objectives for greywater management can be summarized as:

- To avoid damage to buildings and surrounding areas from inundation, waterlogging and freezing.
- To avoid the creation of bad odours, stagnant water and breeding sites for mosquitoes etc.
- To prevent eutrophication of sensitive surface waters.
- To prevent contamination of groundwater and drinking water reservoirs.
- To use greywater as a resource for plant growth, groundwater reclamation and landscaping.

Successful management of greywater involves technical aspects, such as a proper designing and dimensioning of the different technical components involved. Equally important, however, are the 'soft' aspects of the system, such as user participation in running and maintaining the system.

When planning a greywater system all parts of the system from the point of origin to the recipients should be considered. The technical system can be divided into the following components (figure 2):

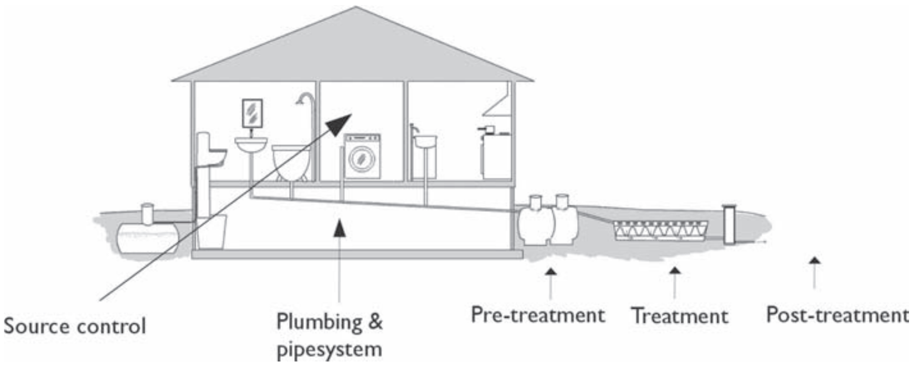

Figure 2. Components of a greywater management system.

SOURCE CONTROL

Any strategy for managing greywater will be made easier by water-conservation measures as well as attention to soaps, cleansers and other household chemicals. Preventing the need for treatment, by measures at household level that reduce and control hydraulic and pollution loads, should be seen as a vital part in all greywater management.

Hydraulic load, the load of easily degradable organic matters and BOD (biochemical oxygen demand), are the main criteria used for dimensioning a greywater system. Technical components such as septic tanks, sand filters, soil infiltration systems or other treatment applications are dimensioned from load of water and BOD. Reducing these parameters at the point of origin gives more options for cost efficient and volume- and area-saving solutions. Source control also makes taking care of the system more robust and efficient in terms of purification.

To reach and control a conservative use of water, experience shows that water-saving equipment (figure 3) installed in households should be combined with economical incentives, i.e. a charging system for water consumed. By combining technical and economical tools for water conservation, greywater production can be reduced significantly without jeopardizing comfort and hygienic standard for the users. Progressive planning for urban sanitation today should allow for a maximum of 80 litres of greywater per person per day, as a mean figure.

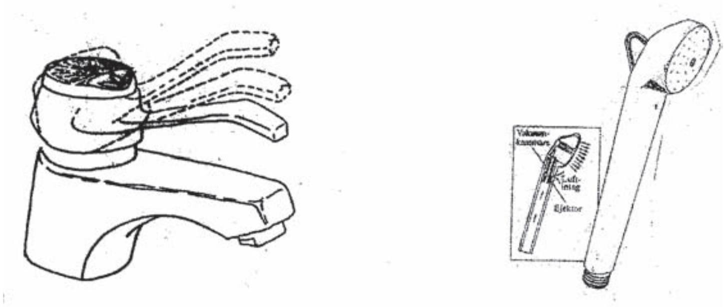

Figure 3. By using water-saving equipment such as mixer taps and water-saving shower nozzles, water consumption can be reduced considerably. The left diagram shows a Swedish technique for a tap where water flow and temperature can be regulated easily. The diagram to the right illustrates how an injector technique can be used in showers for mixing air into water and therefore reduce water consumption. Consequently, the energy consumption for producing hot water is also reduced. In Sweden, the average water consumption has decreased from 220 l/pd (1965) to 190 l/pd (150 l/pd in new houses), mainly due to the development of less water-consuming washing machines, dishwashers etc. The greywater production in new settlements in Sweden is around 100 l/pd, whereas in a German eco-village, where water price and user participation are higher, 60 l/pd is the average greywater volume.

BOD load should be controlled on household level. Such control includes information regarding proper behaviour and appropriate design of the system. In the industrialized countries, overdosing of detergents as well as intensive use of shampoos, shower oils etc. is common and is responsible for the increased levels of BOD often observed in wastewater in recent years. Correct use of these products is thus an important part of greywater management. BOD levels in greywater are also a function of grease and oil used in food preparation. Hot greasy liquids from cooking and frying should, if possible, be cooled before throwing into the sink. This reduces BOD- pollution to water and also prevents the pipe system from clogging.

All larger particles, fibres and grease, should as far as possible be removed to prevent clogging of the pipe system. Kitchen sinks, showers, tubes, washing machines and other equipment must always be equipped with appropriate screens, filters or water traps. For kitchen wastewater from restaurants and in households where a lot of grease and oil is handled for food preparation, it can be necessary to install special grease traps to protect the pipe system from clogging (see below).

As mentioned above, high levels of organic matter, phosphorus, toxic organic substances and heavy metals sometimes found in greywater, originate largely from detergents and other chemicals used in households. It makes sense, since these elements influence the biological systems downstream, to always prevent them at the source. Greywater management should therefore involve information regarding, for example, which household chemicals are environmentally friendly. Often there are good substitutes to environmentally non-friendly household chemicals. For example, low phosphorus washing and dish-washing powders can easily be used instead of those containing large amounts of phosphorus (figure 4). In cases where greywater is used or considered for irrigation, liquid soaps containing potassium should be preferred to hard soaps. This is because hard soaps often contain sodium which increases the risk of soil salinization. Chlorine is very toxic and persistent and should therefore be substituted with biodegradable cleaning chemicals.

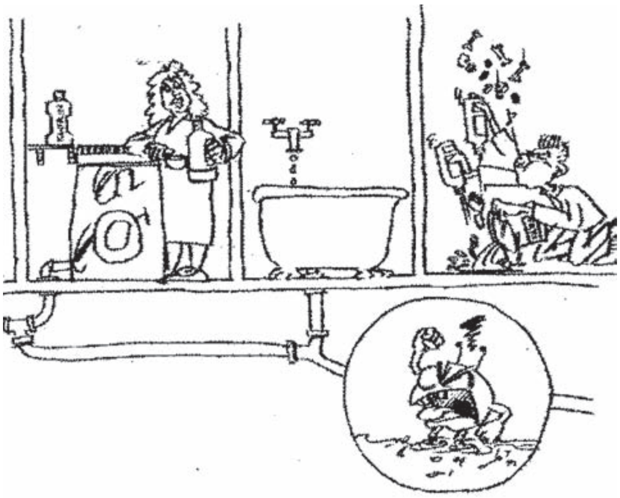

Figure 4. User participation is important for successful greywater management. Using environmentally friendly washing and dish-washing powders and responsible behaviour reduce pollution and need for treatment significantly. It is important that the user learns that the sewage system is not a sink for all waste products. Toxic chemicals should always be avoided. Chlorine is still common in many countries but it is a harmful chemical not only for the environment but also for the micro-organisms we want to use for treatment (drawing: Per Hardestam, Karlstad Reklam AB).

PLUMBING AND PIPE SYSTEM

A pipe system is always needed to collect and lead water to where is treated or used. Designing and plumbing a collecting system is similar for greywater and mixed wastewater. As there is no need for transporting toilet waste, thinner pipes can be used for greywater compared to mixed wastewater. All pipe systems must be equipped with ventilation for air and smell evacuation. Normally a self-ventilating pipe arranged as a chimney above the roof is enough for this. Bad odours will sooner or later arise in the collecting system. Therefore all pipe connections in the house must be equipped with water traps.

Clogging from fats is a potential risk in greywater systems that must always be considered, especially when the pipe system is enlarged and water cools in the ground. Pipes must be put straight (no necks or depressions) with gradient of at least 0.5 % (i.e. 5 mm/m). The pipe system must always be equipped with flushing pipes/wells if clogging could occur.

In smaller systems, direct use is often the most appropriate option for taking care of greywater. In these systems greywater is led directly to a mulch bed where water is used for growing plants or trees. Such a system must be designed and dimensioned so that water and its contents can be assimilated by the soil-ecosystem.

An appropriate solution in such a system is to connect each source of greywater to an individual mulch bed. Then the pipe system can be arranged very simply, and no flow splitter would have to be used. In countries with cold winters and water shortage, as in Northern

China, a summer/winter system should be considered. Such a system can be operated for direct use in the summertime and for treatment and percolation to groundwater in the wintertime.

PRE-TREATMENT

Need for special technical components for pre-treatment and treatment arise as soon as greywater is collected in larger pipe systems or stored for longer periods. Without such pre-treatment the fats and other biodegradable organic compounds will clog the system or create bad odours. In pre-treatment, suspended solids (SS) are removed mechanically by gravity, screens, filters or similar. The need for SS removal (design of pre-treatment) depends on how the water will be treated and used. The septic tank concept is an efficient and reliable technique, which is very useful in soil infiltration systems in more densely populated areas. It is described below.

The septic tank system

A septic tank is constructed for gravimetric separation of particles from the water. Floating particles are collected as a scum in the top of the tank and sinking particles are collected as sludge at the bottom.

A septic tank is usually constructed in watertight concrete or plastic (figure 5). Larger volume tanks can be constructed with bricks or excavated ponds sealed with a rubber membrane can be used. Attention must always be taken of the risk for leakage and smell. Therefore tanks must be sealed to the ground and to the air. If connected to a gravity system (water running by gravity) the tank should be ventilated through the incoming pipe. When designing, access for sludge removal must be considered.

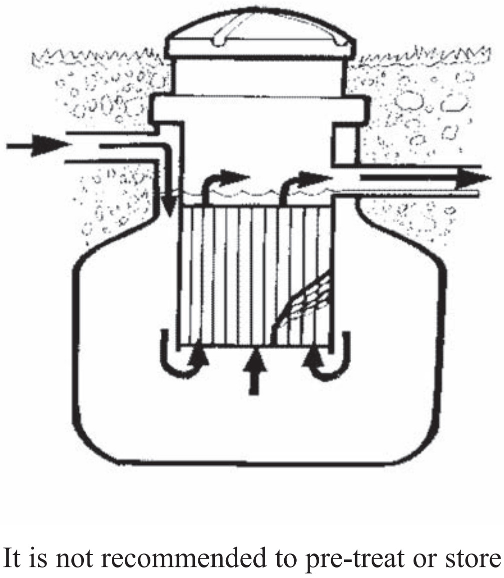

Figure 5. A septic tank for greywater pre-treatment should be constructed with one or several chambers. The first chamber should be the largest and constructed with storage volume at the top since much of the sludge is floating. An effluent filter applied in a vertical outlet tube, improves security for sludge flight (drawing: WM-Ekologen/P. Ridderstolpe).

It is not recommended to pre-treat or store untreated greywater in open ponds. Such ponds will look unpleasant and create odours. Also storage of untreated greywater will serve as a perfect environment for bacteria and mosquitoes.

Dimensioning a septic tank is decided from water load and volume preferred for sludge storage. The following design criteria can be seen as a rule of a thumb:

1. Surface hydraulic load should be less than 0.5 m3/m2. Hydraulic load is calculated from expected maximum momentaneous flow. Surface is calculated from mean surface area in the tank.

2. Time for sedimentation (retention time) should be more than 6 hours. Volume for detention is calculated from maximum momentaneous flow.

3. Enough volume for sludge must be secured. The sludge production probably differs from different kinds of households. In a high standard household, a primary sludge volume of about 50 kg per person a year can be used for rough estimation. If space is conserved in the tank for long periods of storing (many years) the yearly sludge production will decrease due to mineralisation and compaction.

When dimensioning and designing septic tanks, the risk for re-suspension of sludge should be taken into consideration. Therefore it is often a good idea to dimension with extra volume and possibly, as illustrated in figure 5, to use an effluent filter (coalescens filter) for the outlet water.

Screens, seals and filters

Different pre-treatment techniques based on screens, seals and filters are available on the market. Such prefabricated techniques are useful in large wastewater systems and in special applications such as drop-irrigation systems. For the ordinary applications, they will seldom be found reliable enough or as cost efficient as septic tanks.

Home-made seals or filters constructed of gravel may be appropriate in the very small scale. For example, in rural areas in warm climates an open gravel filter combined with soil infiltration is often a very good greywater solution.

TREATMENT

Greywater compared with mixed wastewater is harmless from an environmental and hygienic point of view. Problems connected with greywater are relatively small and local. On the other hand, if not managed properly, greywater will be a strong source for smell. A primary target should therefore be to remove the high levels of easily degradable compounds that are responsible for this. This must be done quickly since anaerobic conditions and odours will occur very soon (within hours if warm). It should be required that wherever greywater is freely exposed to people, it should first be treated to secure that BOD do not cause anaerobic conditions.

A secondary target, is to reduce levels of pathogens and other micro-organisms in the water. A further ambition for treatment and post-treatment (see below) should be to reduce levels of organic pollutants and heavy metals. This is especially important when greywater is used for groundwater recharge and for irrigation.

Normally the most appropriate measure for achieving the above targets is to use aerobic attached biofilm techniques. Typically in these techniques biological degradation of organic matters takes place in aerated conditions. Attached biofilm techniques can conceptually be ranged in a continuum from the extensive land application systems to the intensive applications such as trickling filters and biorotors (figure 6).

Aquatic systems such as ponds and wetlands will, in some locations, be found appropriate for greywater management. They are simple to construct and operate, but are not always the best solution to solve the wastewater problem. In countries with cold winter climates and in areas where water is scarce, ponds and wetlands should be questioned. On the other hand, where the climate condition is favourable (no freezing and no long dark periods) aquatic systems could serve as an appropriate solution for greywater treatment. This is especially the case if the aquatic biomass can be harvested and sold at the market.

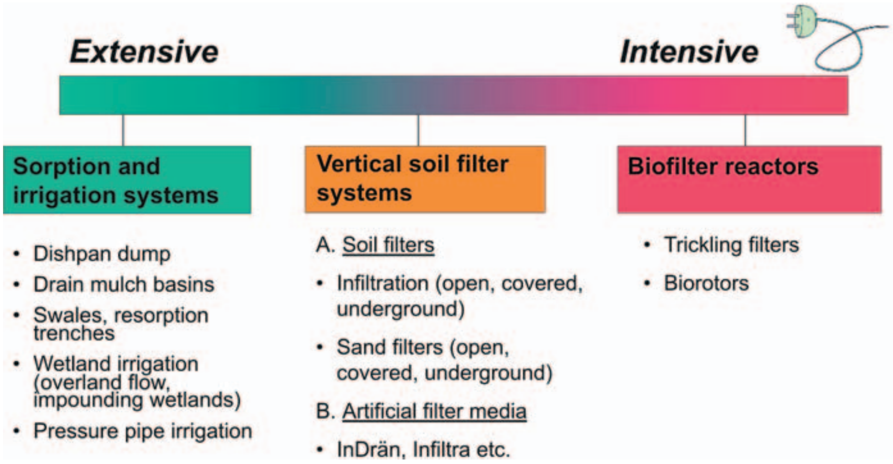

Figure 6. Examples of aerobic attached biofilm techniques ranged in a continuum from extensive to intensive applications. Energy used for running the treatment processes in the examples on the left side is provided by the sun and the carbohydrates within the water; instead of artificial energy they need large land areas. On the right side, intensive applications are found. These systems are compact but need electricity to work. Furthermore, sludge is produced that has to be handled. The systems in the middle need a minimum of artificial added energy and produce no or very little sludge. These systems use soil as filter media and are often found to be the most appropriate solutions for greywater treatment.

Sorption and irrigation

Sorption and irrigation systems (slow rate systems) use a soil ecosystem to convert polluted water into valuable plant production. These systems should therefore be dimensioned from the need of the green plants. Hydraulic loads vary typically from 2-15 litres per square metre and day (l/m2/day) depending on the evapotranspiration rate. Too much water may lead to saturated conditions in the soil, something that many crops will suffer from. On the other hand, too little water also stresses the plants and makes them sensitive. In arid climates, too little water may also lead to soil salinization.

Dishpan dump, drain mulch basins and similar simple applications of direct use do not need pre-treatment. Figure 7 illustrates direct application of greywater to a mulch bed. The mulch bed is constructed beside a tree or a berry bush. The bed is excavated and filled with gravel, bark or wood chips. The application device and the design of the bed must secure water to be spread all over the area without clogging the inlet. Water load must be calculated from the need of the plant. Overload will lead to reduced or damaged plant growth. Normally water is applied by gravity but a pressurised system can also be used.

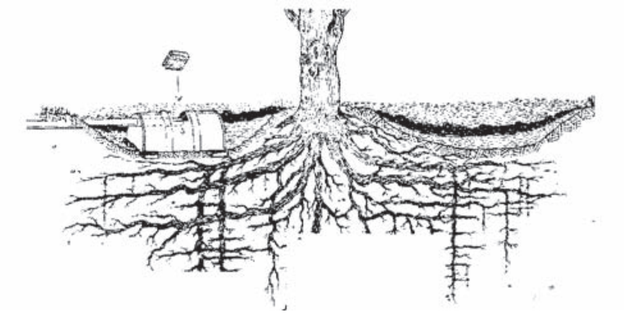

Figure 7. In direct use, different greywater sources are often treated separately and without any pre-treatment. In the diagram, water enters a mulch bed constructed for irrigating a tree. Water should be applied below surface into coerce substrate (typical wood chips or gravel). The application point should be arranged separately from the substrate to protect the pipe from being clogged. The application point should also be constructed to allow inspection and service, as illustrated (Ludwig, 1994).

A simple and robust technique for a pressurised system is to use is to use a pump-sump from where water is pumped by a submerged pump regulated by water level control. The pump-sump should be equipped with some kind of a straining facility to get rid of coarse material, especially fibres such as hair or plastics that will otherwise easily damage the pump or the irrigation system. An appropriate system for irrigation is a flexible man-manoeuvred hose system or plastic pipe system laying on the ground with drilled holes. Drip irrigation or using nozzles with smaller orifices than 6-8 mm is not to be recommended.

As mentioned above, greywater will rapidly turn anaerobic when stored. Therefore a pump-sump should not be dimensioned to have a retention time longer than six to ten hours.

Vertical soil filter systems

Soil filter systems are often appropriate for greywater treatment. In literature various names are found for these systems: rapid infiltration systems, high rate systems or vertical soil filter systems. Green plants can be found in these systems, but they do not play any essential role for purification.

Polluted water is typically applied to the filter from the top, whereupon it pours down through the media vertically by gravity. To work properly, the water should percolate through the soil in an unsaturated flow. In such a flow water pours hygroscopically within the finest pores while the bigger pores are left open and aerated. This is essential for the treatment capacity because the filtering capacity and the aeration to bacteria is much better than in a soil with saturated condition (figure 8).

Figure 8. Unsaturated flow (left) gives better filtration and oxygenation of the water than saturated flow (right) (Jensson & Heistad, 2000).

It should be mentioned that the concept ‘constructed wetland’ often seen in literature, creates some confusion and misunderstanding. A soil filter for SS and BOD removal should not be designed and operated as wetland. A soil saturated or impounded with water has a limited capacity for SS removal and more or less no capacity for gas exchange. Today most engineers constructing wetlands for wastewater treatment in Europe, use the vertical flow principle where water should seep in unsaturated flow. Wetland plants may cover the filters but still the soil must be aerated. A more appropriate name for constructed wetlands is therefore proposed: ‘planted vertical soil filters’.

Figure 9. Vertical soil filter planted with common reed used for greywater treatment in an ecological residential area, Hamburg, Germany. The water is applied from the top and percolates vertically through the bed in an unsaturated flow. The dimensioned load is 60 l/m2/day (photo: P. Ridderstolpe).

If appropriately designed and operated, a soil filter has a high removal efficiency for suspended solids and organic compounds. Removal efficiency for SS and BOD is typically around 90-99%. Bacteria and virus removal is also proved to be high. 95-99% removal can be expected for most pathogens (Ziebell, 1975; Swedish EPA, 1987; Stevik et al., 1999).

In natural soil filter systems, phosphorus and heavy metal removal is significant. Depending on soil property, depth of unsaturated zone and wastewater load, removal efficiency of phosphorus in a soil filter can be estimated as 30-95% during its lifetime (25-30 years). Nitrogen is reduced in a soil filter bed by nitrification and denitrification.

Soil filters fed by mixed wastewater typically show a nitrogen removal efficiency of about 30%. Vertical soil filter systems are dimensioned based upon the hydraulic load and the BOD load. Typical loads for soil infiltration filters are 40-80 l/m2/day or 4-6 g BOD m2/day. To be used for filtering, the soil must be neither too coarsely nor too finely textured. Normally the levels of fine particles decide the suitability for infiltration, since too many fine particles will make the soil clog. As a rule of thumb, the fraction of fine sand (i.e. particles less than 0.125 mm in diameter) should not exceed 10%. High levels of soft and easily weathered minerals will also contribute to the risk of clogging.

Texture should be analysed in a laboratory, but a rough estimation test on the fine sand content in a particular soil can be given if a sample of soil is put into a jar of water and then shaken. After one day of sedimentation (the jar is put in a calm place) the tail of fine particles can be seen as an upper fine layer distinct separate from sand and coarse material beneath.

Where it is found that the natural soil is not appropriate for infiltration, its capacity can be improved by using filter sand as an infiltration layer. Filter sand used for improving infiltration capacity should originate from hard rock and should contain spherical particles ideally around 1-2 mm in diameter. A soil filter entirely constructed with artificial sand and supplied with a drainage layer in the bottom for collecting and discharging treated water is called a sand filter (figure 10). Sand filters should be used where natural soil cannot be used or where groundwater should not be used as a recipient for treated water.

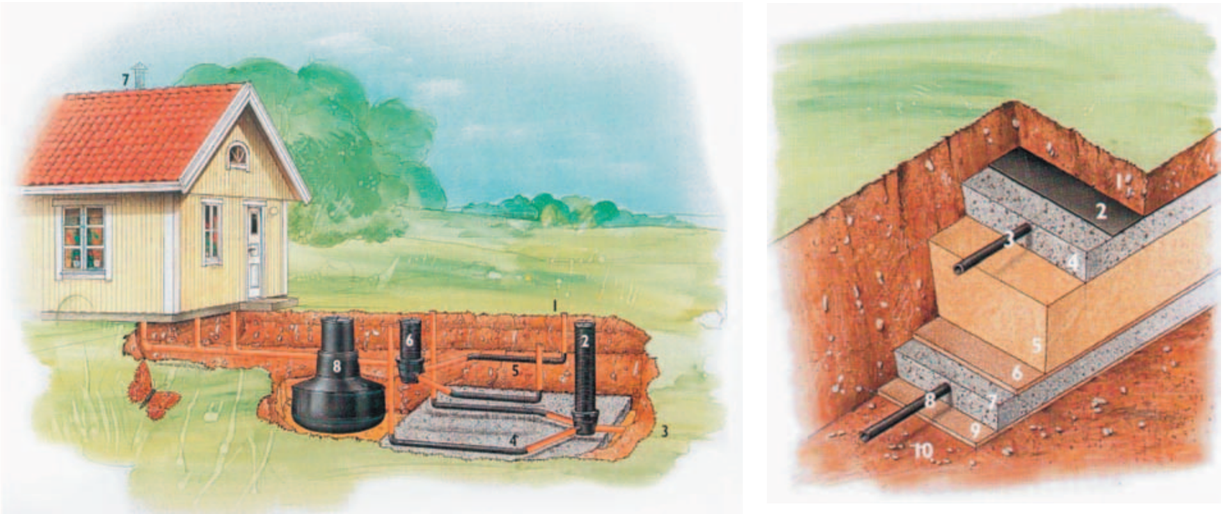

Figure 10. Design of a typical conventional sand filter system for onsite solution used in Sweden. Diagram to the left: 1. Flushing pipe connected to distribution pipe, 2. Collecting (measuring) well, 3. Discharge pipe, 4. Drainage pipe, 5. Distributing pipe, 6. Distributing (flow splitting) well, 7. Ventilation chimney, 8. Septic tank.

Diagram to the right: 1. Refilling (with isolation), 2. Separating layer (geotextile), 3. Distribution layer, 4. Distributing pipe, 5. Filter sand, 6. Separating sand layer, 7. Drainage layer, 8. Drainage pipe, 9. Underlay (with sealing), 10. Original soil. (IFÖ Sanitär AB)

Gravity systems are preferable in small applications. It is a good idea to put the filter as close to the ground as possible. This reduces the excavation work and makes the filter more accessible for retrofitting. It also creates a longer safety buffer to groundwater. A buffer layer of at least one metre of unsaturated soil between water application and groundwater should be seen as a minimum degree of safety.

It is often problematic, when working with soil filter systems, to spread the water evenly on the surface. Uneven distribution causes deep clogging zones where no or little treatment takes place, while the main part of the filter is left unused. In the worst case, the water will seep by plug flows (flow of water in big pores) straight to the groundwater with no or little pollutant removal.

In gravity systems, one way to overcome the problem is to use so-called 'controlled clogging' as a measure for self-helping distribution. Controlled clogging is achieved by digging the infiltration as a narrow trench and allowing the bottom be clogged with biofilm (a mucus layer of aerobic and anaerobic heterotrophic bacteria). When the bottom of the trench starts to clog, water will impound and spread horizontally and infiltration of water will take place along the walls of trench. In the interface between water and the soil of the trench wall, an active aerobic bacteria community develops ensuring decomposition of organic pollutants.

The controlled clogging also helps to buffer water loads. When loaded, the water level will rise some centimetres and when lowered the water level sinks.

The principle of controlled clogging has been used in some artificial filter media techniques. Such a filter can be constructed of a folded geo-textile creating a filter structure of many communicating valleys and ridges (figure 11). Such an artificial filter can be constructed in a multi-layer structure enabling a very compact design.

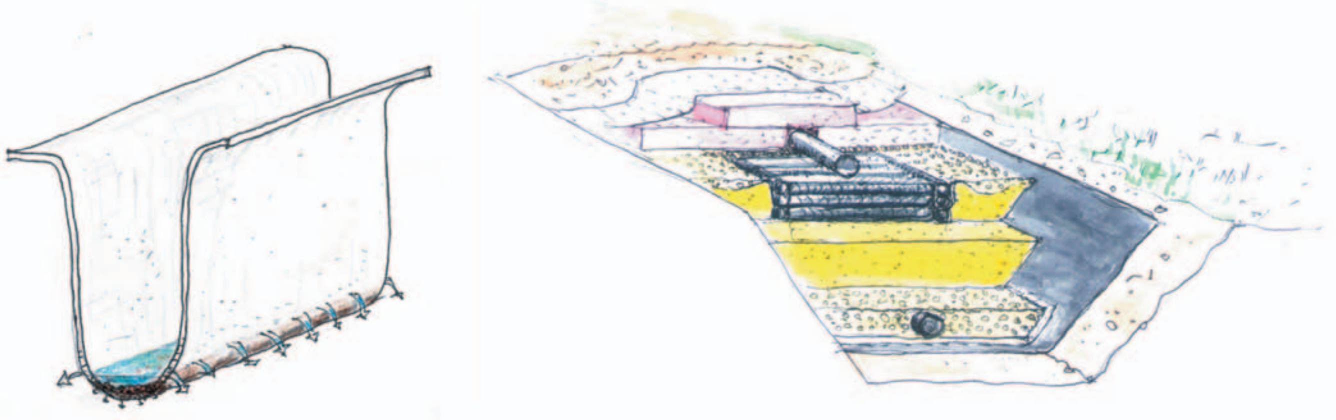

Figure 11. The principle of controlled clogging used in some artificial filter media techniques. The diagram shows how the principle of controlled clogging can be used in vertical soil filter systems. On the right the artificial filter media (Infiltra) is arranged in a sand filter bed. The construction allows the biofilm to grow on foamed geotextile (diagram on the left) enabling water to be biologically treated and evenly distributed over the sand surface. (Ridderstolpe, P, Firma Ekologisk Teknik. Infiltra Compact Filterbed)

In larger soil treatment facilities spreading by gravity is difficult and should not be recommended. Where topography permits, mechanical flushing mechanisms or siphons can be use to help distribute water, but normally using an electric pump is a cheaper and more flexible and reliable option. By taking advantage of the pressure created using an electric pump, it is possible and wise to design filters with an open and therefore accessible sand surface. This enables service and control. In larger systems it is also often a good idea to construct the treatment with several separate lines to facilitate repairs and servicing.

Filtering effects, as well as the biological purification process in a sand filter, work better the more evenly the water can be spread over the surface and over the time. In reality, practical limitations make it necessary to dose a filter intermittently. A pump-sump with a certain volume and a regulation device for steering the pump is always necessary. Distribution of water to the filter can be performed by different techniques. Three main options are common in soil filter applications:

1. Surface flooding

Water is applied to the filter from a centrally-located vertical distributing pipe. Quite a high amount of water must be distributed in a short period to make the water evenly overflow the whole filter area. As rule of a thumb, the dose of water should correspond to a 5 cm water column, calculated from area to be flooded, applied in five minutes. To avoid plug flows, the filter sand should not be too coarse, instead it should contain quite a large tail of fine texture fractions. This is a robust technique also applicable in cold climates. To avoid freezing, water must be drawn back to the pump-sump after dosing.

Figure 12. Open sand filter bed in Alsen, Krokom municipality in Sweden. Pre-treated wastewater is distributed on the surface by flooding (Photo: E. af Petersens).

2. Water application from perforated horizontal pipes and drop irrigation

The most common and reliable system is to use plastic pipes with drilled holes. Pipes are typically located in a distributing layer of coarse material, for example macadam, on the filter media. A pipe system with drilled holes is simple to construct and easy to operate and maintain. A benefit compared to the flooding technique is that water can be added in smaller doses. This is beneficial for purification and also requires less volume in the pump-sump.

Drop irrigation is a sophisticated method for water distribution, primarily developed for irrigation. The system has been used in greywater treatment but is quite sensitive to clogging. It put high demands on efficient pre-treatment and needs servicing regularly, e.g. to flush out secondary growth of biofilms. Drop irrigation should not be considered as a first option in greywater treatment.

Figure 13. Plastic pipes for distributing water in wastewater irrigation in Salix, Enköping, Sweden. The nearest pipe uses drilled holes for water distribution, while the pipe behind uses the drop irrigation technique (Photo: P. Ridderstolpe)

3. Spraying techniques

Distributing water by sprinklers is common in irrigation and in conventional waste treatment engineering, for example using trickling filters. This technology can also be used to spread water on a sand filter surface. A spraying technique recently developed in Norway has proved to be feasible and very efficient in greywater treatment. In this technique water is distributed by nozzles adapted 0.5-1 m above the filter media. To protect the environment from aerosols and the water from freezing when cold, the nozzles are typically sheltered in domes covered with wood chips. In larger applications the filter and the application system can be located indoors, e.g. in a greenhouse.

The use of a turbulent chamber technique allows for wide orifice nozzles (5-6 mm) where risk for clogging can be managed. The distribution of water is, compared to the above methods, much more efficient. It uses a coarser filter media (4-6 mm). Due to this and the aeration during spraying where toxic gas (hydrogen sulphate) is removed, treatment is also secured in high load conditions. The Norwegians suggest dimensioning for a load of about 200 l/m2/day, but the capacity for loads can probably be allowed to be significantly higher (Arve Heistad, pers. comm.).

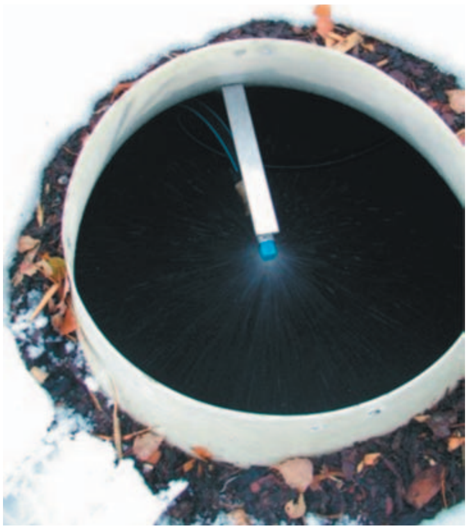

Figure 14. Spraying techniques improve soil filter techniques by efficient distribution and aeration or anaerobic water from sulphur hydrogen. A technique developed in Norway uses turbulent chambers spraying with 5-6 mm orifices. The nozzles can be installed in domes (like in the picture) or in a simple greenhouse or similar. Picture from Ångersjön, Hudiksvall, Sweden (photo P. Ridderstolpe).

Experiences from Norway show that the spraying technique in a vertical soil filter, combined with horizontal filtering in a porous reactive filter media for phosphorous removal, is a compact and low maintenance system that also constitutes attractive landscape elements. At Klosterenga in Oslo, an onsite system has been constructed to serve a block of houses. The facility has been effectively integrated with a playground and landscaping in the courtyard beside the houses (Jenssen, 2004) (figure 15).

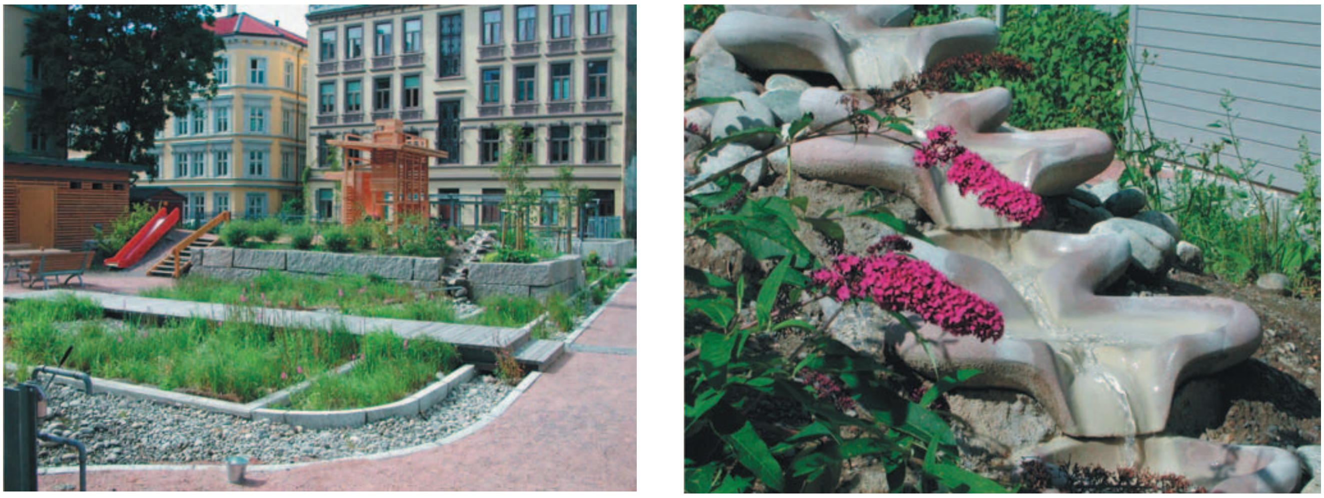

Figure 15. At Klosterenga in Oslo, an onsite greywater system constructed serving a block of houses. The facility integrates a playground and attractive landscaping (photos used by permission of P Jenssen).

Trickling filter and rotating biological contractors (biorotors)

These systems purify water by using attached biofilm in filters heavily loaded with water. In a trickling filter, the water is flushed over the filter media by rotating arms or nozzles. The filter is constructed of, or filled with, a strong filter media with a large surface area and big pores so that it is not clogged by biofilm. Earlier applications used brick towers filled with round stones but today prefabricated plastic material has more or less replaced the stone filters (figure 16).

Figure 16. The trickling filter is a well-proved and robust technique for biological treatment of BOD-polluted water. Earlier applications used stones but today plastic media is more common. (Photos: left from Metcalf & Eddy (1989), right from P. Ridderstolpe)

It is important that the water distributed on the filter is flushed at a certain intensity so that the old rather than the living biofilm is removed from filter media. To achieve high enough flush intensity, water is therefore recirculated over the filter. This also means that water can be treated over and over again. Normally a trickling filter constructed with artificial plastic media is designed for a recirculating ratio of 2 or 3 and a hydraulic load of about 20-200 m3/m2 per day. This means that tricking filters compared to soil filters are very compact, however they cannot achieve the same level of removal efficiencies as soil filters. A sludge is also produced that must be taken care of.

In rotating biological contractors (biorotors), the media is mechanically rolled up and down in the water. Thus the biofilm is fed intermittently by water, organic matter and air. As in a trickling filter, sludge is produced. The maximum BOD removal efficiency in trickling filters and biorotors is about 80%.

The sludge produced from trickling filters and biorotors can be managed in many ways. A well-proved and natural way to dewater the sludge is to use so-called drainage beds. If such a bed is planted with reeds or other helophytes, the sludge will be converted to a substrate similar to humus. It has been proved that concentrated blackwater (toilet waste) and sludge from conventional treatment plants can be composted in reed drainage beds to form useful organic soil with a significantly lowered level of pathogens (Pabsch et al., 2003).

Figure 17. Sludge drainage beds are a well-proved method for sewage sludge management. With the planting of plants (e.g. common reed) a valuable humus soil is produced.

END USES AND POST-TREATMENT (PRECAUTIONS)

After treatment the water is used for irrigation or brought back to nature. The following recipients (end uses) can be identified:

1. Discharge to surface water
2. Percolation to groundwater
3. Use in irrigation

Discharge to surface water

This is often the easiest and most natural way to return the treated greywater to the environment. If the water is treated in a soil filter or a trickling filter, it can normally be discharged without inconvenience in open ditches and soak away together with stormwater. Treated greywater can be used for 'landscaping', i.e. creation of wetlands and dams in parks. It should be observed though that the water, in spite of the treatment, might still contain levels of oxygen-consuming or fertilizing substances to high to produce an attractive and stable aquatic ecosystem. In such a case, the treated greywater would have to be polished (or post-treated) for example by letting water trickle through the root zone in an open trench before discharging into the open pond environment.

Percolation to groundwater

When treated greywater is returned to the groundwater, the following precautions should be taken:

- The greywater must be treated with tested and reliable methods.
- After treatment the water should percolate through the ground in an unsaturated zone of one metre or more. The subsoil should consist of sand (or smaller grain size).
- Safety zones around water extraction wells should be adhered to. As a rule of a thumb, a one-month retention time in a saturated zone must be secured before water extraction. The limit of the safety zone must be determined according to local geohydrological conditions.

Use in irrigation

When the greywater is used for irrigation special precautions are required. There are as yet no official guidelines worked out for greywater irrigation, but the following recommendations should always be followed:

- Method of application: Water should be applied on the ground or sub-surface rather than sprinkled.
- Choice of crop: Crops where leaves or stems are not eaten directly, such as fruit trees, berry bushes etc., are suitable for irrigation. Vegetables where leaves or stem are directly consumed, such as salad and mangold, should be avoided.
- Waiting period: When irrigating crops where leaves and stems are directly consumed, a waiting time of at least four weeks between irrigation and harvest is recommended.

Finding the right solution

The choice of greywater management system depends on a number of factors such as climate, density and type of habitation, land-use patterns, existing drainage systems, degree of pollution and the sensitivity of the recipient. The requirements for treatment and other precautions are governed very much by how the greywater is regarded in the area from an environmental and public health point of view. The best solution must therefore suit the local conditions and consider the potential risks the different techniques bring about. It is recommended to always study and compare different alternative solutions when planning for new or retrofitting old systems. It recommended that solutions, new in the area or innovative in general, always should be tested and evaluated in a small scale before implementing on a large scale.

When planning for new wastewater treatment, different tools can be used to facilitate the planning process. The ‘open wastewater planning’ method suggests that to find the right solution, targets for hygiene, environmental protection, and resource reclamation on one side, and practical and economical consideration on the other side, should be taken into account. More information on planning for ecological sanitation are found in the EcoSanRes Planning Tool, B1 c) 32902.

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EcoSanRes is an international research and development programme sponsored by Sida (Swedish International Development Cooperation Agency). It involves a broad network of partners with knowledge/expertise in various aspects of ecological sanitation ranging from management and hygiene to technical and reuse issues. The partners represent universities, NGOs and consultants and they are involved in studies, promotion activities and implementation of projects in Asia, Africa and Latin America.

The network hub is Stockholm Environment Institute (SEI) which holds a formal contract with Sida. EcoSanRes has become an authoritative networking body within the field of ecological sanitation and also collaborates with other bilateral and multi-lateral organisations such as WHO, UNICEF, UNDP, UNEP, GTZ, WASTE, IWA, WSP, etc.

The EcoSanRes programme has three main components:

- outreach
- capacity
- implementation

The outreach work includes promotion, networking and dissemination through seminars, conferences, electronic discussion groups and publications.

Capacity building, is achieved through training courses in ecological sanitation and the production of studies and guidelines, with content ranging from eco-toilet design, greywater treatment, architectural aspects, agricultural reuse, health guidelines, planning tools, etc.

Implementation puts theory into practice with ecological sanitation pilot projects in diverse regions around the world. Because the most important factor to successfully implementing an ecosan system is local adaptation, EcoSanRes provides a logical framework for prospective pilot projects and insists the projects meet stringent criteria before approval.

EcoSanRes is currently running three major urban pilot projects in China, South Africa and Mexico. In addition preparations are being made to develop similar projects in Bolivia and India.

For more information about the partner organisations and programme activities please consult

www.ecosanres.org