ENVIRONMENTALLY SOUND TECHNOLOGIES
in wastewater treatment
for the implementation of the
UNEP GLOBAL PROGRAMME OF ACTION (GPA)
"GUIDANCE ON MUNICIPAL WASTEWATER"

in collaboration with
Murdoch University Environmental Technology Centre

This document has been prepared by UNEP DTIE IETC as a contribution to the UNEP GPA and is based upon the "Recommendations for Decision-making on Municipal Wastewater: Practical Policy Guidance for Implementing the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) on Sewage" (Version 10 November 2000). It is recognized that this latter document is under review and will be replaced by "Guidance on Municipal Wastewater: Practical Guidance for Implementing the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) on Sewage" that is being prepared. Therefore, the UNEP DTIE IETC document will be subject to revision following adoption of this latter document by the UNEP GPA.

Preface

The UNEP Global Programme of Action for the Protection of the Marine Environment from land-based Activities (GPA) has produced a publication entitled 'Guidance on Municipal Wastewater'. This document aims to provide practical guidance to decision-makers by recommending key principles, practices and procedures for environmentally sound systems of wastewater management. It details an integrated and stepwise approach to environmentally sound wastewater management. It discusses suitable enabling environments, institutional arrangements, financial mechanisms and, in brief, sustainable technologies for wastewater management. It was agreed that the IETC would provide further detail on environmentally sound technologies to augment the guidance provided by GPA.

The UNEP-IETC has prepared an 'International Source Book on Environmentally Sound Technologies for Wastewater and Stormwater Management', published by IWA and IETC. The Source Book was the result of collaborative effort by many experts and institutions. The project was launched with an 'International Experts Meeting on Sustainable Management of Wastewater and Stormwater' in Osaka, Japan on 6 – 8 May 1998. UNEP IETC and METC (Murdoch University Environmental Technology Centre) refined the proposal from the meeting under the leadership of the Managing Consultant and Editor Dr. Goen Ho of the METC. Several consultants prepared the regional overviews and compiled the lists of information sources. Peer review was conducted internally by all consultants, as well as externally for different sections. In addition, training materials were prepared and feedback was obtained from decision-makers from 18 countries in Central and South America at the pilot training workshop held in Rio de Janeiro 27 – 31 March 2000.

The Source Book consists of three sections:

Section 1: Toward a Framework for Wastewater and Stormwater Management
Section 2: Environmentally Sound Technologies and Practices
Section 3: Regional Overviews and Information Sources - including Africa, Asia (West), Asia

(Pacific), America (North), America (Central and South), Europe (West), Europe (East), and Small Island Developing States (Caribbean and Pacific).

Training Modules have also been prepared based on the Source Book. They are directed at 3 types of audience: Top level decision makers, Professionals and Community leaders.

This document is a summary of Section 2 of the Source Book and provides information on the available environmentally sound technologies as a supplement to “Recommendations for Decision-making on Municipal Wastewater: Practical Policy Guidance for Implementing the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) on Sewage”. It responds to Version 1.0 (November 2000), which states “The high cost of wastewater management warrants a very careful search for low-cost and thus more sustainable technologies and approaches” and lists the following recommendations. UNEP IETC’s contribution in response to the recommendations are indicated alongside.

UNEP GPA Recommendations	**UNEP-IETC Contribution based on Source Book**
1. Introduce appropriate strategies and incentives that target waste prevention and minimisation, water conservation, and the efficient use of water.	See Section 2 of this document
2. Apply more cost effective technologies such as lagoons, natural systems, anaerobic treatment, and reuse schemes.	See Section 4 of this document
3. Adapt land use policies and financial and other regulation to promote the segregation of industrial effluents unsuitable for municipal wastewater treatment by relocating industries, recycling waste streams, and using the best available technologies.	See Sections 3 and 6 of this document
4. Promote the exchange of experience with the implementation and operation of different technologies.	UNEP IETC will assist with the dissemination of information and the exchange of experience by conducting workshops using the Training Modules of the Source Book

This document, the Source Book and the practical guidance for the implementation of the Global Programme of Action (GPA) for the protection of the marine environment from land based activities, bear essentially the same message. Much of the pollution from land based activities are directly attributable to wastewater and stormwater. Sound environmental management of these systems is essential.

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Environmentally Sound Technologies

1. Overview

Environmentally Sound Technologies are technologies that help protect the quality of the environment. It may be argued that technologies used to manage wastewater and stormwater are inherently environmental technologies, because without these technologies the pollutants in wastewater and stormwater will negatively affect the environment. Some of these technologies may utilise less energy than others, produce less air pollution or hazardous sludge, or are more suited to wastewater and sludge reuse. Hence some of these technologies are more sustainable. The application of a technology is dependent on local physical factors including land availability, its topography, climate, soil, availability of energy and existing land uses. Sound technology practice is therefore dependent on being able to fit the technology to the local conditions.

Sound practice is also dependent on the context of the local community where the technology is to be applied. Long term sustainability is a function of community resources (funds, skills) to afford the technology and its willingness to pay for the technology and its operation. Sound practices are therefore practices that fit into the environmental, economic, social, cultural and institutional setting of the community.

In this document, wastewater and stormwater characteristics are described to set the context for technologies that need to be used to manage the pollutants they contain. The description is also meant to indicate the resources that are contained in human excreta, and therefore its potential for reuse. Technologies for collection, treatment, reuse and disposal are then described, so that options for different local environmental, economic and social contexts can be evaluated. The description is not meant to be exhaustive, but to enable the scientific basis of the technologies to be understood.

2. Wastewater and Stormwater Characteristics

Household wastewater derives from a number of sources (Figure 1). Wastewater from the toilet is termed ‘blackwater’. It has a high content of solids and contributes a significant amount of nutrients (nitrogen, N and phosphorus, P). Blackwater can be further separated into faecal materials and urine. Each person on average excretes about 4 kg N and 0.4 kg P in urine, and 0.55 kg N and 0.18 kg P in faeces per year. In Sweden it has been estimated that the nutrient value of urine from the total population was equivalent to 15–20 % of chemical fertiliser use in 1993 (Esrey et al., 1998). This represents a considerable potential resource that is generally underutilised.

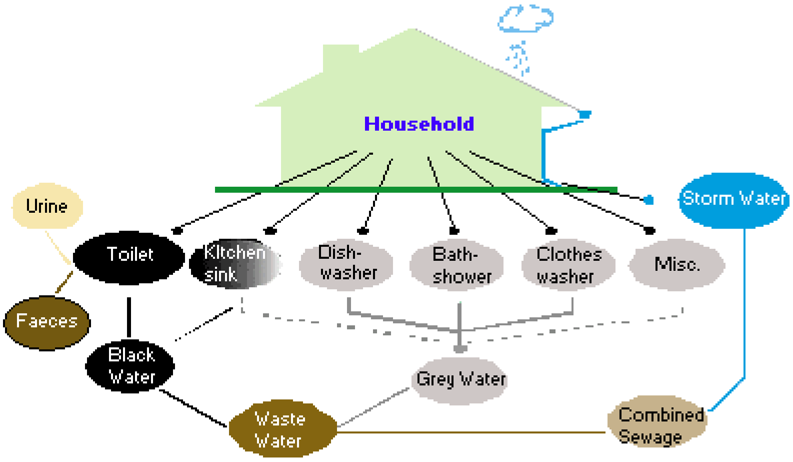

Figure 1: A range of possible sources of household wastewater showing wastewater from toilet, kitchen, bathroom, laundry and others

Greywater consists of water from washing of clothes, from bathing/showering and from the kitchen. The latter may have a high content of solids and grease, and depending on its intended reuse/treatment or disposal, can be combined with toilet wastes and form the blackwater. Both greywater and blackwater may contain human pathogens, though concentrations are generally higher in blackwater. The flow of wastewater is generally variable with peak flows coinciding with high household activities in the morning and evening, while in the night minimal flow occurs. Pollutant loads vary in a similar manner.

Stormwater in a community settlement is produced from house roofs, paved areas and from roads during rainfall events. In addition, stormwater is produced from the catchment of a stream or river upstream of the community settlement. The amount of stormwater is therefore related to the amount of rainfall precipitation as well as the nature of the surface. Vegetated surfaces slow the rate of runoff to stormwater and also allow rainfall to penetrate the soil whereas impervious surfaces do not and therefore produce more run-off. During a storm event, the peakflow of stormwater is higher and duration shorter with an impervious surface, while the peakflow is lower and duration longer with a vegetated surface. Stormwater run-off may contain as much solids as household wastewater depending on the debris and pollutants in the path of the stormwater run-off, although in general the pollutant load of stormwater is lower than that of wastewater.

The environmental impact of wastewater and stormwater can be substantial. Solids in both wastewater and stormwater form sediments and can eventually clog drains, streams and rivers. Grease particles form scum and are aesthetically undesirable. The nutrients N and P cause eutrophication of water bodies, with lakes and slow moving waters affected to a greater degree than faster flowing waters. In the former the algae that are fertilised by the nutrients, settle as sediment when they decay. The sediment acts as a store of nutrients and regularly releases the nutrients to the water column, thus the cycle of bloom and decay of the algae is intensified. In the early stages of eutrophication, aquatic life is made more abundant because fish, for example, graze on the algae. With too high a concentration of algae, the decaying algae contribute to the biological oxygen demand (BOD) and the water is deoxygenated. Thus wastewater, which has been treated to reduce BOD but still high in nutrients, can still have a significant impact on the receiving water. In addition, some algae produce toxins that can even be fatal to humans and animals. Eutrophic water adds to the cost of water treatment, when the water is used for drinking purposes.

Other pollutants in wastewater and stormwater are heavy metals and possible toxic and household hazardous substances. Heavy metals include copper, zinc, cadmium, nickel, chromium and lead. The content and concentration are dependent on the pipe materials employed to convey drinking water, household-cleaning agents used, and for stormwater, the type of materials used for roofing and guttering. In high enough concentrations these heavy metals are toxic to bacteria, plants and animals, and to people. Toxic materials may also be disposed with household wastewater. These could be medicines, pesticides and herbicides that are no longer used, as well as excess solvents, paints and other household chemicals. These substances can corrode sewer pipes and seriously affect the operation of treatment plants. They will also limit the potential of water reuse, and therefore should not be disposed with household wastewater.

Spills of chemicals, particulates from motor vehicle exhausts and deposition of atmospheric pollutants can similarly contaminate stormwater. These pollutants will affect downstream receiving waters, and treatment systems if the stormwater is treated.

Wastewater and contaminated stormwater can contaminate groundwater. This is through infiltration of the wastewater or stormwater through the soil to an unconfined groundwater aquifer. Soil can filter some pollutants, but soluble pollutants (e.g. nutrients and heavy metals) and very small particles (e.g. viruses) travel with the water to the groundwater aquifer.

2.1 Integrated Waste Management

Integrated Waste Management, as the name suggests, refers to the practice of considering wastewater, stormwater and solid waste management as inextricably linked. This is in contrast to the practice of viewing each waste stream as independent and separate from the others. Critical to wastewater and stormwater management are solid wastes and wastewater produced by industry. In many instances these may not differ in characteristics from domestic wastes, consisting primarily of biodegradable organic substances. Industry, however, produces numerous types of wastes that may be toxic to the bacteria that are utilised to treat domestic wastewater. The practice in many communities is for industrial wastes to be disposed with domestic wastes and this often leads to problems.

One principle that logically emerges from adopting an integrated approach to waste management is that different types of waste should not be mixed. Solid wastes should not be dumped into stormwater drains, but should be collected, recycled, reused, or treated and disposed separately. Dumping of solid wastes in stormwater drains will not only restrict the flow of stormwater, but also contaminate stormwater. Treatment of the stormwater will involve separating the solids and other contaminants from the water. Similarly industrial wastes should be treated separately, and industrial wastewater should be pre-treated if they are to be discharged to the sewer.

Table 1: The waste management hierarchy
Step 1: Prevent or reduce waste generation
Step 2: Reduce the toxicity or negative impact of the waste
Step 3: Recycle waste in its current form
Step 4: Reuse waste after further processing
Step 5: Treat waste before disposal
Step 6: Dispose in an environmentally sound manner

A useful tool that can help towards achieving integrated waste management is the waste management hierarchy. It has been used to direct waste management towards achieving environmentally sound practice. The waste management hierarchy in its most general form is shown in Table 1. In using this tool for waste management we systematically go down the list to see if step 1 (Prevent or reduce waste generation) can be implemented, before considering the next step (2) and so on. Only when steps (1) to (5) have been fully considered that we consider disposal of the waste (step 6).

2.2 Sustainable versus Unsustainable Wastewater and Stormwater Management

In nature, waste materials are produced by living organisms (plants, animals and people). These wastes include faecal materials, leaf litter, food wastes and dead biomass. Yet streams and rivers flowing through a pristine forest, or freshwater lakes in a forest, have generally an excellent water quality. There are natural processes that purify the naturally produced wastes and provide a basis for determining environmentally sustainable management practices for wastewater and stormwater. Discharge of wastewater and stormwater into an environment exceeding the natural purification capacity of that environment will result in the accumulation of organic materials (carbon), nitrogen, phosphorus or other pollutants that cannot be absorbed by the ecosystem constituting the receiving environment. Accumulation of organic materials will result in a high oxygen demand that cannot be met by oxygen transfer from the atmosphere and anaerobic conditions result.

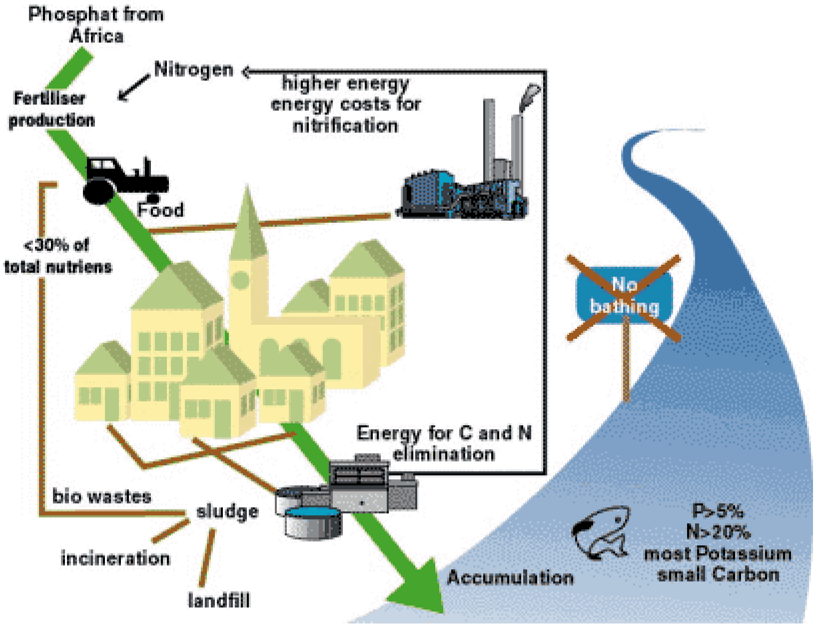

Figure 2: Unsustainable wastewater management exceeding the natural purification capacity of the receiving environment (Lange and Otterpohl, 1997)

In figure 2, the nitrogen and phosphorus in wastewater are discharged to a river resulting in their accumulation in the river, leading to eutrophication. The nitrogen and phosphorus in the wastewater come from food consumed by people. To grow this food fertilisers containing nitrogen and phosphorus are required. These are manufactured chemically from atmospheric nitrogen and from phosphate rock. The flow of materials (N & P) is one way from the atmosphere for N and from the phosphate rock mine for P into the river. There is depletion of a resource (mined phosphate rock) and accumulation and pollution in the river. This practice is unlikely to be sustainable in the long term, because phosphate rock deposits will be exhausted and pollution of the river by N and P needs further treatment of the wastewater.

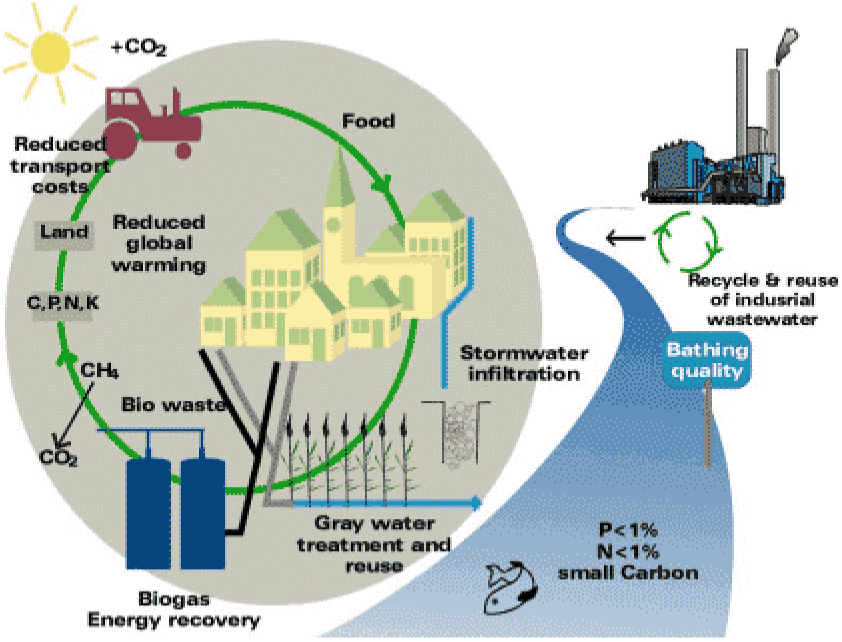

Figure 3: Sustainable wastewater management practice (Lange and Otterpohl, 1997).

In a sustainable wastewater management system, nutrients in the wastewater are reused to grow food. In this way there is not the need to use as much chemical fertiliser and at the same time, there much less discharge of nutrients to the river. The problem of resource depletion and pollution of the river is overcome by closing the material cycles. Figure 3 also emphasises the need to treat industrial wastewaters containing toxic substances separately, and not to mix industrial wastewaters with domestic wastewater. In addition stormwater should be separately collected and treated and infiltrated locally.

3. Wastewater and Stormwater Collection

A sewerage system collects wastewater and can be in the form of blackwater separated from greywater, or mixed with it (sewage). Gravity is used wherever possible to convey the wastewater. It is not surprising therefore that natural stormwater drainage is usually used, because this is how rainwater run-off is conveyed in nature by gravity. The principle of using gravity as the driving force for conveying wastewater in a sewerage system should be applied wherever possible, because this will minimise the cost of pumping. Natural stormwater drainage occurs in what is usually termed a catchment basin. In a catchment basin, rainwater run-off flows to a common point of discharge, and in so doing, forms streams and rivers. Crossing a catchment boundary may mean that the water has to be unnecessarily pumped, requiring an energy source. A wastewater sewerage system should therefore be within a stormwater catchment basin.

Sewerage systems can be classified into combined sewerage and separate sewerage. Combined sewerage carries both stormwater and wastewater, while separate sewerage carries stormwater or wastewater separately. Recent trends have been for the development of separate sewerage systems. The main reason for this is that stormwater is generally less polluted than wastewater, and that treatment of combined wastewater and stormwater is difficult during heavy rainfalls, resulting in untreated overflows (commonly termed combined sewer overflow, CSO). In practice there is usually ingress of stormwater into wastewater sewerage pipes, because of unsealed pipe joints, and unintentional or illegal connections of rainwater run-off. Conversely there may be unintentional or illegal wastewater connections to stormwater sewerage.

Wastewater sewerage systems can be classified into three major types:

- Conventional sewerage
- Simplified sewerage
- Settled sewerage

3.1 Conventional sewerage

Conventional sewerage is also termed deep sewerage because the sewerage pipes are laid deep beneath the ground. Pumping is generally required at various stages of the sewer pipe network, especially if the landscape is fairly flat. The larger the population served by the sewerage system, and the longer the planning horizon is to cope with future population increases, the larger the diameter of the final pipes becomes. The costs of the pipes, inspection manholes, pumps and pumping stations and their construction/installation are therefore high. The costs of operation and maintenance are correspondingly high because of very conservative design assumptions.

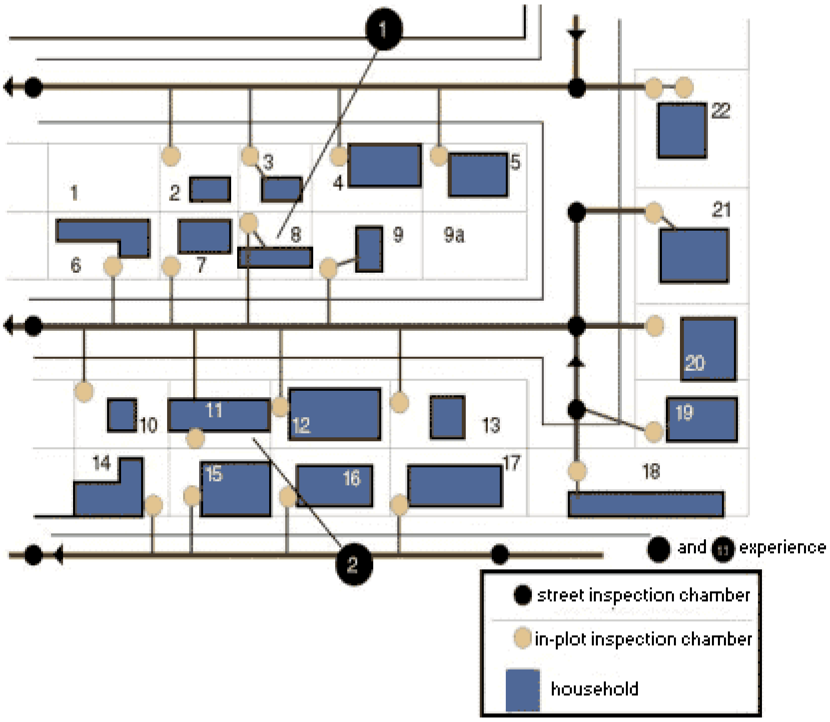

Figure 4: Pipe Layout for Conventional Sewerage

3.2 Simplified sewerage

Simplified sewerage is also known as shallow sewerage, reflecting the shallower placement of the pipes in contrast to the conventional or deep sewerage. The purpose of simplified sewerage is to reduce the cost of construction and the corresponding cost of operation and maintenance. Simplified sewerage design is based on hydraulic theory in the same manner as for conventional sewerage but has less conservative design assumptions. Smaller diameter pipes are used when water use per person is known to be less and the minimum depth of cover of pipes can be as low as 0.2 m when there is only light traffic. Manholes can be replaced by inspection cleanouts because of the shallow pipes. The design planning horizon can be shorter because the population projection may be uncertain. In a variation of the simplified sewerage, the pipe layout passes through property lots (condominial) rather than on both sides of a street (conventional). Figures 4 and 5 show the sewerage layouts in conventional sewerage and in condominial sewerage. The cost of construction of simplified sewerage can be 30 to 50 % less than conventional sewerage depending on local conditions.

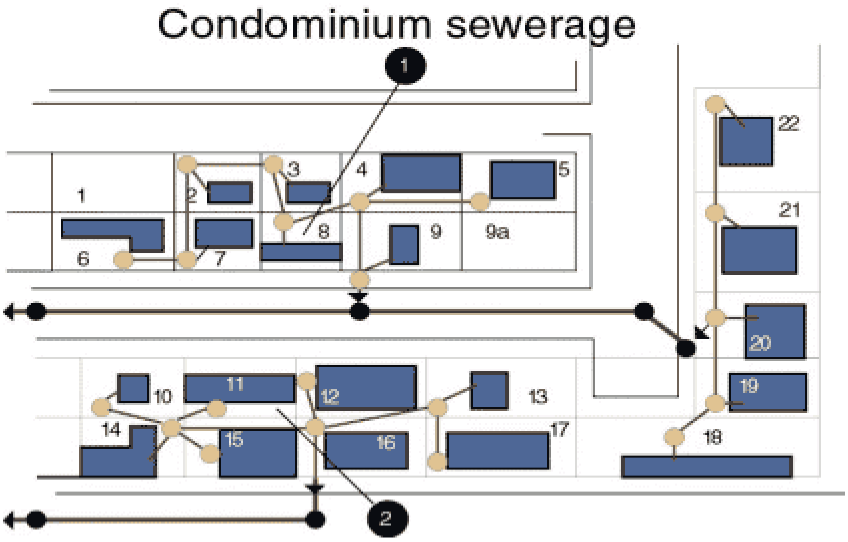

Figure 5: Pipe layout for condominium sewerage

Shallow sewerage is also conducive to local community participation because sewer pipes have to cross property boundaries. The community has to agree to this arrangement which extends after construction for maintenance (e.g. unblocking of sewer pipes). The shallow pipe, and hence the shallow trenches, also allow members of the community to participate by, for example, providing labour for digging the trenches. This is in contrast to conventional sewerage where specialised machinery is required for the deep trenches.

Simplified sewerage was originally developed in Brazil and is increasingly being used in other parts of the world. The ‘International Source Book on Environmentally Sound Technologies for Wastewater and Stormwater Management’ (hereafter referred to as the Source Book), published by IWA and IETC, provides useful case studies.

3.3 Settled sewerage

Settled sewerage refers to sewerage for conveying wastewater that has been settled, for example, in a septic tank. Settled sewerage originated to convey the overflow from septic tanks where the soil cannot cope or absorb the overflow. This usually occurs when the groundwater table is high, or where the soil permeability is low, or where there are rock outcrops. It can also be used when effluent from septic tanks pollutes groundwater and it is necessary to convey the effluent off-site and treat it. Because there are no solids that can potentially sediment in the sewerage pipes, there is no requirement for the self-cleansing velocity. Smaller pipes and lower gradients can be used. The cost of settled sewerage is between a third and a half of conventional sewerage. Originally developed in South Australia to overcome problems with failing septic tanks, it has been used quite widely worldwide to upgrade septic tank systems.

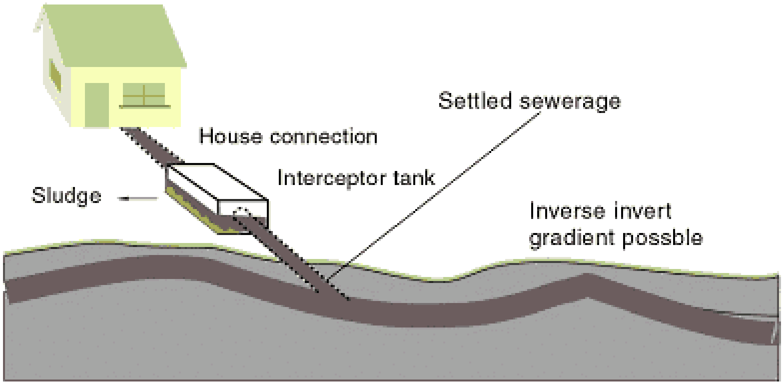

Figure 6: Interceptor tank in settled sewerage

Where there is no existing septic tank, an interceptor box or tank can be used. It functions like a septic tank and designed in the same way (Figure 6). To reduce cost, the wastewater from a group of houses can be connected to one interceptor tank. Just like in a septic tank, the accumulation of sludge has to be removed regularly from an interceptor tank.

3.4 Stormwater collection

Stormwater flows through the landscape's natural drainage system. Piped stormwater collection was a development in European cities to overcome odour and improve aesthetic appearance of wastewater disposed with stormwater. The covering of ditches used for combined sewerage was an intermediate step in using natural drainage to construct sewerage for combined wastewater and stormwater. Piped sewerage also allows more land area for road and footpaths. With the separate collection of wastewater there is an opportunity to return some stormwater flow path to its more natural state to improve urban amenity value.

4. Wastewater and stormwater treatment

The treatment of wastewater and stormwater means the reduction and removal of pollutants from the water. The first principle to bear in mind therefore is to prevent pollutants from entering the water in the first place. In the case of stormwater we need to ensure that surfaces through which stormwater run-off passes over should as far as possible be free from solids and other wastes. Thus the collection of solid wastes is an important part of stormwater treatment as is the separate collection of wastewater and stormwater. The treatment of industrial wastewaters before discharge to the sewer is also extremely important in preventing pollutants from entering the wastewater and stormwater systems.

In the case of wastewater, separating blackwater and greywater can mean less energy is required in treatment. This is because blackwater contains most of the solids, which during treatment have to be removed from the mixture. Further separating urine and faecal materials may also mean that the urine can be reused without much treatment and the faecal materials can be more simply treated. The use of water to convey toilet wastes may be questioned based on this principle, because treatment means separating these wastes from the water.

Besides preventing pollutants entering the water, water conservation means that a lower volume of water has to be treated. Since the size of treatment systems is primarily governed by the volume of water to be treated rather than the amount of pollutants in the water, a lower volume means smaller treatment plants and a corresponding capital cost. Use of less water to flush toilets belongs to this principle.

A range of wastewater treatment technology options is presented below. Treatment of wastes on-site is considered first (4.1), followed by off-site treatment of the wastewater (4.2). Each technology requires maintenance and proper operation. The demand of each technology for maintenance varies and this is also discussed, as well as the public health and environmental impacts of the technology. Treatment options for stormwater are presented in section 4.3.

4.1 On-site wastewater treatment systems

On-site treatment relies on decomposition of the organic wastes in human excreta by bacteria. This can take place in a simple pit in the ground or in specially designed tanks to promote the bacterial decomposition of the wastes. Unless re-use of the wastewater is specifically intended (see Section 6 on Wastewater reuse), the overflow from the pit or tank is allowed to soak into the ground. Further bacteriological decomposition and soil filtration, absorption and purification processes take place in the soil. The potential for groundwater pollution, however, exists with on-site treatment and disposal systems, because not all pollutants (e.g. nitrate) are removed by these processes.

Pit latrine, pour flush latrine, composting toilet, septic tank and two improved on-site treatment units are described below because they represent major types of on-site treatment systems. Variations of these exist and are used in different areas of the world. Some of these are described in greater detail in the Regional Overviews in the Source Book published by IWA and IETC. The treatment principles are, however, covered under these major types.

4.1.1 Pit latrine

A pit latrine collects excreta in a pit dug in the ground beneath the toilet structure. If the soil is loose the pit needs to be lined with, for example, loose bricks to prevent the wall from collapsing. During storage in the pit decomposition of the organic substances takes place under anaerobic conditions. The anaerobic decomposition releases gases (carbon dioxide, methane and sulphuric gases) and reduces the volume of sludge.

Seepage of water into the surrounding soil takes place through the sides and bottom of the pit. During seepage further decomposition of organic matter by soil bacteria takes place reducing the BOD of the water. There will also be die-off of bacteria and viruses during storage and as the water percolates through the soil. Bacteria under these conditions do generally not remove nutrients, so pollution of groundwater will occur.

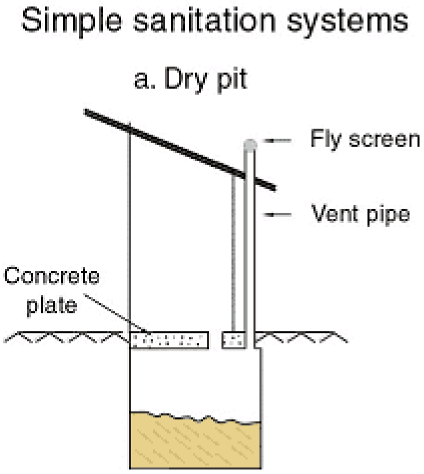

Figure 7: Ventilated Pit Latrine

Control of odour and insects are important with a pit latrine. This is achieved by having a vented pit (Figure 7). The vent acts to draw odour and insects into the pit and up the vent. Gases (methane and carbon dioxide) produced by the decomposition of the excreta also leave through the vent. Ensuring that the vent protrudes well above the roof of the housing allows ventilation through natural convection. Facing the vent towards the sun (southward in the Northern hemisphere and northward in the Southern hemisphere) and painting the vent black to maximise absorption of heat from the sun will help venting by heat convection. The heated air in the vent rises and draws air from the toilet. Ventilated improved pit (VIP) toilets are widely used in Africa.

Pit latrines pose problems when groundwater is shallow and the pit is in groundwater or close to it. There is no soil barrier to protect the water quality of the groundwater, and mosquitoes may breed inside the pit. A pit is also difficult to dig when the ground is rocky. Pit latrines should not be used in these cases.

The pit will eventually fill with faecal sludge and needs to be emptied. The period between emptying depends on the size of the pit and its usage. It is desirable to design the pit to store at least one year of sludge production. Emptying requires mechanical suction of the sludge. The sludge requires treatment prior to re-use or disposal (see Section 5). Two adjoining pits can be used alternately. Further decomposition of sludge in a full pit takes place while the adjacent pit is in use. Its content after further decomposition can be manually removed.

An alternative way of dealing with a full pit is to dig another pit and relocate the sanitary platform and toilet housing to the new pit. The full old pit can then be covered with soil, preferably of greater than 15 cm depth to prevent disease vectors (rodents and insects) from burrowing into it.

4.1.2 Composting toilet

Rather than the decomposition of the faecal sludge under anaerobic conditions (no oxygen) in the pit of a pit latrine, decomposition under aerobic conditions (with oxygen) can be promoted in an above ground (elevated) latrine (Figure 8). Air can be introduced through an opening to pass through the sludge and exit through the vent, while excess liquid is allowed to drain for collection or evaporation. With two adjoining composting chambers or vaults used alternately, the process of composting in an already full chamber can be allowed to proceed until the chamber is to be used again, and produce mature compost for direct re-use in the garden. Other household organic wastes (e.g. food wastes) can be added to the faecal sludge, and materials such as newspaper or sawdust can be added to balance the carbon to nitrogen ratio for optimal composting. Because mature compost takes several months to produce under ambient temperatures, it is desirable for the chambers to be sized to hold at least 6 months of waste. Worms can also be added to assist with vermi-composting. Further details on handling and composting of sludge can be found in Section 5.

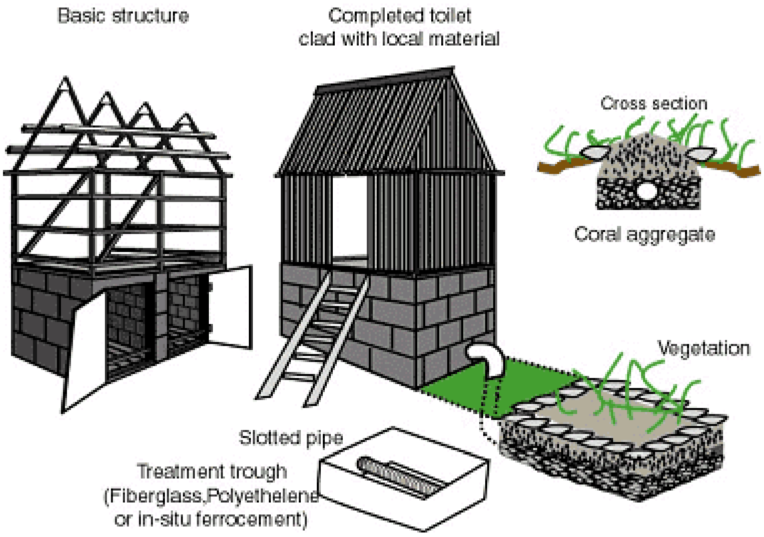

Figure 8: Composting toilet

4.1.3 Pour flush toilet

A pour flush toilet (Figure 9) has a water seal. The problems associated with odour and insects are avoided by having the water seal. Excreta deposited in the latrine pan is flushed by pouring 2 to 3 L of water into it. The mixture is directed into a pit in the same way as for a pit latrine. The processes of biodegradation of the organic wastes in the pit are exactly the same. More water percolates through the soil surrounding the pit, and the potential for groundwater pollution is higher. A pour flush toilet with a pit is therefore not suitable when groundwater table is close to the surface.

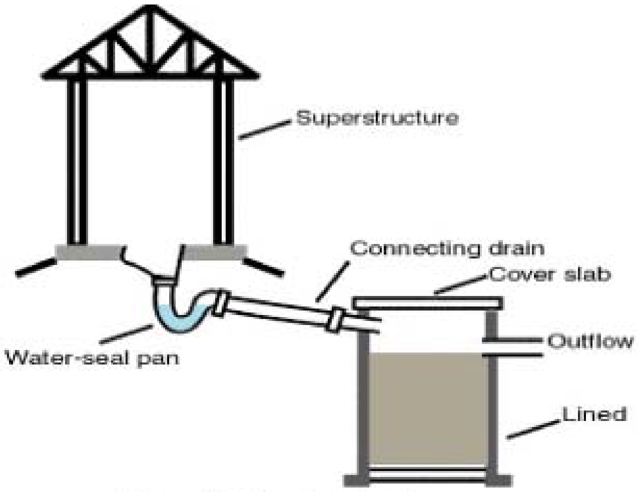

Figure 9: Pour flush latrine pan.

Sludge has to be regularly emptied from the pit. The use of two adjoining pits alternately enables the sludge in a full pit to undergo further decomposition while the other pit is being used, and enables manual sludge emptying after further sludge decomposition.

With the use of the pit latrine, composting toilet and pour flush latrine, greywater (sullage) has to be separately treated. Greywater can be reused directly or after treatment (see Section 6 on Wastewater Reuse). Disposal of greywater on-site is by use of a leach pit or trench (See below under Septic tank). Limitations of disposal of greywater by leach pit or trench are similar to those applicable to septic tank.

4.1.4 Septic tank

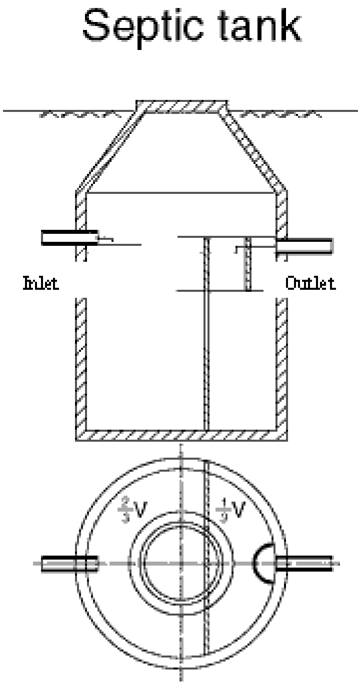

Figure 10: Septic tank

A septic tank is a watertight tank, usually located just below ground, and receives both blackwater and greywater (Figure 10). It can be used with pour flush toilets or cistern flush toilets. It functions as a storage tank for settled solids and floating materials (e.g. oils and grease). The storage time of the wastewater in the tank is usually between 2 and 4 days. About 50% removal of BOD and Suspended Solids (SS) is usually achieved in a properly operated septic tank due to the settling of the solids during wastewater storage.

A septic tank can be constructed of bricks and mortar and rendered, or of concrete. Its shape can be rectangular or cylindrical. A septic tank can be partitioned into two chambers to reduce flow short-circuiting and improve solids removal.

The overflow from a septic tank is directed to a leach pit or trench. A leach pit (Figure 11) is similar to the pit of a pit latrine or pour flush latrine. The pit must be sized to allow percolation of the volume of wastewater generated. A pit works well in soils with high permeability. In soils with lower permeability a trench can provide the larger surface area of percolation (Figure 12). The trench is usually filled with gravel and a distribution pipe for the wastewater is placed in this gravel layer. Soil is then placed above this gravel layer to the ground surface.

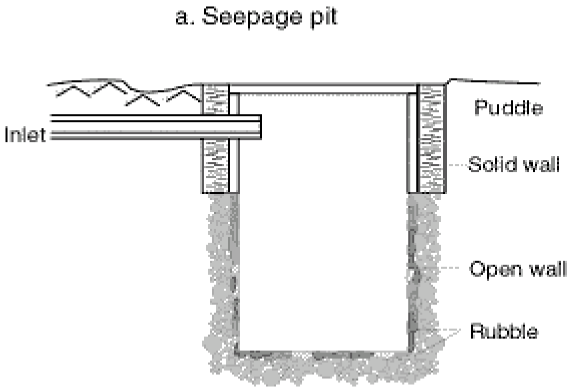

Figure 11: Leach pit (Seepage pit)

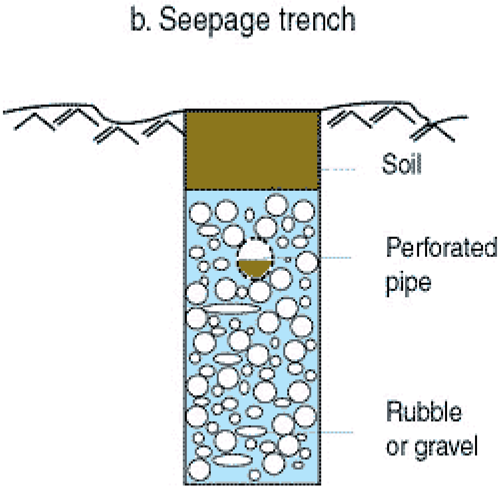

Figure 12: Leach trench for disposal of septic tank effluent

A leach pit or trench does not work when the soil permeability is too low (e.g. clayey soil or hard rock). In regions where annual evaporation is high, trees and shrubs can be used to help pump the water into the atmosphere by evapotranspiration. An evapotranspiration bed can be designed similar to a leach trench, but a suite of suitable local vegetation species tolerant of high nutrients and water are planted above and surrounding the trench (Figure 13). The trench should be sized to store water during the rainy season or low evaporation periods.

A leach pit or drain does not work either when the groundwater table is close to ground surface. In this case off-site disposal is necessary using a settled sewerage system (3.3 above). If the groundwater table is not too close, an inverted leach drain as described under Improved On-site Units below (4.1.5) can be used.

The organic solids in a septic tank undergo anaerobic bacterial decomposition just as in the pit of a pit latrine. The sludge needs emptying, and the period between emptying is usually designed to be between 3 to 5 years. The sludge has to be further treated before reuse or disposal (Section 5).

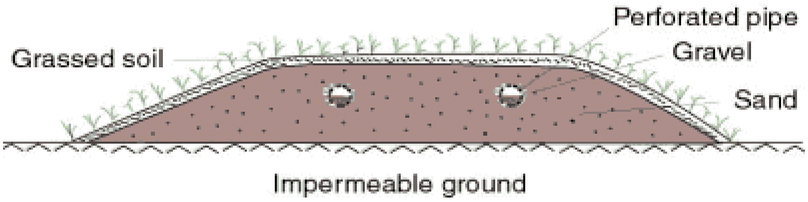

Figure 13: Evapotranspiration bed

The septic tank overflow undergoes further bacterial decomposition as it percolates through a leach pit or trench. Soil bacteria, usually under aerobic conditions undertake the decomposition. The BOD of the wastewater can reach a low figure (<20 mg/L) if the distance between the bottom of the pit or trench to the groundwater table is greater than 2 m. Nutrients are not significantly removed by the bacteria and usually pollute the groundwater. Pathogenic bacteria are removed by die-off or filtration by the soil, but viruses may travel further in the soil or groundwater.

Percolation of septic tank overflow is much slower compared to rainwater percolation. This is because a layer of bacterial slime grows on the surfaces of the soil particles, restricting flow. Two leach pits or trenches used alternately, say every 6 months, are better than a single leach pit or trench of the same total area for percolation, because as one is used the other will recover its percolation rate.

4.1.5 Improved on-site treatment units

Improved on-site treatment units refer to treatment units that improve the performance of one of the above on-site systems, for reducing BOD, SS and/or nutrients. Two designs are described to illustrate the main principles used. A principal aim of the improvements is to prevent groundwater pollution or enable water reuse of the treated wastewater on-site. Many designs are available using similar principles.

(a) Inverted trench

In the system illustrated in Figure 14, a plastic or impermeable liner underlies the trench of the septic tank. The liner is filled with sand or a fairly permeable soil. Overflow from the septic tank is introduced at the base of the sand layer. It flows up through the sand layer and flows over into the surrounding soil. The sand layer acts as a slow sand filter, where bacteria growing on the surfaces of the sand particles degrade the organic substances to reduce BOD. Because of the fluctuating flow of wastewater with peak flows in the morning and in the evening, the upper region of the sand layer alternates between aerobic and anaerobic conditions. Under these conditions a significant part of nitrogen in the wastewater can be removed by nitrification (bacterial conversion of ammonium in the wastewater to nitrate under aerobic conditions) and denitrification (bacterial conversion of nitrate to nitrogen gas under anaerobic conditions. In addition if materials that can remove phosphate are mixed with the sand, phosphorus in the wastewater is also removed. One material, that has been found to remove phosphate effectively with a capacity for phosphorus removal for several years, is bauxite refining residue (red mud).

(b) Aerobic Treatment Unit

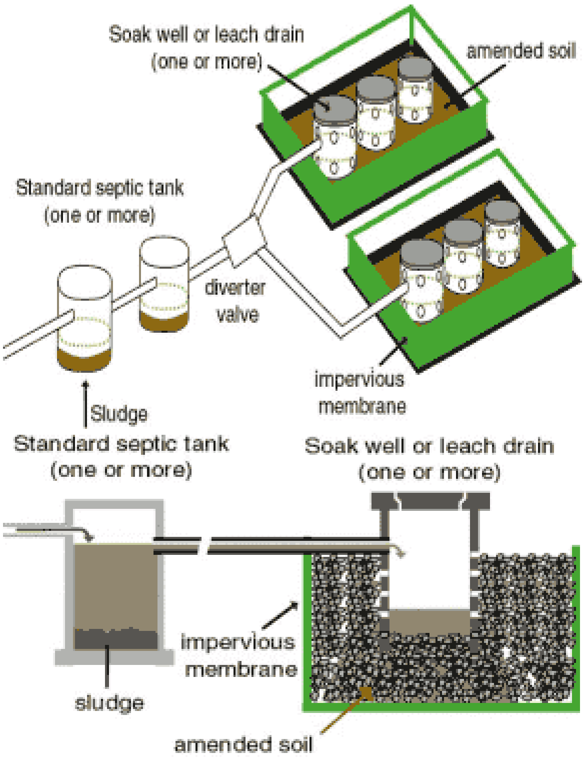

Figure 14: Inverted trench (Ecomax)

An aerated treatment unit consists of a tank similar to a septic tank. The tank is partitioned into four compartments (Figure 15). The first compartment receives the wastewater and acts as a sedimentation tank for solids. The overflow from the first compartment goes to an aeration compartment. The aeration compartment is fitted with corrugated plastic sheets to enable bacteria to attach themselves. The aeration supplies oxygen to the bacteria decomposing the organic matter in the wastewater thus reducing its BOD. After aeration, the wastewater passes to a third compartment which acts as a second sedimentation tank. Sludge from this second sedimentation tank is pumped to the first compartment for storage. After sedimentation the wastewater overflows to a fourth compartment for storage and pumping, usually for irrigation of garden beds. If required, chlorine is applied by inserting chlorine tablets in the pipe between the third and fourth compartments. Chlorination is required when sprinklers irrigate the treated wastewater. Sub-surface irrigation is preferable, because it does not require chlorination.

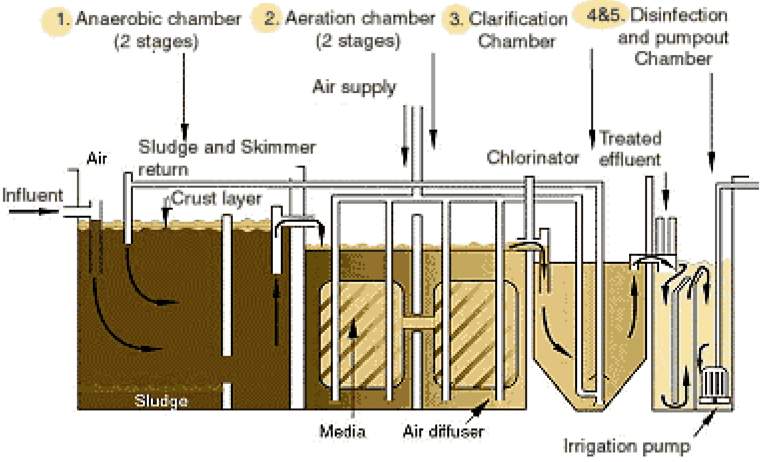

Figure15: Aerated treatment unit (Biomax)

Power is required for aeration and pumping. For a system serving a household of up to 10 persons, the power supply rating needed is 100 W (2.5 kWh per day). This on-site unit is a miniature of an activated sludge treatment plant usually used for centralised treatment (see Section 5). One difference is that surfaces are provided in the aeration tank to retain bacteria during peak flows. The other difference is that sludge from the second sedimentation tank is returned to first tank for storage.

4.2 Off-site wastewater treatment systems

Off-site treatment is the treatment of wastewater that has been conveyed using a sewerage system (Section 3). Activated sludge treatment is now considered the conventional means of large-scale off-site treatment of sewage, and is described first. Trickling filtration, which was developed before the activated sludge process, is described next. There have traditionally been other more simple, but as effective methods of treating sewage. These include the use of ponds or lagoons, land based treatment (sewage farming), and aquaculture.

Several general principles common to treatment systems will be discussed first. The main aim of treatment is to reduce biochemical oxygen demand (BOD) and suspended solids (SS) to acceptable levels. This is achieved by removing solids and aerating the wastewater to satisfy the oxygen demand of the wastewater. The different treatment systems remove solids and provide oxygen in different ways. It should be noted that if the systems are properly designed, constructed, operated and maintained, they should all achieve the required standard of treatment. The latter is generally a reduction of BOD to less than 20 mg/L, and SS to less than 30 mg/L.

Nutrients (nitrogen and phosphorus) may need removal if the wastewater is discharged to water environments sensitive to enrichment by nutrients. Nitrogen is very difficult and costly to remove at low concentrations and the high standards used in many developed countries are difficult meet. The Source Book, published by IWA and IETC, contains details of methods for removing nutrients in the North America and Western Europe Regional Overviews, because nutrients have been found to be a problem in many receiving waters. Nitrogen Heavy metals and other pollutants are not generally a problem unless the sewerage system receives industrial discharges. In this case treatment of industrial wastes prior to discharge to the sewerage system is the solution to this problem.

Removal of SS and BOD produces sludge, and the sludge has to be treated prior to reuse or disposal (Section 5). Anaerobic treatment has recently been suggested for wastewater. The main reason for the use of an anaerobic process is the recovery of energy (in the form of methane) from the wastewater. The upflow anaerobic sludge blanket process is described at the end of this section.

4.2.1 Activated sludge treatment

The term 'activated sludge' refers to sludge in the aeration tank of an activated sludge treatment process. It consists of flocs of bacteria, which consume the biodegradable organic substances in the wastewater. Because of its usefulness in removing organic substances from wastewater, the sludge is kept in the process by separating it from the treated wastewater and re-circulating it. A typical arrangement of an activated sludge process is schematically shown in Figure 16.

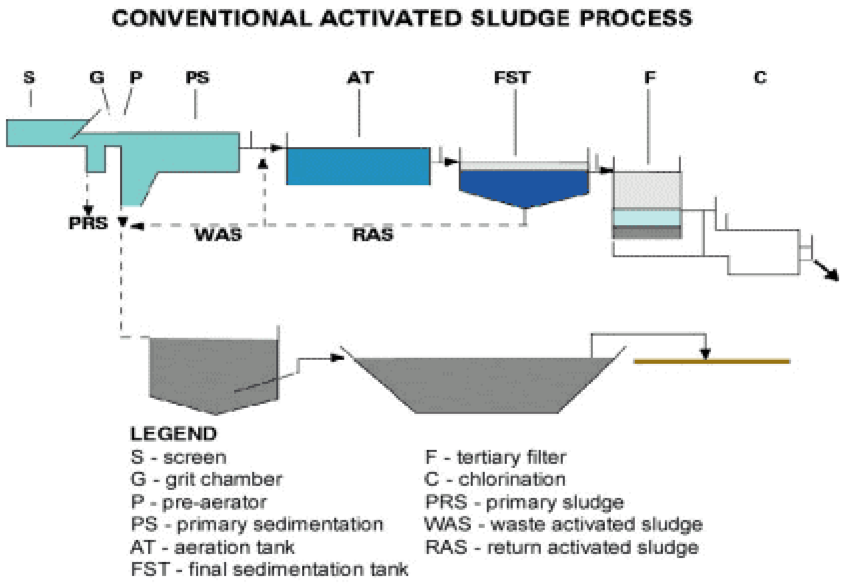

Figure 16: Schematic diagram of an activated sludge wastewater treatment process

Wastewater entering an activated sludge treatment plant is usually passed through a bar screen to remove gross materials such as napkins, rags and other materials that may damage mechanical equipment further down the treatment plant. The bar screen consists of vertical bars separated by a distance of about 1 cm. Screened solids are continually scraped off the bars. The screenings can be landfilled or incinerated.

Sand and similar heavy particles are removed next in a grit chamber. This chamber can be aerated to separate these particles from other suspended solids. The wastewater spends a relatively short period in the grit chamber (in the order of minutes). The sedimented sand and grit is usually landfilled.

The finer solids are removed in a settling or sedimentation tank, where the wastewater spends of the order of an hour to allow the solids to settle or float. The mechanical removal of solids as described above is usually called 'primary treatment', the sedimentation tank as primary sedimentation tank, the overflow from the sedimentation tank as primary-treated wastewater (primary effluent) and the sludge produced as primary sludge.

The primary-treated wastewater is then passed to an aeration chamber. Aeration provides oxygen to the activated sludge and at the same time thoroughly mixes the sludge and the wastewater. Aeration is by either bubbling air through diffusers at the bottom of the aeration tank, or by mechanically agitating the surface of the water.

In the aeration tank, the bacteria in the activated sludge consume the organic substances in the wastewater. The organic substances are utilised by the bacteria for energy, growth and reproduction. The wastewater spends a few hours in the aeration chamber before entering a second sedimentation tank to separate the activated sludge from the treated wastewater. The activated sludge is returned to the aeration tank. There is an increase in the amount of activated sludge because of growth and reproduction of the bacteria. The excess sludge is wasted to maintain a desired amount of sludge in the system. This part of the treatment process is called 'secondary treatment', the sedimentation tank as secondary sedimentation tank, the overflow from the sedimentation tank as secondary-treated wastewater (secondary effluent) and the excess activated sludge as secondary sludge.

Depending on the flow rate of wastewater, several parallel trains of primary and secondary stages can be employed. There are several ways to operate an activated sludge process. In a 'high rate' process a relatively high volume of wastewater is treated per unit volume of activated sludge. The high amount of organic waste consumed by the activated sludge produces a high amount of excess sludge. In an 'extended aeration' mode of operation the opposite condition takes place. A relatively low amount of organic waste is treated per unit volume of sludge with little excess sludge to be removed. Removal of BOD is higher in the extended aeration mode compared to the high rate mode, but more wastewater can be treated with the latter mode.

An activated sludge treatment plant is a highly mechanised plant, and is suited to automated operation. The capital cost for building such a plant is relatively high. The energy requirement, particularly for providing air to the aeration tank, is also relatively high. There is a need for regular maintenance of the mechanical equipment, which requires skilled technical personnel and suitable spare parts. The operation and maintenance costs of an activated sludge treatment plant are therefore relatively high.

An activated sludge treatment process can be operated in batches rather than continuously. One tank is allowed to fill with wastewater. It is then aerated to satisfy the oxygen demand of the wastewater, following which the activated sludge is allowed to settle. The treated wastewater is then decanted, and the tank is filled with a new batch of wastewater. At least two tanks are needed for the batch mode of operation, constituting what is called a ‘sequential batch reactor (SBR)’. SBRs are suited to smaller flows, because the size of each tank is determined by the volume of wastewater produced during the treatment period in the other tank.

4.2.2 Trickling filtration

A trickling filter is a bed of solid media for bacteria to attach on its surfaces. Wastewater is irrigated on the solid media (Figure 17). It is also called a biological filter to emphasise that the filtration process is not mechanical straining of solids, but removal of organic substances by use of bacterial action.

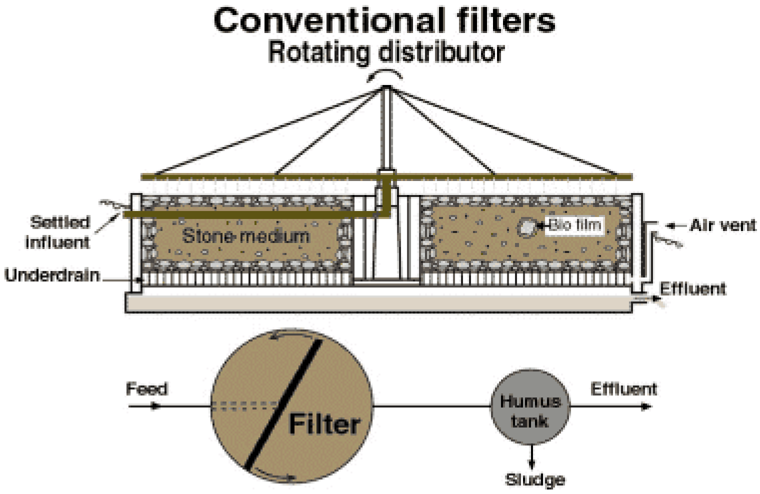

Figure 17: Schematic diagram of a trickling or biological filter

The solid media can be stones, waste coal, gravel or specially manufactured plastic media. The latter can be corrugated plastic sheets or hollow plastic cylinders, with the main aim being to provide a large surface area for bacteria to attach to, while at the same time allowing free movement of air. Typically the solid media is placed in a tank on a support with openings to allow air to move up by natural convection and for treated wastewater to be collected in the under-drain.

Wastewater has to undergo primary treatment (See Activated Sludge Treatment above, 4.2.1) before trickling filtration, otherwise solids will block the filter. As wastewater trickles over the surfaces of the solid media organic substances are trapped in the layer of bacterial slime. The bacteria consume the organic substances in the same manner as in the activated sludge process, while air diffuses into the slime layer from the air spaces in the bed of the trickling filter. Growth and reproduction of the bacteria take place and result in an increase of thickness of the slime layer, particularly at the top of the biological filter. Periodically bacterial slime sloughs off the surfaces of the filter media and leaves with the treated wastewater.

Solids derived from the sloughing off of bacterial slime are separated from the treated wastewater in a sedimentation tank. Sludge from this sedimentation tank is not returned to the trickling filter, but treated prior to reuse or disposal (Section 6). Treated wastewater can however be returned to the trickling filter, if this will assist with either treating the wastewater further (second pass) or more generally for a more uniform distribution of water over the trickling filter bed. The trickling filter and associated sedimentation tank is also termed 'secondary treatment'.

The energy requirement for operating a trickling filter is less than for an activated sludge process, because oxygen supply to the bacteria is provided by natural diffusion of air. The area requirement of a biological filter is, however, larger than for an activated sludge process to achieve the same quality of treated wastewater.

4.2.3 Lagoons

Ponding or lagooning is effective in treating wastewater and can reduce BOD and SS to the same levels as mechanical treatment plants (e.g. Activated Sludge Treatment). In addition because of the longer residence time of wastewater in the lagoon (days), removal of pathogenic bacteria and viruses by natural die-off is greater than in an activated sludge treatment plant (residence time usually several hours). Cysts of parasites and helminth eggs are also usually removed through sedimentation in the lagoons.

A lagoon is a shallow excavation in the ground (1 to 2 m deep). It is generally unlined percolation of wastewater into the soil and groundwater takes place. With time the percolation rate will reduce, because of formation of a sediment layer. Evaporation loss of water can be significant in arid climate regions. The soil itself is, however, not involved in the physical and biochemical wastewater treatment processes taking place in the lagoon. A lagoon can therefore be lined with a layer of clay or with an impermeable plastic membrane if protection of groundwater is desired, without affecting the performance of the lagoon. Wastewater lagoons are also called 'waste stabilisation lagoons', because the organic substances in the wastewater are converted to more stable (less degradable) forms.

The following processes take place in a lagoon. As wastewater enters a lagoon, sedimentation of solids occurs. Because of the long residence time of the wastewater in the lagoon system, much of the solids in the original wastewater are removed. Aeration of the water from the atmosphere occurs by a process of diffusion aided by turbulence caused by wind movement on the surface of the water. This process is the same as the natural process of aeration of a lake.

Oxygen is also supplied by algae in the lagoon which thrive on the nutrients (nitrogen and phosphorus) released by the decomposition of the organic wastes. The photosynthetic activity of algae, however, only takes place when there is sunlight. Thus oxygen produced by photosynthesis is only available during this period. A symbiotic relationship exists between the bacteria and the algae. Bacteria take up oxygen and release carbon dioxide, while algae take up carbon dioxide released by the bacteria and produce oxygen for the bacteria (Figure 18).

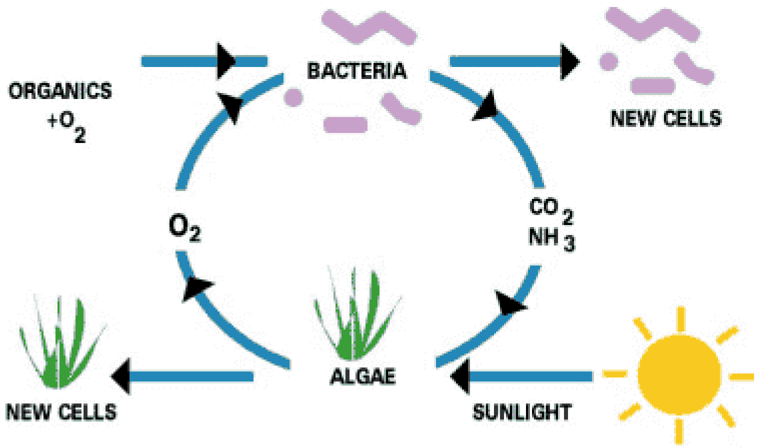

Figure 18: Symbiotic relationship between bacteria and algae in a wastewater

Depending on the oxygen demand of the bacteria in the lagoon, the following conditions occur:

Anaerobic lagoon	The oxygen demand of the bacteria exceeds oxygen supply by surface aeration and algal photosynthesis. Biodegradation of the organic wastes is by anaerobic bacteria. Methane gas is a by-product. Odorous gases are produced, but impact is reduced when a layer of scum forms at the water surface.
Facultative lagoon	The oxygen demand of the bacteria is met by surface aeration and algal photosynthesis, but is not met when the latter is not active. The water environment is aerobic during the day, but turns anaerobic at night. Biodegradation of organic wastes is by facultative bacteria, which can operate under both aerobic and

	anaerobic conditions.
Aerobic lagoon	The oxygen demand of the bacteria is met by surface aeration and algal photosynthesis.

It is common to have a series of lagoons with the first one or two being anaerobic lagoons, the middle ones facultative lagoons and the last few aerobic lagoons. The sediment at the bottom of lagoons is anaerobic, and undergoes anaerobic bacterial decomposition. The first lagoon in a series will eventually be filled with solids. The sludge produced can be removed and treated for re-use or disposal (Section 6) or allowed to undergo further biodegradation in the lagoon prior to re-use. Anaerobic lagoons can be made deeper so that more sludge can be accommodated and the need to remove sludge made less frequent.

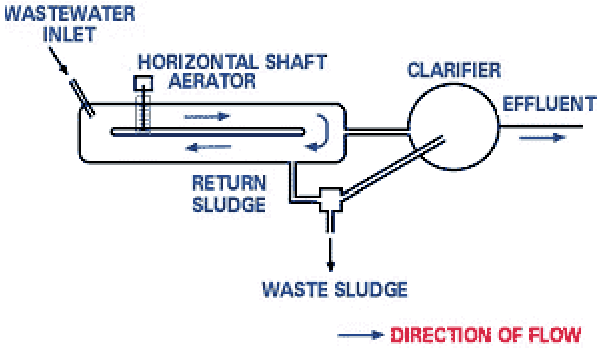

Figure 19: Oxidation ditch

Lagoon performance is affected by temperature. At a higher ambient temperature (e.g. in the tropics) a shorter residence time of wastewater in the lagoon is required to achieve the same level of treatment compared to when the temperature is lower. Because algae are present in treatment lagoons, they leave with the treated effluent. One way of harvesting the algae is through aquaculture (see Section 6).

Oxygen transfer from the atmosphere into lagoons can be increased by mechanically agitating the surface of the water. This can be done by using a vertically mounted impeller, and the lagoon becomes more like the aeration tank of an activated sludge process. The agitation can also be provided using a horizontally mounted rotor. A configuration that can be used to apply this is a circular ditch (Figure 19), and the water is continuously circulated around the ditch so that its movement is like that in a river.

4.2.4 Land based treatment

Land based treatment of wastewater relies on the action of soil bacteria to degrade the organic wastes in the wastewater. In what is termed 'Soil Aquifer Treatment' wastewater is applied to unlined basins in cycles of flooding and drying of approximately one week each (Figure 20). During flooding wastewater percolates through the soil beneath the basin to the unconfined groundwater aquifer. Soil bacteria consume organic substances, suspended solids are trapped at the bottom of the basin, and the percolation rate decreases. During drying the layer of solids accumulating at the bottom of the basin are degraded by bacteria and also undergo drying. The percolation capacity for wastewater is therefore rejuvenated.

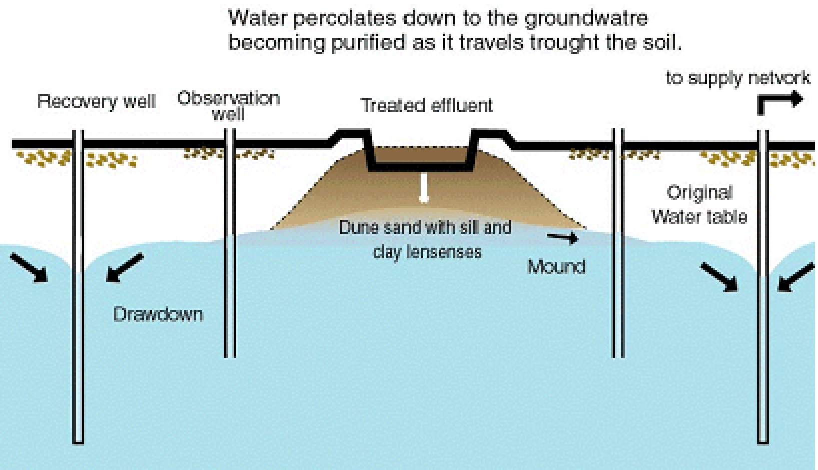

Figure 20: Soil aquifer treatment or rapid-rate land application system

Soil aquifer treatment is also known as rapid-rate land application. It works well when the soil permeability is high (> 1 m/day), and the highest groundwater table is at least 2 m below the bottom of the basin. Upon reaching the groundwater the SS and BOD of the water is generally low. Furthermore if the soil beneath the basin contains clay minerals, pollutants like heavy metals may be adsorbed by the clay minerals. The groundwater aquifer acts as storage for the treated wastewater, which is usually withdrawn for reuse.

In what is termed 'slow-rate land application system' wastewater is applied to land through channels in the upper part of the gradient and treated wastewater is collected in channels in the lower part of the gradient of a slightly inclined ground (Figure 21). The application is intermittent and its rate is dependent on the permeability of the soil and the loss of water due to evaporation. The organic substances in the wastewater are biodegraded by soil bacteria at the surface of the soil and during percolation through the soil. Vegetation is usually part of the treatment process. It takes up nutrients (nitrogen and phosphorus) released from the degradation of the organic substances. The vegetation (usually grasses) is harvested by grazing animals (cattle or sheep). In New Zealand, treated wastewater is successfully disposed by spray irrigated into forests and crops. The trees and crops take up the disposed nutrients and use then to promote growth. This is mainly for disposal purposes and not for re-use. Crops (usually grass) are harvested as silage and then fed to live stock. This disposal system is referred to as “cut and carry” as the livestock do not graze the irrigated paddocks. The silage is of good quality and there is a demand for it. Sub-surface irrigation disposal of wastewater for silage is also being promoted.

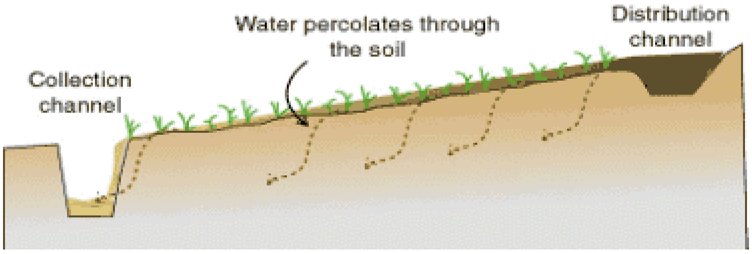

Figure 21: Slow-rate land application system

When the soil is saturated with water (e.g. during the rainy season), 'overland flow' or 'grass filtration' mode of operation is used. In this case wastewater flows over the soil surface and bacteria attached to the vegetation and soil surface remove the organic substances (Figure 22).

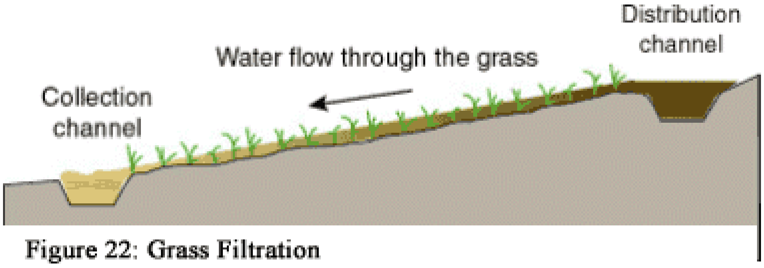

Figure 22: Grass Filtration

Raw wastewater can be used in any of the above land based treatment system provided that the application rate is small. Settled wastewater needs to be used for higher rates of application. Land application treatment systems work well in arid or semi-arid regions, where the soil is generally not saturated with water over much of the year, and reuse of wastewater for agriculture is attractive. Particular attention has to be given to public health requirements.

4.2.5 Constructed wetlands

Constructed wetlands lie in-between lagoons (4.2.3) and land based treatment systems (4.2.4). They are based on natural wetlands, which act as a water filter and purifier. A constructed wetland consists of a gravel bed in which wetland species, such as reeds, are planted (Figure 23). Wastewater, usually after the settling of solids, passes through the gravel bed. The flow of wastewater can either be surface or sub-surface. The bacteria that are attached to the surfaces of the bed and plant roots degrade organic substances. The reed beds remove N and P as or more effectively than conventional wastewater treatment plants. They are suitable for treating domestic sewage as well as other forms of wastewater such as contaminated groundwater and agricultural and animal waste. Wetland plants take up nutrients (nitrogen and phosphorus) when water residence time is long. Long-term nutrient removal requires harvesting of the plants. Constructed wetlands need to be designed to minimise problems with insects (mosquitoes and midges).

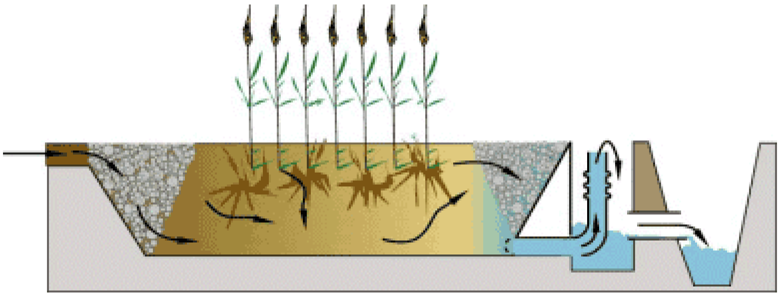

Figure 23: Constructed wetland

Constructed wetlands are particularly of interest in low-income areas as they are simple to construct, operate and maintain, usually by trained local people. This keeps the both the capital and operating costs low.

4.2.6 Anaerobic treatment of wastewater

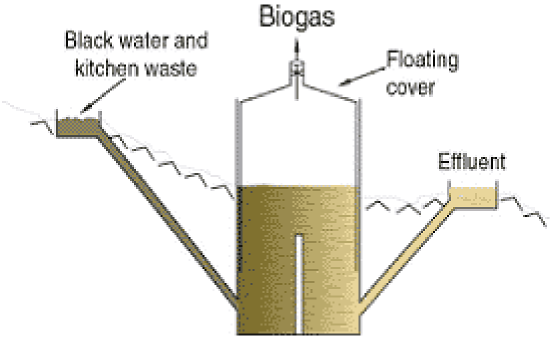

Figure 24: A simple anaerobic treatment of blackwater and kitchen

Anaerobic treatment is more suited to wastewater high in BOD. It is used to treat the sludge from an activated sludge treatment or biological filtration process (see Section 5). In households where there is cottage industry (such as food processing to supply restaurants or food market) the wastewater may be high in BOD. Wastewater high in BOD may also be generated when water conservation measures result in less water being used. A simple method to treat blackwater and kitchen waste is shown in Figure 24. The biogas produced can be combusted for use in cooking.

In the Upflow Anaerobic Sludge Blanket (UASB) process settled wastewater is passed upward through a sludge blanket. The sludge blanket consists of anaerobic bacteria, which have developed into granules. Because of the high settling velocity of the granules, the granules are not carried over in the upflowing wastewater. A high concentration of bacteria is therefore retained in the tank. The tank itself has no internal moving parts (Figure 25). If wastewater is distributed evenly at the base of the tank, mixing between the wastewater and the granules of bacteria is promoted by the carbon dioxide and methane gases produced by the anaerobic treatment process and the upward moving flow of the wastewater.

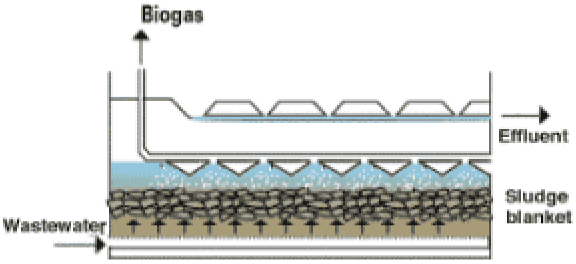

Figure 25: Upflow anaerobic sludge blanket (UASB) reactor

Although the reactor itself has a simple configuration with no moving parts, pumping of the feed is still required. Methane gas is produced which needs special handling procedures to prevent leakage and explosion. Wastewater treated anaerobically requires further aerobic treatment to reduce its BOD and odour. Excess granules need to be treated prior to reuse or disposal, although currently there is a demand for the granules to start up UASB reactors. The mixture of methane and carbon dioxide (termed 'biogas') can be combusted and used for heating the content of the anaerobic reactor or for other purposes.

4.3 Stormwater treatment

Stormwater can be polluted as discussed in Section 2. When collected in a combined sewerage system it is treated with the wastewater, though treatment is not effective during peak heavy stormwater run-off periods resulting in combined sewer overflow (CSO) that is not treated. Storage basins or tanks can be used to accommodate moderate peak flows of combined stormwater and wastewater, and treating the stored water at night when wastewater flow is a minimum. Further details on CSO can be found in Source Book's Regional Overview for Western Europe, which devotes a full sub-section on CSO.

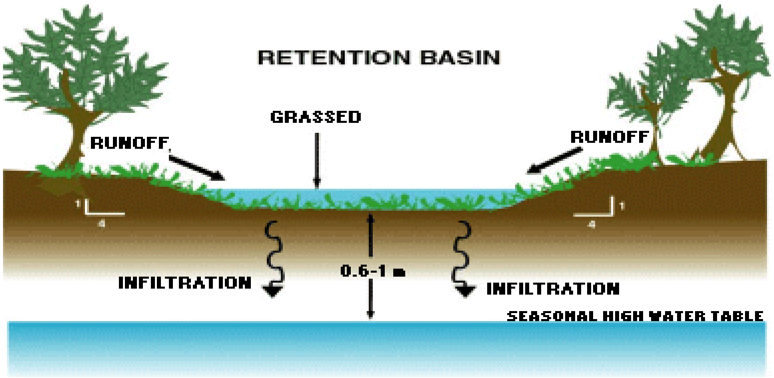

Figure 26: Stormwater treatment by settling

Separately collected stormwater is generally treated by passing it through a settling basin to remove solids (Figure 27). The retention time in the settling basin is designed so that solids can settle in say 20 minutes for a one in five year storm-event. For storm-events less than the design value, removal efficiency is greater, while for storm-events greater than the design value removal efficiency is lower. Mechanical devices have been developed that can trap gross solids. Both settling basins and mechanical traps need to be cleaned regularly to maintain solids removal efficiency.

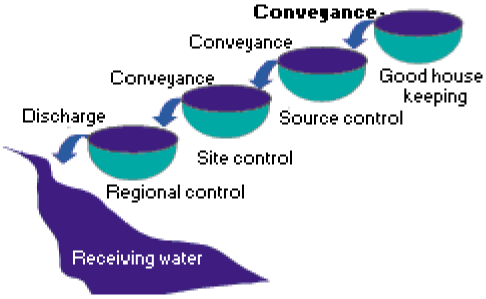

Figure 27: Management train for stormwater at the local sub-catchment and catchment levels

Naturally landscaped stormwater drains can help filter out fine sediments through the action of vegetation slowing down the flow and trapping solids. Permeable surfaces allow rainwater to percolate into the soil, thus treating the water in much the same manner as land based treatment of wastewater (4.2.4.) and at the same time reduce the amount of run-off. Pavements have been designed and manufactured for this purpose. Directing run-off to vegetated area (rainwater harvesting) can reduce down-stream flow and reuse the water for maintaining plant growth. This is especially beneficial in arid climates. Four techniques for stormwater treatment are described below. Used judiciously these can treat stormwater locally (at source, Figure 27). Applying these on a sub-catchment scale (site), or whole catchment scale (region) can reduce flooding and the undesirable impacts of stormwater described in Section 2, while at the same time improve the amenity value of the landscape through creation of, for example, passive recreation water bodies.

4.3.1 Filter strips and swales

Figure 28: Filter strip and swale in an urban landscape

Filter strips and swales are vegetated surface features that drain water evenly off impermeable areas (Figure 28). Swales are long shallow channels, while filter strips are gently sloping areas of ground. They allow run-off to flow in sheets through vegetation, slowing and filtering the flow. Swales also act to temporarily store and infiltrate the run-off into the ground. Sediments are removed from the water, and vegetation can take up any nutrients in the water. Swales and filter strips can be integrated into the surrounding land use, for example, road verges. Local grasses and flower species can be introduced for visual effect and to provide a wildlife habitat. Maintenance consists of regular mowing, clearing litter and periodic removal of excess silt.

4.3.2 Filter drains and permeable surfaces

Filter drains consist of permeable materials located below ground to store run-off. Run-off flows to the storage area via a permeable surface (Figure 29). The permeable surface can be in the form of grassed or graveled areas, paving blocks with gaps between individual units or paving blocks with vertical voids built in. Water is therefore collected from a large surface area, stored in the filter drains and allowed to infiltrate through the soil. The permeable fill traps sediments and thereby cleans the run-off. Filter drains and permeable surfaces are currently used for road verges and car parks. The surfaces should be kept clear of silt and cleaned regularly to keep the voids clear. Weed control may be necessary.

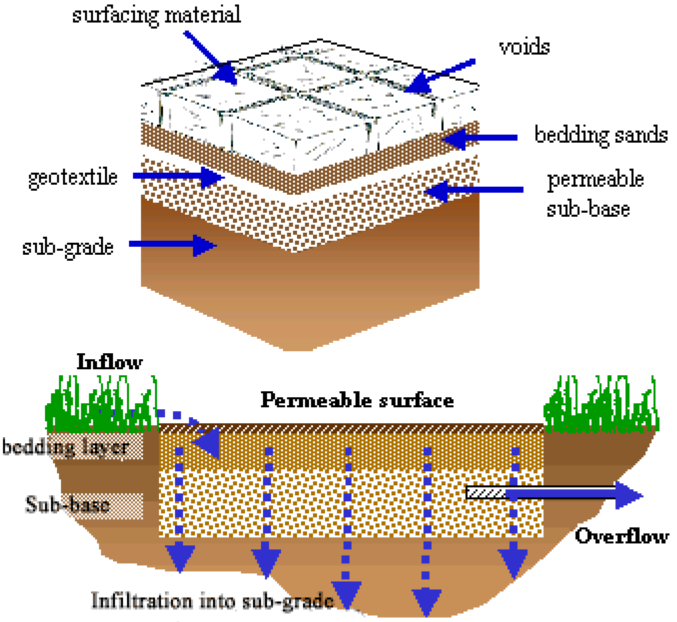

Figure 29: Permeable pavements

4.3.3 Infiltration devices

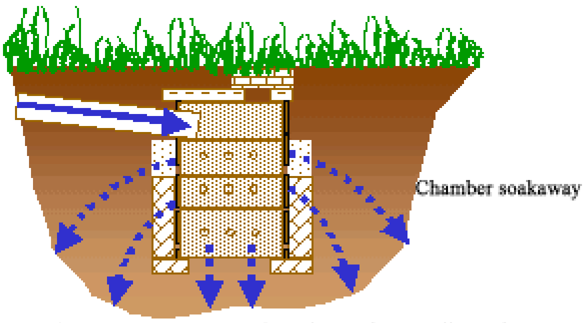

Figure 30: Cross section through a traditonal soakway or a chamber soakway (CIRIA, 1999)

Infiltration devices drain water directly into the ground. They include soakways and infiltration trenches, which are located below ground, and into which stormwater run-off is directed. They function by storing water and allowing the water to infiltrate into the ground. Figure 30 shows a cross-section through a traditional soakway or a chamber soakway. They work well when the soil is permeable and the groundwater table is not close to the surface. Maintenance consists of regular inspection to ensure the infiltration capacity is maintained. Areas draining to an infiltration device should be kept clear of silt, as this will get washed into the device and reduce its permeability as well as filling up space that should be used for storage.

4.3.4 Basins and ponds

Basins are areas for storage of run-off that are dry during dry weather, whereas ponds have permanent water (Figure 31). Both store water and therefore attenuate the flow of water during a storm. Flow downstream of the basins or ponds can therefore be controlled. Basins and ponds also act as infiltration devices (Section 4.3.3). Basins and ponds are usually used at the end of a train of treatment for stormwater, and provide additional step if source control (Sections 4.3.1 to 4.3.3) does not have an adequate capacity to control run-off. Detention time is of the order of two to three weeks. Both basins and ponds can be vegetated, so that we can have a range of features, including wetlands that have amenity values for passive recreation or wildlife habitat. Run-off water quality is improved upon storage in basins or ponds because of sedimentation of solids, bacterial action and nutrient uptake by vegetation. Water stored in ponds can also be used for irrigation of parks and gardens or for fire-fighting and other purposes. Basins and ponds need to be maintained to control vegetation and removal of accumulated silt.

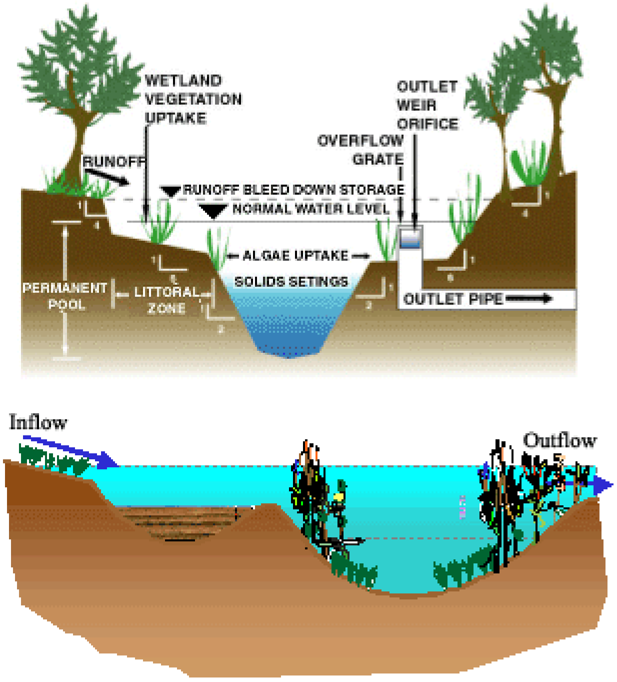

Figure 31: Pond, basin and constructed wetland for stormwater treatment

5. Sludge treatment, reuse and disposal

Sludge is produced from the treatment of wastewater in on-site (e.g. septic tank) and off-site (e.g. activated sludge) systems. This is inherently so because a primary aim of wastewater treatment is removing solids from the wastewater. In addition, soluble organic substances are converted to bacterial cells, and the latter is removed from the wastewater. Sludge is also produced from the treatment of stormwater (Section 4.3), although it is likely to be less organic in nature compared to wastewater sludge.

Bucket latrine and vault latrines store faecal sludge, which needs to be collected and treated. These two types of latrine are not discussed in Section 4, because no treatment is involved at the latrines. In the former case human excreta is deposited in a bucket and the content of the bucket is emptied daily, usually at night giving the term 'night soil' to the faecal sludge. In the latter the excreta is stored in a vault for a longer period of up to two weeks before removal. The content of the vault should preferably be removed mechanically.

The characteristics of sludge vary widely from relatively fresh faecal materials generated in bucket latrines to sludge which has undergone bacterial decomposition for over a year in a double pit latrine. The treatment required is therefore dependent on the characteristics of the sludge. The former may contain large numbers of pathogens, whereas the latter will contain much less due to pathogen die-off. Sludge should, however, always be handled with care to avoid contact with pathogens. Sludge may be contaminated with heavy metals and other pollutants, especially when industrial wastes are disposed into the sewer. Pre-treatment of industrial wastes is therefore essential before discharge to the sewer. Treatment of sludge contaminated with high concentrations of heavy metals or toxic chemicals will be more difficult and the potential for re-use of the sludge will be limited.

Faecal sludge contains essential nutrients (nitrogen and phosphorus) and is potentially beneficial as fertilisers for plants. The organic carbon in the sludge, once stabilised, is also desirable as a soil conditioner, because it provides improved soil structure for plant roots.

Options for sludge treatment include stabilisation, thickening, dewatering, drying and incineration. The latter is most costly, because fuel is needed and air pollution control requires extensive treatment of the combustion gases. It can be used when the sludge is heavily contaminated with heavy metals or other undesirable pollutants. Prevention of contamination of the sludge by industrial wastes is preferable to incineration. A conversion process to produce oil from sludge has been developed, which can be suitable for heavily contaminated sludge (Skrypsi-Mantele, et al 2000). The costs of treatment of sludge are generally of the same order as the costs of removing the sludge from the wastewater.

5.1 Stabilisation

Faecal sludge collected from bucket or vault latrines has a very high biochemical oxygen demand (BOD) and is generally putrid and odorous. Primary and secondary sludges from an activated sludge treatment plant also have a high BOD and may be difficult to dewater. Even sludge from a septic tank, which has undergone bacterial decomposition over at least a year, still has a high BOD. Stabilisation is the term used to denote the process of BOD reduction. The stabilisation process can be carried out under aerobic or anaerobic conditions.

Aerobic stabilisation of primary and secondary sludges can be carried out in an aeration tank in the same manner as in an activated sludge process. Because of the high oxygen requirement, this process is energy intensive and costs are high. Aerobic stabilisation requires less energy when carried out as part of a composting process. For composting of sludge, its solids content should be increased to at least 15 % so that it can be handled as a solid. Thickening and dewatering (see below) of primary and secondary sludges are required to achieve the required solids content. Faecal sludge may contain high enough solids. Mixing with dry materials such as dry sawdust may assist with achieving the required solids content as well attaining the required carbon to nitrogen ratio for composting.

5.2 Composting

Composting is an aerobic bacterial decomposition process to stabilise organic wastes and produce humus (compost). Compost contains nutrients and organic carbon which are excellent soil conditioners. Composting takes place naturally on a forest floor where organic materials (leaf litter, animal wastes) are converted to more stable organic materials (humus) and the nutrients are released and made available for plant uptake. The process is slow on a forest floor, but can be accelerated under optimum conditions.

The optimum conditions for composting are a moisture content of about 50 %, a carbon to nitrogen ratio of about 25 to 30, and temperature of 55 oC. Because wastewater sludge is rich in nutrients, its carbon to nitrogen ratio is low (5 to 10). It is also high in moisture. Addition of dry sawdust, which is very high in carbon to nitrogen ratio (500) can adjust both the moisture and carbon to nitrogen ratio. Other waste materials that can be used for this purpose are mulched garden wastes, forest wastes and shredded newspaper.

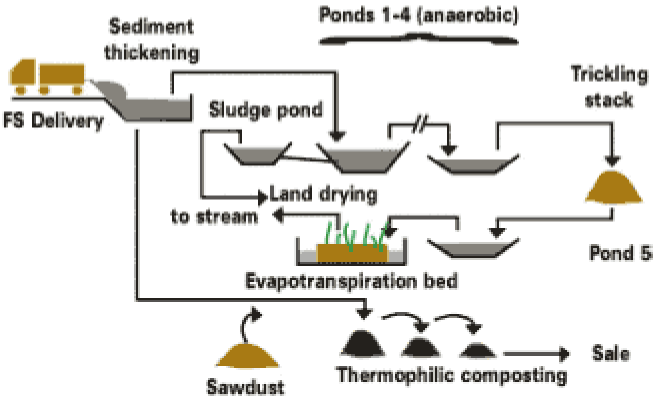

Figure 32: Windrow composting of faecal sludge (FS)
(from Heinss et al., 1999)

Composting can be carried out in a specially built composter, such as an inclined rotating cylinder, fed on one end with the raw materials, and the aerated product collected at the other end. As the materials are slowly tumbled over a period of about one week, they are mixed and aerated. Because bacterial decomposition produces heat, temperatures in the insulated composter can easily reach 55oC. The immature compost is then windrowed for at least 12 weeks to allow the composting process to complete, with occasional turning of the windrow.

Composting can be more simply carried out in windrows (Figure 32). Regular turning of the windrows assists with mixing of the materials and more importantly supply the oxygen to the bacteria. Temperatures can reach 55 oC, because compost has a good heat insulating property. Turning of the compost also ensures that all parts of the windrow reach the required 55oC essential for pathogen destruction. Turning is required every two to three days in the first two weeks when temperature is 55oC or above. After this period frequent turning of the compost windrow is not required as less heat is generated and less oxygen is required while the compost undergoes maturation.

5.3 Anaerobic digestion

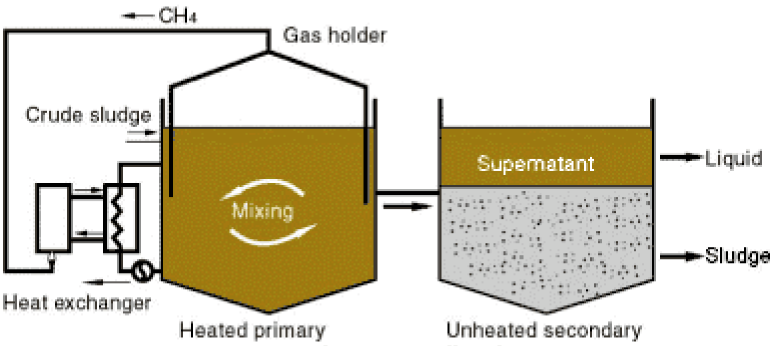

Figure 33: Simple anaerobic digestion process

Anaerobic digestion is a bacterial decomposition process that stabilises organic wastes and produces a mixture of methane and carbon dioxide gas (biogas). The heat value of methane is the same as natural petroleum gas, and biogas is valuable as an energy source. Anaerobic digestion is usually carried out in a specially built digester, where the content is mixed and the digester maintained at 35 oC by combusting the biogas produced. After digestion the sludge is passed to a sedimentation tank where the sludge is thickened. Biogas is collected from the digester (Figure 33). The thickened sludge requires further treatment prior to reuse or disposal.

Anaerobic digestion can also be carried out at a slower rate in an unmixed tank or pond. Covering is usually by a UV resistant plastic sheet, because of the large area needed to be covered, and biogas is collected from the top of the sheet. Storage of biogas can be in a cylindrical tank with a floating roof. The cylindrical roof floats on water and its position is determined by the volume of the gas stored under the pressure of the roof. Biogas can also be stored in a balloon, but only under low pressure.

5.4 Thickening

Sludge contains a high concentration of solids, but its water content is still high. Combined primary and secondary sludge from an activated sludge treatment plant contains about 2 % solids and hence 98 % water. One kg of dry sludge is associated with 49 L of water. Thickening to 5 % solids means one kg of dry solids is associated with 19 L of water, thus 30 L of water has to be removed.

Thickening is carried out in a sedimentation tank or in a sedimentation pond (Figure 34). The latter is advantageous if land area is available, because the sludge can be allowed to settle over a much longer period and a higher solids content of the thickened sludge is achieved. The water removed from thickening needs treatment. It can be returned to the inlet of an off-site wastewater treatment plant, or in the case of sludge from on-site units by an aerobic treatment process such as lagooning.

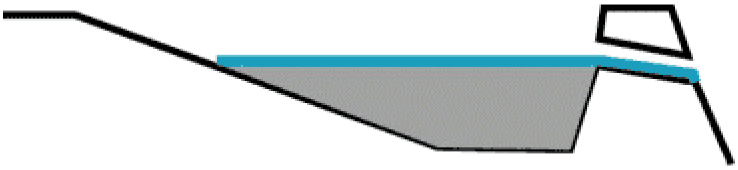

Figure 34: Sludge thickening pond (Ghana) (Heinss et al., 1999)

5.5 Dewatering and drying

Dewatering aims to reduce the water content further so that the solids content of the sludge is about 20 % (equivalent to 1 kg dry sludge with 4 L of water). The sludge can then be handled like a solid. Dewatering can be done mechanically using a filter press (employing pressure or vacuum), or a centrifuge. It can also be done using drying beds. A drying bed consists of a 30 cm bed of sand with an under-drainage (Figure 35). Sludge is applied on the sand bed and is allowed to dry by evaporation and drainage of excess water over a period of several weeks depending on climatic conditions. Bacterial decomposition of the sludge takes place during the drying process while moisture content is sufficiently high. During the rainy season the process may take a longer time to complete and sizing the area of the drying beds should take this into account.

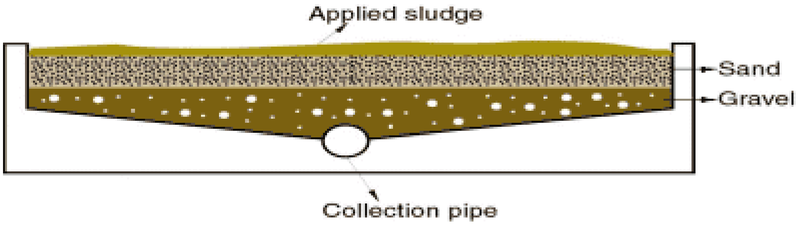

Figure 35: Sludge drying bed

5.6 Sludge reuse

Raw sludge from activated sludge treatment plants has been applied directly onto agricultural land particularly in the United Kingdom. This practice is considered unsatisfactory because of the presence of pathogens in the sludge in high numbers. There has been no thorough study, however, which has shown that there is an increase in the risk of acquiring illnesses associated with pathogens in the raw sludge when proper handling procedure and non-entry to the land following application is observed.

Reuse of composted sludge as a soil conditioner in agriculture and horticulture returns carbon, nitrogen, phosphorus and elements essential for plant growth back to the soil. Less chemical fertilisers are required and the organic carbon helps to improve soil structure for soil aeration, water percolation and root growth. The nitrogen and phosphorus are also released gradually for plant uptake compared to the more soluble chemical fertilisers. The potential of leaching of the nutrients to ground or surface water by rainfall run-off is much reduced. Pathogens and heavy metals can, however, limit the reuse of sludge.

Pathogens should be reduced to levels that do not pose health hazards to workers handling the sludge, potential health hazards from the spreading of helminth eggs and from horticultural produce contaminated by pathogens. Composting of the sludge to attain a temperature of 55 oC for two weeks followed by windrow maturation produces compost that meets these conditions. Stabilised sludge, which has been dewatered and dried on sand beds to attain a low moisture content, can meet the same conditions.

Heavy metals and toxic chemicals are difficult to remove from sludge. Preventing these chemicals from entering the wastewater or sludge should be the aim of wastewater management for sludge intended for reuse in agriculture or horticulture. Reuse may still be possible for purposes such as mine site rehabilitation, highway landscaping or for landfill cover. Sludge that has been conditioned for reuse is called ‘biosolids’

Conversion of sludge, which is heavily contaminated by heavy metals or toxic chemicals, to oil is technically feasible (Enersludge process). A full-scale plant is operating in Perth, Western Australia (Bridle et al., 2000). The conversion is by a pyrolysis process, heating dried sludge to a high temperature in the absence of oxygen or with a controlled amount of oxygen. Capital and running costs of an oil from sludge process are high.

5.7 Sludge disposal

Final or ultimate disposal of sludge, which cannot be reused, is by landfilling or incineration. Since sludge for landfilling usually contains heavy metals or toxic chemicals, lining of the landfill with clay or plastic liner may be required to prevent contamination of groundwater. Incineration of sludge is by a multiple hearth furnace or fluidised bed furnace. Energy input is required to dry the sludge before combustion is self-sustaining. Combustion flue gases usually need treatment to meet air pollution control standards. Investment and operating costs are high.

6. Wastewater and stormwater reuse

Human excreta and wastewater contains useful materials. These are water, organic carbon and nutrients and should be regarded as a resource. In their natural cycles they are broken down by micro-organisms and become useful to plants and animals, thus sustaining natural ecosystems. When improperly disposed these substances can cause pollution, because the organic materials exert oxygen demand, and the nutrients promote algal growth in lakes, rivers and near-shore marine environments.

Human excreta and wastewater also contain pathogens. Reuse of the wastes must ensure that public health is maintained. Planned reuse is the key to wastewater reuse. Planning for reuse ensures that public health and protection of the environment are taken into account. Reuse of treated wastewater for irrigation of crops, for example, will need to meet (i) standards for indicator pathogens, and (ii) plant requirement for water, nitrogen and phosphorus. WHO and others have developed standards for reuse of wastewater for various purposes. Further details of these standards can be found in the Regional Overviews in the Source Book, published by IWA and IETC. Plant requirements for water and nutrients are plant-specific and site-specific (dependent on soil type and climate) and information on these requirements need to be obtained from local information sources.

6.1 Wastewater reuse from off-site treatment plants

6.1.1 Wastewater reuse for agriculture

Treated wastewater from off-site treatment plants can be reused for irrigation of parks and gardens, agriculture and horticulture, tree plantation and aquaculture, if these exist or can be established not far from the wastewater treatment plants. For these purposes the wastewater should generally be treated to secondary wastewater standard (< 20 mg/L BOD and < 30 mg/L SS). Total coliforms should be < 1000 organisms per 100 mL for irrigation by spraying. When sub-surface irrigation is used this requirement may not be necessary. A period of non-entry to irrigated sites may need to be observed, particularly for wastewater-irrigated parks and gardens. Irrigation of vegetables for direct human consumption requires a much stricter guideline.

Because requirement of wastewater for plant growth is governed by climatic conditions, soil and plant type, there may be a need for storage of the wastewater. An alternative to storage, if land area is not available for this purpose, is to dispose of wastewater that is excess to requirement. A combination of wastewater for irrigation and aquaculture (see below) is also an option that can be considered.

Land application for treatment of wastewater described in Section 4.2.4 (Slow rate land application and grass filtration) when combined with growing of grasses for grazing by sheep or cattle plus the “cut and carry” system can properly be considered as treatment and reuse of wastewater.

6.1.2 Wastewater reuse for aquaculture

Wastewater reuse for aquaculture has been practised in many countries for a considerable period of time. It has the potential of wider application in the tropics. There is great diversity of systems involving cultivation of aquatic species, (mainly fish) and plants (mainly aquatic vegetables such as water spinach). The Source Book, published by IWA and IETC, contains a detailed section on aquaculture and a case study is presented in the Regional Overview for Central & South America.

Farmers and local communities have developed most reuse systems; the primary motivating factor has been reuse of nutrients for food production rather than wastewater treatment, and with scant attention to either waste treatment or to public health. In most aquaculture systems, wastewater is not reused directly in aquaculture and the nutrients contained in the wastewater are used as fertiliser to produce natural food such as plankton for fish. These nutrients, mainly nitrogen and phosphorus, are also taken up directly by large aquatic plants such as duckweed which is cultivated for animal feed, and aquatic vegetables such as water spinach and water mimosa cultivated for human food.

As wastewater provides a source of nutrients for aquaculture, it is technically feasible to link it up with most sanitation technologies, providing that land is available at reasonable cost. Farmers have learned by experience how to culture fish, first in static-water nightsoil-fed ponds and more recently in conventional wastewater-fed fishponds. Research has provided a scientific basis for the key parameters in wastewater-fed aquaculture practice developed earlier by farmers and these can be found in the Source Book, published by IWA and IETC.

There are a number of constraints to wastewater-fed aquaculture and they need to be considered where the practice is considered to be an option. They include:

- lack of knowledge of aquaculture as a technical option in wastewater treatment and reuse.
- limited available sites in peri-urban areas where wastewater is available for reuse
- rapid urbanisation in developing countries threatens the existing wastewater-fed systems
- rapid eutrophication from both urbanisation and industrialisation
- improved sanitation reduces the availability of nightsoil for agriculture and aquaculture.
- rapid industrialisation contaminates nutrient-rich domestic wastewater with industrial wastewater.
- social and cultural acceptance of wastewater-fed
- climate - wastewater-fed aquaculture involves the farming of warmwater organisms

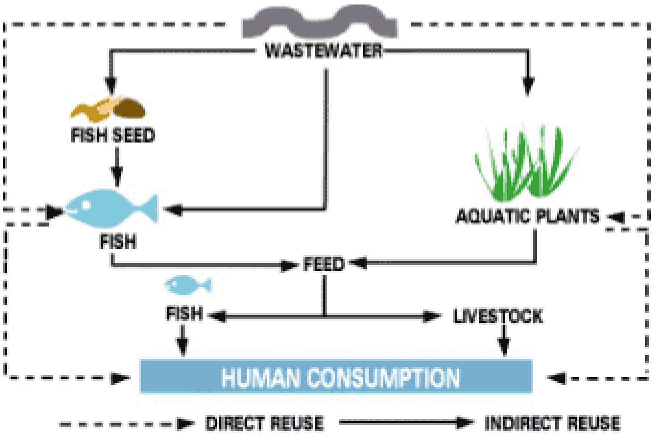

Figure 36: Schema of wastewater reuse strategies (Edwards 2000)

Despite the constraints listed above, there is considerable potential for the reuse of wastewater in managed aquaculture in the tropics. A correctly managed system would limit public health risks and wastewater should never be reused without prior treatment if the produce (fish or aquatic vegetables) is intended for direct human consumption. Figure 36 presents strategies for the reuse of wastewater through aquaculture.

There are a number of situations where wastewater-fed aquaculture has significant potential for incorporation into existing and proposed improved sanitation schemes:

- Developing countries that cannot afford mechanical wastewater treatment schemes. Although aquaculture in stabilisation ponds requires more land, it produces significant benefits such as increased employment for local people and revenue from sale of produce which, in turn, can be used to subsidise the wastewater treatment.
- Arid and semi-arid countries have an increasing need to reuse water as well as nutrients contained in wastewater. Pilot projects on culture of fish in treated stabilisation pond effluents have been successfully completed in arid areas in Egypt, the Middle East, Peru and in Latin America.

6.1.3 Wastewater reuse for industry

Treated wastewater can also be used for industrial purposes if suitable industries are not far from the treatment plant. Industry’s requirement for water quality ranges widely, from very pure water for boilers of electricity generation to lower water quality for cooling towers. Treated wastewater can fulfil the lower range of this requirement, e.g. water for cooling towers. Secondary-treated wastewater after chlorination may be adequate for this purpose.

With off-site treatment plants reuse of wastewater may be limited by the need to pipe treated wastewater to where it is needed. To implement wastewater reuse in houses for toilet flushing, watering of gardens and other purposes which do not need drinking quality water, a third pipe-reticulation system is required, that is in addition to the reticulation to provide drinking water and the sewer to collect the wastewater. Care is also needed to prevent cross-connection between drinking water and treated wastewater.

'Sewer mining' is the term given to the withdrawal of wastewater from a sewer for reuse near to the point of withdrawal. This provides an opportunity for reuse without having to pipe treated wastewater from the centralised treatment plant. Wastewater needs to be treated to the standard required for the reuse, and may duplicate the function of the centralised treatment plant.

6.2 Reuse of wastewater from on-site systems

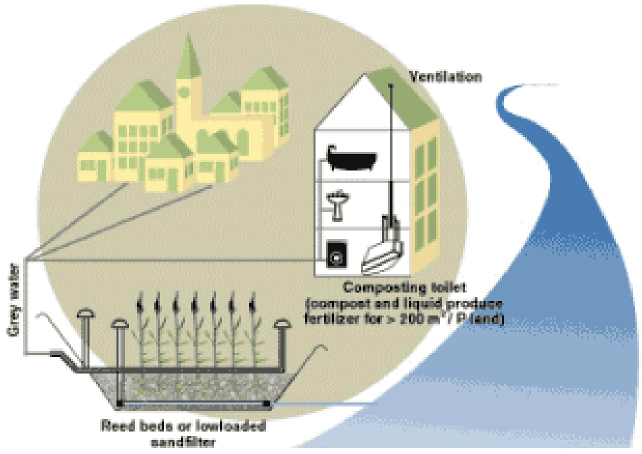

Figure 37: Separation of household wastewater for on-site reuse (Lange and Otterpohl, 1997)

Many options are open to a householder who wishes to reuse wastes on-site. One option is separation of all wastes. Urine can be separately collected and stored for later use as a liquid fertiliser, rich in nitrogen, phosphorus and potassium. Toilet wastes can be composted and used as a soil conditioner, rich in organic carbon, nitrogen and phosphorus. Greywater can be treated in a constructed wetland and used for sub-surface irrigation of the garden beds (Figure 37). This option may be suitable for a householder who is interested in managing wastes for beneficial uses in the garden. Sufficient garden area needs to be available for this purpose.

Another option is the use of an evapotranspiration system for growing shrubs and trees (see Section 4.1.4). This is a passive system, not requiring household attention on a regular basis, except desludging of the septic tank every 3 to 5 years. There is a fairly wide choice of shrubs and trees to choose from depending on local soil and climatic conditions.

6.3 Stormwater reuse

Stormwater is generally of a higher water quality than wastewater. Reuse (or strictly 'use') of stormwater can take place at two levels (household and municipal) or even at a larger (regional) scale if desired. Use at the household and municipal levels is described below.

6.3.1 Household level

Householders can use stormwater by collecting roof run-off in a tank for use as drinking water (common in arid regions), flushing toilets or for irrigation of the garden. The first flush of roof run-off can be contaminated by dust particles, leaf litter and animal droppings. The first flush can be simply diverted using a simple diverter (Figure 38). A screen can be placed at the inlet to the tank to filter gross particles. Water for drinking will still need to be boiled to denature pathogens.

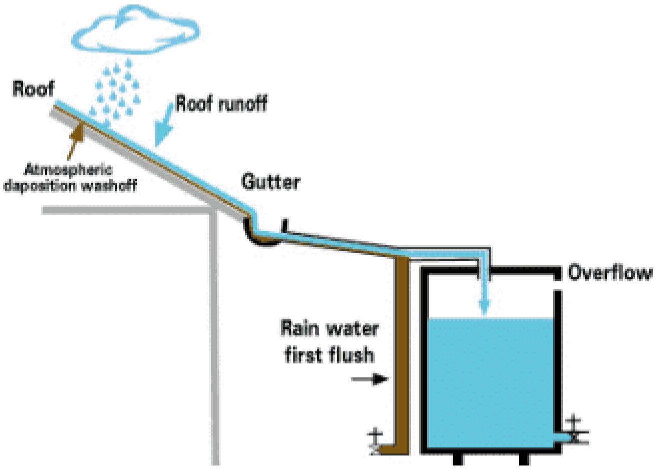

Figure 38: Diverter for the first flush from roof run-off

Water from the roof can be directed to the garden beds directly rather than through soakways, and in this way shallow rooted vegetation can benefit from the water, especially in arid regions.

6.3.2 Municipal level

At the municipal level stormwater can be stored in ponds for use for irrigation of parks and gardens and for fire-fighting purposes. This is in addition to employing the ponds for flood control and for improving the amenity value of the water as described in Section 4.3. Other uses are for groundwater recharge, either as a means of storing water, e.g. during the rainy season, for withdrawal in the dry season. Groundwater recharge can also be used to prevent encroachment of seawater near the coast where there is heavy groundwater withdrawal in excess of natural replenishment by precipitation.

7. Wastewater and stormwater disposal

Disposal of wastewater and stormwater should preferably be considered only when reuse options are not feasible. Ultimate disposal of wastewater is either onto land or water (river, lake, ocean).

7.1 Land-based disposal of wastewater

Disposal onto land takes the form of effluent from on-site and off-site treatment systems being allowed to percolate through the ground. For a septic tank, for example, this occurs through the soakage of overflow from the septic tank in a leach drain (Section 4.1.4). Disposal onto land generally pollutes groundwater, and may reach surface water when groundwater eventually discharges into surface water. The impact of BOD and nutrients in the wastewater on the surface water has been attenuated by soil processes and is therefore not as severe as direct disposal into surface water. Disposal from an off-site treatment plant for groundwater recharge to control encroachment of seawater in coastal areas is a form of reuse.

7.2 Wastewater disposal to water environments

Disposal into a lake, stream or ocean needs to take into account the ability of the receiving water to assimilate wastewater. The natural purification capacity of the environment is limited. Even when wastewater is disposed to the ocean, the area surrounding the outfall can be sufficiently polluted and the pollutants (including pathogens) can be washed towards the beaches. Nutrients (nitrogen and phosphorus) promote the growth of algae in the receiving water. In lakes and sensitive water environments the removal of nutrients may be required. Furthermore if the wastewater contains high levels of heavy metals and toxic chemicals, these may have to be removed before wastewater disposal. Over the years the requirement for disposal into water environments have become stricter as the impact of pollutants is better appreciated. It can be expected that this trend towards more stringent discharge requirements will continue (See the Source Book's Western Europe and North America Regional Overviews).

7.3 Stormwater disposal

The ultimate disposal for stormwater is onto land (by infiltration to groundwater) and to water environments (river, lake, ocean). These have been covered as part of stormwater treatment (4.3) and reuse (6.3), because they utilise infiltration as a general technique. Techniques for stormwater reuse are those that delay its ultimate flow to water environments to improve flow management and hence reduce the frequency and extent of flooding. At the same time these techniques also generally remove pollutants (particulates and oils) prior to the water reaching a river, lake or the sea, while creating amenities such as wetlands, waterfowl habitats and water-based passive and active recreational facilities.

8. Sound Practices

8.1 Technology choice

Environmentally sound practices in wastewater and stormwater management are practices that ensure that public health and environmental quality are protected. A range of technologies exist that can achieve this objective (Sections 3 to 7). A summary is shown in Table 2 which, although it does not cover all available technologies, it does represent the major technologies for most situations. The Regional Overviews in the Source Book, published by IWA and IETC, include technologies that are modifications or variations of the listed technologies or represent practices or advances in the regions.

As mentioned before, the processes in environmentally sound technologies are largely akin to the purification and recycling processes taking place in nature. There is a scientific basis for the physical, chemical and biological processes for the removal of pathogens and pollutants from the water. Properly designed, constructed, maintained and operated these technologies can achieve protection of public health and the environment, and can recycle water and nutrients, which are beneficial to sustaining ecosystems and life.

The choice of technology is determined by environmental, economic and social factors. Achievement of protection of environmental quality is implicitly assumed when we consider technologies for wastewater and stormwater management. These considerations are (i) the need to protect the environment and (ii) the imperative of recycling/reusing the water and nutrients in the water. The first factor is usually taken into account by making sure that standards for discharge of wastewater are met. Standards alone should not be relied upon, because it is the capacity of the environment to assimilate the wastes that should not be exceeded. Each local environment has its own capacity depending amongst others on the natural throughflow of water, climatic, vegetation and soil conditions.

Table 2: Technologies for wastewater and stormwater management
(with relative costs, environmental impact and maintenance requirement)
Wastewater management technologies

Technology	Capital cost	Operation & maintenance cost	Environmental impact
On-site technology			
Pit latrine	Low	Low	Pollution of groundwater
Composting toilet	Low	Low	Reuse of nutrients
Pour flush toilet	Low	Low	Pollution of groundwater
Improved on site treatment unit	Medium to high	Low to medium	Reuse of water and nutrients
Off-site technology			
Collection technology			
Conventional sewerage	High	High	Dependent on treatment
Simplified sewerage	Medium to high	Medium	Dependent on treatment
Settled sewerage	Medium	Low	Dependent on treatment
Treatment technology			
Activated sludge	High	High	Nutrients may need removal
Trickling filtration	Medium	Medium	Nutrients may need removal
Lagoons	Low to medium (dependent on cost of land)	Low	Nutrients may need removal; aquaculture can be incorporated

Land-based treatment	Low to medium (dependent on cost of land)	Low to medium	Reuse of water and nutrients
Constructed wetland	Low to medium (dependent on cost of land)	Low	Amenity value
Anaerobic treatment	Medium	Medium	Produces biogas; further aerobic treatment needed

Stormwater management technologies*			
Technology	Source control	Site control	Regional control
Filter strips and swales	x		
Filter drains and permeable surfaces	x		
Infiltration devices		x	
Basins and ponds			x

*Cost increases from source control to regional control technology.

Sound economic practices require that costs are optimised. An indication of relative costs of technologies is provided in Table 2. Optimising the cost of technology for wastewater management needs to consider (1) availability of land, (2) labour costs, (3) land uses and (4) economy of scale. The economics of wastewater management needs to consider the benefits of improvement to public health and long-term affordability of sanitation services to the community.

From a community's point of view the affordability of a wastewater collection and treatment system is an important factor. A percentage of the average person's income in a community, or of the average value of housing appears to be a figure that can be used as a measure of what a community can afford. What the percentage figure should be is determined by the importance given by community members to having the wastewater system in their community. The priority given to wastewater management in turn is dependent on the community having the information that will help them decide on its importance relative to other household and community needs. Hygiene promotion and education is needed to provide this information. An example of an excellent hygiene promotion is a publication by WHO (WSSCC Working Group on Promotion of Sanitation, 1998).

8.2 Selection of technology

Procedures to consider economic and environmental factors in a systematic way have been developed. These range from a single decision-making flowsheet to a computer software package. Figure 39 illustrates a flowsheet that has been developed for the selection of wastewater technology in developing countries in both urban and rural communities. Computerised decision-making software such as SANEX and WAWTTAR are based on the same methodology as illustrated in the flowsheets. SANEX is briefly described in the following boxed sections to illustrate its advantages and limitations.

The WAWTTAR program was designed to assist financiers, engineers, planners and decision-makers in improving their strategies toward sustainable water and sanitation coverage while minimizing impacts on water resources. It was developed specifically for application at the pre-feasibility stage of project development to assist planners select suitable water and wastewater treatment processes which are appropriate to the material and manpower resources available in their particular location at particular time. A more detailed description of WAWTTAR can be found in the Source Book, published by IWA and IETC.

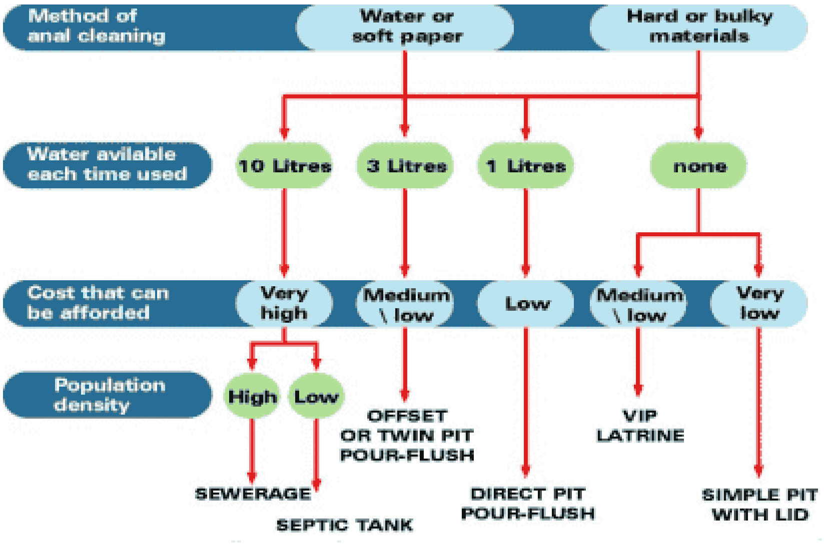

Figure 39: Simple decision making flowsheet for choosing wastewater treatment systems (Pickford, 1995)

Computer software of SANEX: Description of procedure and capability

The purpose of this computer program is to support decision makers and project beneficiaries in identifying feasible alternatives and in evaluating the adequacy of these alternatives with respect to community circumstances. The three questions which the program attempts to answer are:

1. Which sanitation technologies are relevant to rural and urban communities in developing countries?
2. Which are the relevant criteria to evaluate the appropriateness of these technologies?
3. How can these criteria be incorporated into a decision aid that can be applied by decision makers to concrete projects?

Methodology
Two-Stage Evaluation
This model features two distinct evaluation stages (Diagram A). During the screening stage, infeasible alternatives are eliminated based on mainly technical criteria. Subsequently, during the comparative stage, the remaining alternatives are compared with regard to the indicators implementability and sustainability. Apart from technical issues, this stage considers numerous sociocultural objectives. Implementability expresses the probability that sanitation facilities can be constructed within the period and with the financial resources usually required in favourable conditions. Sustainability expresses the probability that facilities serve beneficiaries according to their design throughout their design life.

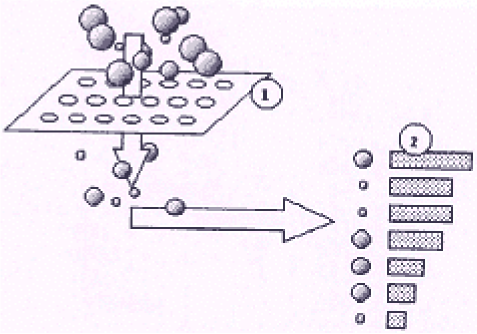

Diagram A: Screening evaluation is symbolised by the screen (1) which lets only technically feasible options (represented by the smaller spheres) pass. Comparative evaluation is symbolised by the horizontal bar graph (2), indicating performance for each feasible option.

Multi-Level Amalgamation

A major obstacle to formulation the comparative component of the algorithm was the amalgamation of numerous criteria outcomes. The application of conventional methods, such as the arithmetic mean, would have resulted in a diminishing effect of the individual criterion. In order to preserve the effect of criteria, a new method for amalgamating criteria on multiple levels was developed, which would also allow the simultaneous application of various methods like the arithmetic and the geometric mean. The combined advantages of multi-level amalgamation are reflected in more plausible evaluation results.

Costing of Sanitation Alternatives

Assuming the planners in developing countries usually have sufficient access to financial expertise, no criteria to assess the affordability of sanitation systems were formulated. Instead, it was decided to develop a costing model that would enable the proposed decision aid to estimate the capital as well as the recurrent costs of all alternatives. Further, a simple method based on the local residential building cost was developed to convert these estimates to costs in local currency units, as they would occur in the project area.

Validation

The above work resulted in an evaluation model for assessing the implementability, the sustainability and for costing sanitation alternatives in developing countries. In 1998, in order to validate this model, a second journey was undertaken to Southeast Asia and to Europe. Based on the application to nine case studies, several modifications emerged to be necessary.

Outcome

The expert system software SANEX© was developed for the MS Windows operating environment. The knowledge base of this software contains more than 80 sanitation alternatives, which are combinations of the technologies outlined in the table below, and uses around 50 technical, sociocultural and financial criteria for their assessment. The costing component employs approximately 50 functions.

Sanitation alternatives considered in SANEX

Toilet facilities: • Pour-flush toilet • Cistern-flush toilet On-site facilities: • Simple pit latrine • VIP latrine • Pour-flush latrine • Aquaprivy • Septic tank • Vault (vacuum cartage) • Seepage pit • Drain field Public facilities: • Public toilet block • Overhung latrine	Resource recovery: • Double-vault composting toilet • Excreta-fed fish pond • Septic tank for excreta reuse • On-site biogas digester Sewerage: • Covered stormwater drains • Conventional sewerage • Simplified sewerage • Settled sewerage Off-site treatment: • Communal septic tank • Imhoff tank • Primary treatment • Waste stabilisation ponds • Activated sludge treatment

Reference: Loetscher (1998)

8.3 Scenarios for Sound Practices

General scenarios can be sketched based on population density to illustrate integration of technology, environmental, economic and social factors. For a low population density and where land is available around dwellings, on-site systems with on-site reuse provide householders with options that are a function of water availability, toilet type and desired reuse of blackwater and greywater. Use of a double vault composting toilet (4.1.2) and greywater for subsurface irrigation is shown in Figure 40. Maintenance requirement will be emptying the vault (say, every 6 months), windrow-composting the content with garden waste and diverting blackwater from a full vault to the one just emptied. An irrigation system for greywater needs to be checked weekly. A system requiring less householder maintenance is a septic tank with an inverted leach drain or evapotranspiration trench (4.1.5). The septic tank needs to be de-sludged every 3 to 5 years by calling a sludge contractor. This service should be available in the community for this option to operate satisfactorily including the safe disposal of the sledge by the contractor.

For a high population density, community ablutions blocks with payment for use can work well. The wastewater can be conveyed to a location where land is available for land-based treatment (4.2.4) and reuse through grazing grasses irrigated by treated wastewater. The operator of the ablutions facilities needs to ensure public health requirements for the wastewater reuse are met.

Another option for high density areas are toilet facilities in individual dwellings with wastewater collected using simplified sewerage (3.2). This can be condominial sewers or with street connections depending on community choice. Collected wastewater is treated using a series of lagoons (4.2.3), with the final lagoon employed for aquaculture (6.1.2.).

Depending on land use downstream of the lagoons, wastewater can be reused further for agriculture, horticulture or tree plantation.

A well-planned sewerage system should be:

- Energy efficient - be developed within a catchment basin to use gravity flow
- Environmentally sound - reuse wastewater nutrients to prevent pollution
- Economically efficient - balancing economy of scale of treatment and the cost of the sewer pipes
- Commmunity orientated for community consultation

These requirements all point to planning for a community-scale collection, treatment and reuse of wastewater. The optimum size of the population served for a community-scale systems will depend on local conditions, which in turn are determined by local geographical (topography, climate, soil), environmental, economic and social/institutional considerations.

A futuristic scenario is depicted in Figure 40 with blackwater and kitchen biowaste collected separately to be anaerobically digested to produce energy (methane). The digested sludge is composted and reused in agriculture. Greywater is treated using wetland and separately reused.

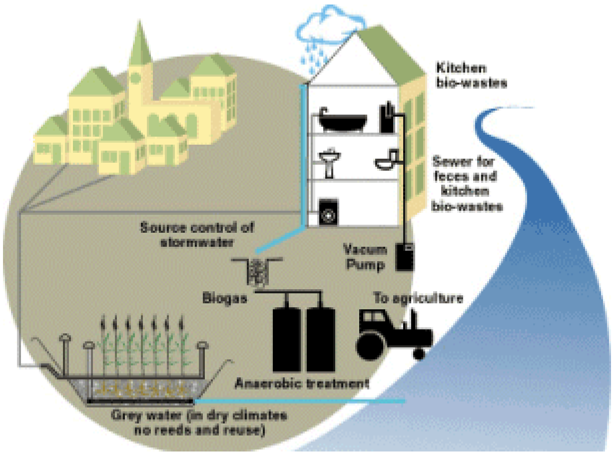

Figure 40: Composting toilet for blackwater and sub-surface irrigation of greywater (Lange and Otterpohl, 1997)

What is clear from the above examples is that there are many technologies that are environmentally sound, from which a community can select based on their local conditions and preference.

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