Project no. 037099

NETSSAF

Workpackage 3 - Assessment of Sanitation Systems and Technologies

Deliverable 22 & 23

Evaluation of existing low-cost conventional as well as innovative sanitation system and technologies

compiled by Chris Zurbrügg and Elizabeth Tilley, Eawag/Sandec

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Introduction

Looking at sanitation systems rather than sanitation technologies

A sanitation **system** - contrary to a sanitation **technology** - considers all components required for the adequate management of human wastes. Each system represents a configuration of different **technologies** that carry out different **processes** on specific **products** (wastes). The sequence of process-specific technologies through which a product passes is a **flowstream;** each system therefore, is a combination of product- and process-specific technologies designed to address each flowstream from origin to disposal.

Technology components exist at different spatial levels, each with specific management, operation and maintenance conditions. Starting at the household level with waste generation, a system can include storage and potentially also treatment and reuse of all **products** such as urine, excreta, as well as greywater, rainwater/stormwater or even solid waste. However, problems can often not be solved at the household level alone. The household "exports" waste to the neighbourhood, town, city and so on, up to a larger jurisdiction. In such cases, it is crucial that the sanitation system boundary be extended to include these larger spatial sections; those that take into account technology components for storage, collection, transport, treatment, discharge or reuse at these levels.

A "good" sanitation system minimizes or removes health risks, is economically viable, and avoids negative impacts on the environment. Ensuring good sanitation systems for the protection of public health and of environment is of public interest and, therefore, a key duty of the public sector. This duty includes the provision of an enabling framework as well as control and supervision to ensure that these conditions are met for all users. "Sustainable" sanitation however goes a step further. Sustainable systems take into account economic aspects (financial capital investments required as well as recurring operation and maintenance costs, affordability), institutional aspects (organisational set-up, opportunities for public-private partnership), environmental aspects (minimum energy requirements, opportunities for resource recovery and reuse, environmental impact, health aspects) and finally social aspects (convenience, dignity, acceptability, and willingness to pay or operate).

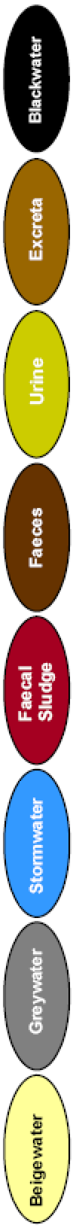
Despite numerous efforts and campaigns, the reality is that large-scale sanitation projects have not been adopted in the past decade and in many cases, the sanitation situation remains unchanged. One explanation for the marginal improvements is the prevailing assumption that the conventional (centralised) water-based sewer system can be the solution in all contexts, and to all sanitation problems in urban and peri-urban or even rural areas irrespective of the differences in the physical and socio-economic conditions. It is only quite recently that research and development have targeted alternative approaches and solutions to the increasing environmental sanitation problem.

The objective of the Workpackage 3 therefore, is to assess existing low cost, conventional and innovative sanitation technologies, in order to determine the feasibility and sustainability of their massive implementation in rural and peri-urban areas of West Africa that lack access to improved sanitation.

This document attempts to define and systematize distinct sanitation systems. In the following chapters, the various systems are briefly described. For each system the relevant flowstreams are explained. A description of the technology components follows. The technologies are categorized according to process: User Interface, On-site Collection, Storage and Treatment, Transport, Off-site Treatment Technologies, Reuse, and Disposal. This document also contains a qualitative assessment of technology components, which does not take into account the specific needs or interests of the users and stakeholders. This assessment was carried out with expert judgement and is structured according to flowstream, using a methodology developed within the framework of the NETSSAF project.

Terminology

Product: A product has classically been known as a 'waste'. Each product differs in its characteristics due to mixing or separating different waste materials. Each product passes through different process steps in its lifecycle, or along its '**flowstream**'. Sometimes the flowstream can have the same name as the product if no products are combined into the same flowstream. Because each product is so unique, it is important then that the technologies comprising the sanitation system are product-appropriate. Products that are presented in the system diagrams are summarized below.



Blackwater is the mixture of urine, faeces and flushing water, along with anal cleansing water (if anal cleansing is practiced) or dry cleansing material (e.g. toilet paper).

Excreta is the mixture of urine and faeces that is not mixed with any flushing water (although small amounts of anal cleansing water may be included).

Urine is urine that is not mixed with any faeces or water.

Faeces refers to (semi) solid excrement without any urine or water.

Faecal Sludge is the general term for the undigested, or partially digested slurry or solid that results from the storage or treatment of blackwater or excreta.

Stormwater is the general term for the rainfall that runs off of roofs, roads and other surfaces before flowing towards low-lying land. It is the portion of rainfall that does not infiltrate into the soil.

Greywater is used water which results from bathing, hand-washing, cooking or clothes-washing. It is sometimes mixed with, or treated along with, other types of products

Beigewater is anal cleansing water. It is generated by those who use water, rather than dry material for washing.

Process A process step can contain, transform, or transport products to another process or a final point of use or disposal. In this document we refer to six different processes. They are summarized in the following table

Table 1: Different processes within a sanitation system

Process Title	Description
▪ User Interface	Describes the way in which users access and interact with the sanitation system
▪ On-site Collection, Storage & Treatment	Describes the technologies that can be used at the household/compound level to collect, store and (partially) treat different flowstreams
▪ Transport	Describes the way in which flowstreams are transferred from the household to a centralized treatment/use facility
▪ Treatment off site	Describes the technologies used to reduce the pathogenicity and/or nutrient loads of the various flowstreams
▪ Reuse	Describes the technologies and /or methods which allow some benefit to be derived from a flowstream
▪ Disposal	Describes the technologies and/or methods which allow the flowstreams to be returned to the environment in a benign/non-detrimental way

Technology: Is a product-specific method or tool designed to collect, store, transform (change), move, or dissipate a product. Each technology component is responsible for performing a process (task). The technologies are described in Part 2, and evaluated in Part 3 of this document

Flowstream: This describes the path that the product takes as it moves from the point of generation to the point of disposal: from 'cradle to grave'. It could be described as the lifecycle of the product as it passes through the various process steps, which transform and transfer the product to its ultimate release into the environment.

Sanitation system: This describes a comprehensive combination of product-specific technology components designed to process each product from the point of generation until the point reuse or disposal (from cradle to grave).

PART 1 System Description

Discussion on the systematization was carried out through an email exchange, an online forum and at the NETSSAF consortium meetings in Eschborn, Germany (22-23 February 2007) Ouagadougou, Burkina Faso (27 February - 1 March 2007) and Bamako, Mali (20-26 June 2007). The consensus of the consortium was to focus the work on 7 main systems. Two main criteria for subdividing the systems are **WET <--> DRY** as well as the various degrees of separating waste flowstreams**.**

"Wet" and "Dry" indicate the presence of flushing water for the transport of excreta. This however only gives a certain indication of how wet or dry the collected waste materials will be. Although flushing water might not be used (and would not therefore qualify as a "Dry system") a system may nevertheless contain anal cleansing water, urine flushing water, or even greywater (as in System 7).

Also, Wet systems are characterized by the production of a parallel product: faecal sludge. In wet systems then, the faecal sludge flowstream must be taken into account and treated accordingly with its own set of process- and product-specific technologies until the point of ultimate disposal.

It is important to note also the similarity in naming convention between **products** and **flowstreams**. For example, blackwater is a product, but the entire process of collecting, treating and disposing of blackwater is referred to as the blackwater **flowstream.** Similarly, greywater can be managed separately as an independent product, but when it is combined and treated along with blackwater, the flowstream is referred to as the 'blackwater mixed with greywater' flowstream. For a complete summary of product definitions please refer to the previous section.

Table 2: Overview on the systems and corresponding flowstreams

No.	System name	Flowstreams
1	Wet mixed blackwater and greywater system with offsite treatment	▪ blackwater mixed with greywater flowstream ▪ faecal sludge flowstream
2	Wet mixed blackwater and greywater system with onsite treatment	▪ blackwater mixed with greywater flowstream ▪ faecal sludge flowstream
3	Wet blackwater systems (blackwater separated from greywater)	▪ blackwater flowstream ▪ faecal sludge flowstream ▪ greywater flowstream
4	Wet urine-diversion system	▪ urine flowstream/ yellowwater ▪ brownwater mixed with greywater flowstream ▪ faecal sludge flowstream
5	Dry greywater-separate system	▪ excreta flowstream ▪ greywater flowstream
6	Dry urine- and greywater-diversion system	▪ urine flowstream ▪ faeces flowstream ▪ greywater flowstream
7	Dry all mixed systems	▪ excreta mixed with greywater flowstream

- Table 2 lists all of the individual product flowstreams that must be accounted for in each system. Stormwater, which is shown in the system description figures, and solid waste, which is not shown in the figures, are referred to only if certain technologies require, or allow, joint handling and treatment with the one of the main flowstreams.

When referring to the system diagrams, please keep in mind the following:

- the **process** name is written across the top of the diagram. Each technology box that falls under this heading, is thus, applicable to this type of process.
- the **products** are represented by coloured ovals. The raw products that contribute to the first flowstream are indicated in the first column. Subsequent products that are generated (e.g. faecal sludge) are indicated at the point where they are generated.

- **flowstreams** are separated by a dashed green line. Thus, each of the technology boxes that falls under a process, and is contained within the boundary of two green lines belongs to the flowstream in question. Flowstreams are labelled on the extreme right side of the diagram. Because not every product or flowstream begins at the user interface, the flowstream boundaries begin only at the point where the relevant processes for that flowstream also begin.
- **arrows** track the path of the products along the flowstream, however two arrows originating from the same technology indicate that either of the next technologies is appropriate, unless the arrow points toward a new product, in which case both flowstreams must be followed.

1.1 Wet mixed blackwater and greywater system with offsite treatment

In this system, all wastewater that is created by households, institutions, industries and commercial establishments are collected, transported and treated without stream separation. There are different user interface technologies available for the collection of blackwater. These can be by high- or low-volume cistern-flush toilets, or pour-flush toilets. After collection, blackwater is mixed with household greywater as it leaves the house; the mixture (referred to as 'wastewater' for simplicity) is transported to a centralized (offsite) treatment plant. Transport technologies may be pipes with gravity flow, pressure flow, or using vacuum systems. The system shown below (Figure 1) describes a separate sewer system where stormwater is not fed into the sewer. When stormwater is drained into the sewer system it is called a ''combined'' sewer system. This may also be an option, however it is usually not recommended as it significantly increases complexity and costs of the system.

There a wide array of technology options for wastewater treatment. Typically, sewage treatment involves up to three stages, called primary, secondary and tertiary treatment. Here, all these stages are summarized in to the term "wastewater treatment plant" (WWTP). During the primary (mechanical) treatment, large, easily settleable solids are separated from the wastewater stream. The dissolved biological matter is progressively converted into a solid mass (faecal sludge or greywater sludge) by water-borne flora in the secondary (biological) treatment stage. Wastewater is sometimes treated in a tertiary processes to further eliminate nutrients and pathogens.

Effluent discharged by the wastewater treatment plant can be either reused (irrigation purposes) or discharged into the environment (e.g. groundwater recharge) depending on the level of treatment and legal requirements. In certain cases, the effluent from the treatment plant may be further treated/disinfected chemically, biologically or physically (e.g. by chlorination, wetlands or micro-filtration).

The **faecal sludge** from the treatment or storage of wastewater can either be disposed of (e.g. land disposal or incineration) or can be treated further (e.g. composting) and re-used (e.g. agriculture). Faecal sludge that has been hygienised and can be applied safely to the land is referred to as ''biosolids''. For clarity, here we refer only to treated faecal sludge. Also, it is important to note that sludge resulting from flowstreams which include faeces is called 'faecal sludge' while sludge resulting from just greywater is called 'greywater sludge' (although for simplicity, greywater sludge is not included in the system diagrams).

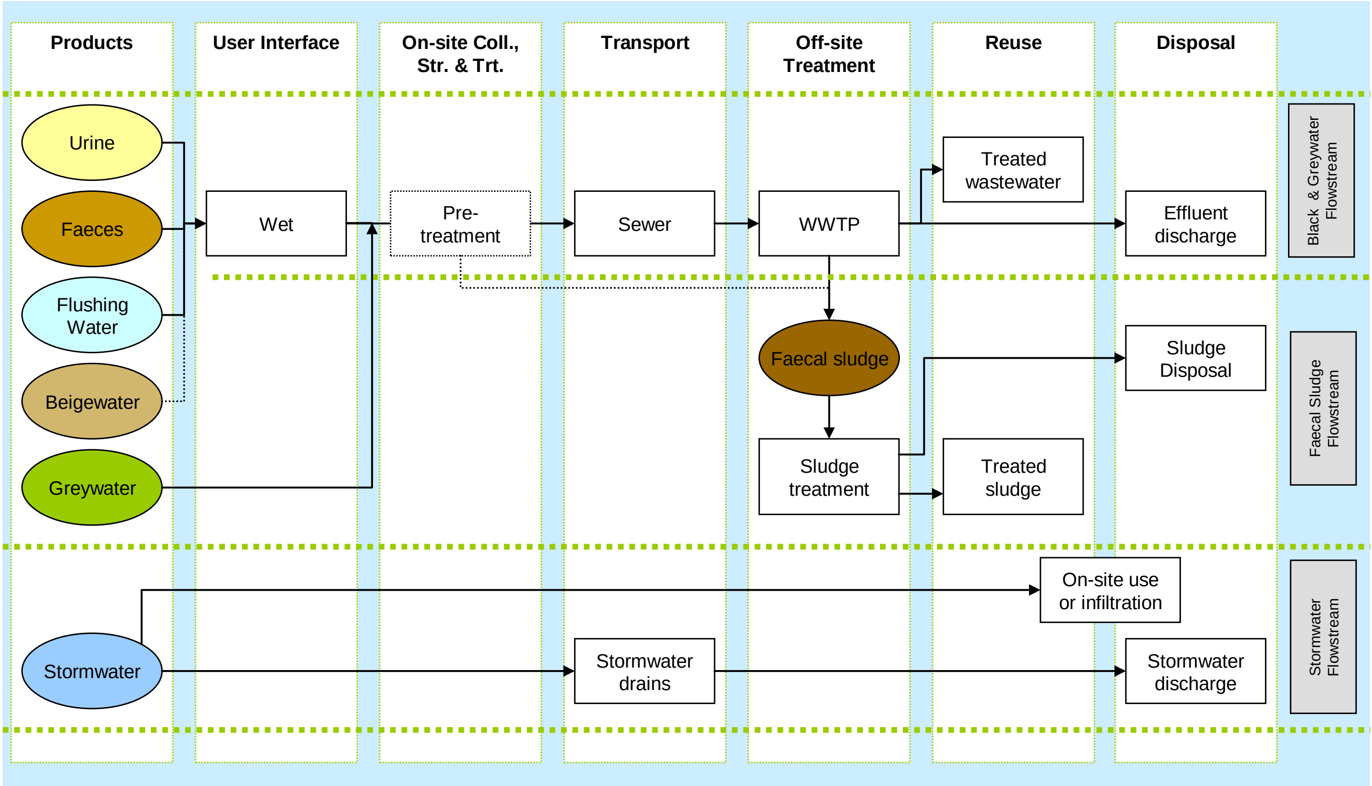


Figure 1. Wet mixed blackwater and greywater system with offsite treatment

Mixed blackwater and greywater flowstream

The blackwater flowstream consists of urine, faeces, flushing water and either anal cleansing water or anal cleansing material like toilet paper; this is then combined with greywater. As mentioned above, stormwater may or may not be diverted into sewer systems and mixed with wastewater.

Faecal sludge flowstream

In water-based sanitation systems sludge is generated. Sludge, or faecal sludge is the general name given to the thick, viscous material that can be mostly fresh faecal material (e.g. from pit latrines), semi-digested faecal material (e.g. from septic tanks), or mostly biological (e.g. sloughed from trickling filters).

Depending on the physical, chemical and/or biological processes that the sludge undergoes, the degree of stabilization will be variable which in turn affects the subsequent ease of treatment (e.g. solids/liquids separation). Thus, faecal sludge is one of the most variable flowstreams and its proper treatment depends on careful characterization.

Emptying/Removing faecal sludge can be done either mechanically (motorized or non-motorized pumps) or manually. Two objectives of the sludge treatment are to reduce the number of pathogens and the vector attraction which can be achieved by a variety of methods.

Sludge derived from wastewater with industrial inputs may contain high levels of toxic chemicals which may end up in the sludge and/or the effluent. Faecal sludge from only the household usually does not show high levels of heavy metals or other toxic substances. Thus, depending on the origin of the sludge and the level of treatment and the resulting pollutant content, the treated sludge (**'biosolids'**) can be used in regulated applications ranging from soil conditioning to fertilizer for food or non-food crop-production or distribution for unlimited use.

1.2 Wet mixed blackwater and greywater system with decentralized treatment

This system, like the previous one, is characterised by flush toilets (full, low, vacuum or pour flush toilets) at the user interface. Here however, the treatment technology is located close to the source of waste generation. Depending on the plot size, the treatment technology will be appropriate for one house, one compound or a small cluster of homes. Accordingly, transport before treatment is limited to short distances mostly by gravity sewers. There are various low-cost technology options for on-site wastewater treatment, which differ from those typically used as centralised, off-site technologies. Examples include septic tanks, filters, constructed wetlands, anaerobic baffled reactors, and biogas plants, among others. Although it is commonly practiced, pits should not be used as an on-site treatment method for combined blackwater and greywater treatment. Excessive water will shorten the life of the pit by exhausting the absorptive capacity of the soil and by filling it quickly, which results in more frequent and costly emptyings.

Sludge generated at on-site treatment facilities is relatively unstable and must undergo significant treatment to convert it into biosolids. It is important when designing this type of system that proper treatment and disposal of faecal sludge be included.

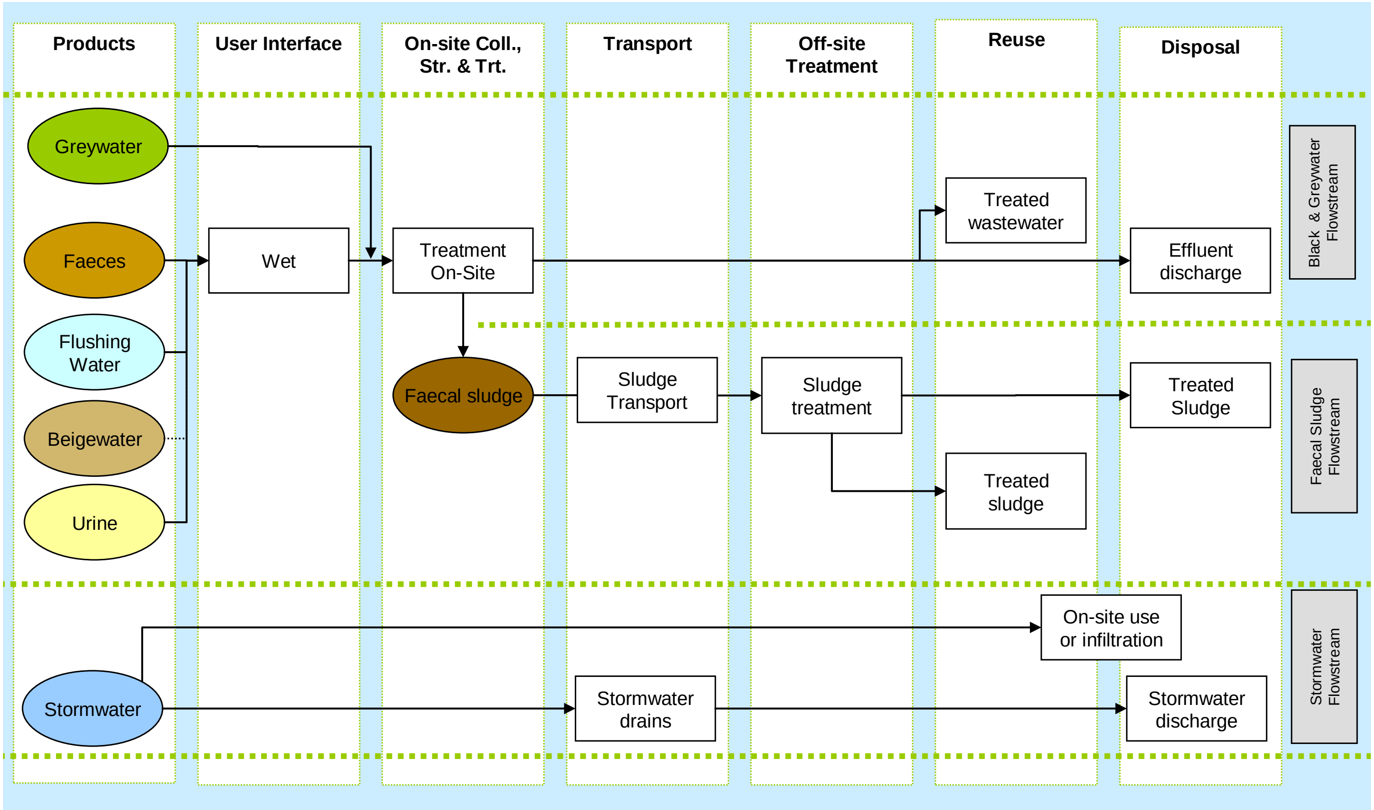


Figure 2: Wet mixed blackwater and greywater system with onsite treatment

Relevant Flowstreams

Mixed blackwater and greywater flowstream (refer to 1.1)

Faecal sludge flowstream (refer to 1.1)

1.3 Wet onsite blackwater system

In this system, urine, faeces and flushing water (blackwater) are collected, transported and treated together however, greywater is kept separate. Since greywater accounts for approximately 60% of the wastewater produced in homes, this separation simplifies blackwater management.

The most common and frequently practiced example of this system is the double-pit pour flush toilet; this technology allows users to have the comfort of a pour-flush toilet and water seal, without the trouble of having to pump out the sludge, since it is removed only once it has matured into a solid, humic-like substance. To avoid overloading the pits, a separate system for greywater management must be implemented. However, since separated greywater contains few if any pathogens, and usually low concentrations of nitrogen and phosphorus, it does not require the same level of treatment as blackwater or mixed wastewater. Greywater can be recycled for irrigation, toilet flushing, exterior washing, and other water-conservation measures.

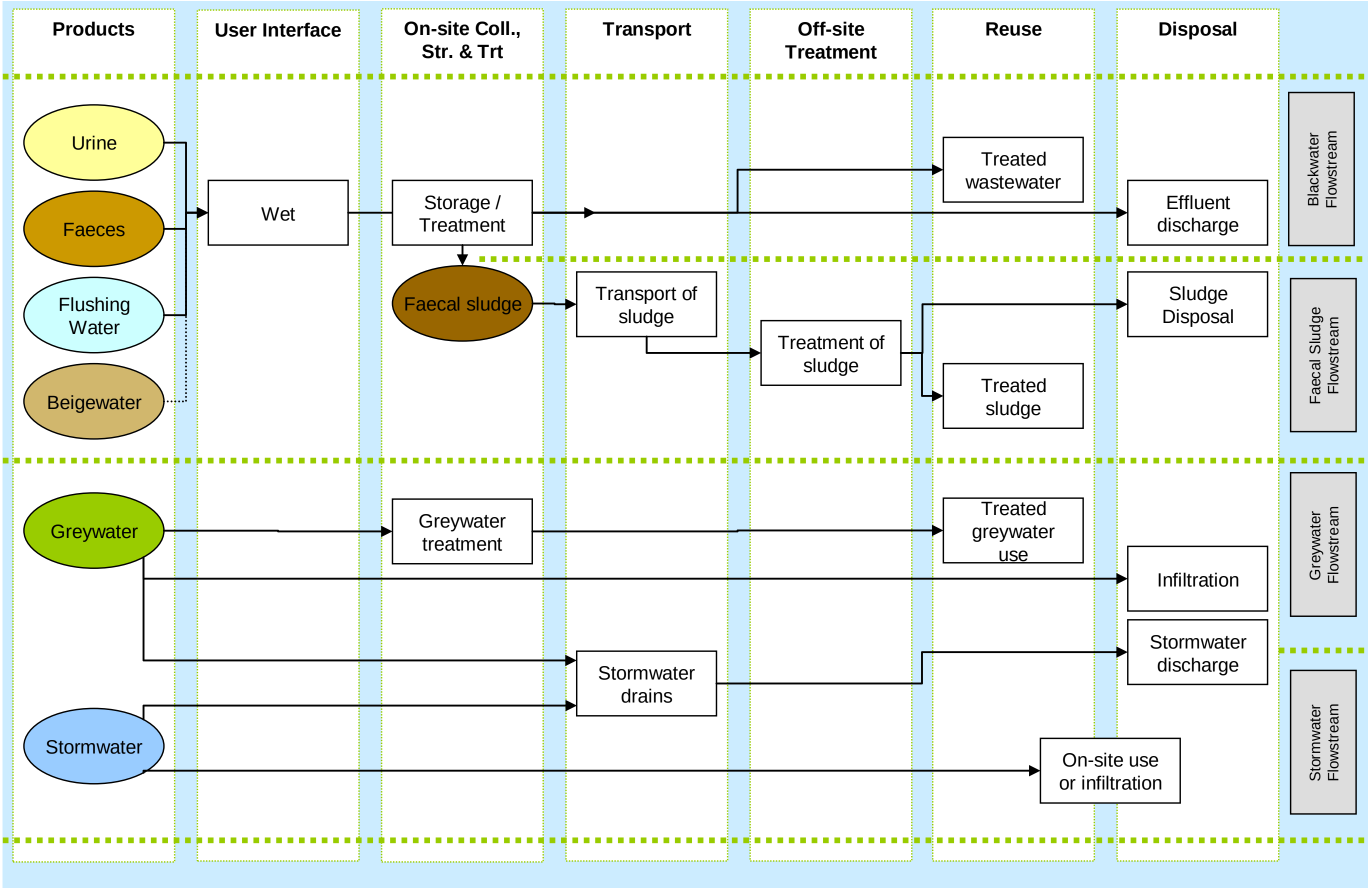


Figure 3. Wet blackwater system where greywater is managed separately

Relevant Flowstreams

Blackwater flowstream

The blackwater flowstream consists of urine, faeces, and flushing water, along with either anal cleansing water or material (like toilet paper). Figure 3 shows that the blackwater is treated onsite, however in some special circumstances there is also the possibility to transport and treat it offsite. In this system the lack of greywater may limit the self-cleansing velocity in a sewer network: if very little water is used for flushing (e.g. low-flush or pour-flush toilets), it may not be realistic to transport the blackwater offsite, especially if there is well-functioning greywater treatment on-site.

The On-site Collection, Storage and Treatment process involves settling the solid fraction, and partially treating the liquid and solid fractions. The liquid fraction is then infiltrated, reused, or discharged, whereas the remaining solids are handled separately as a faecal sludge flowstream. Alternatively, the wastewater can be collected in a tank on-site and transported by truck to a treatment plant where the blackwater is treated and reused or disposed.

Faecal sludge flowstream (refer to 1.1)

Greywater flowstream

Greywater is wastewater from the kitchen, bathtub, shower, sinks, laundry and dish washing; essentially it is all used water except for toilet water. Greywater often accounts for around 60% of the wastewater produced in homes with flush toilets. It contains few if any pathogens and its flow of nitrogen is only 10-20% of that in blackwater, although it has a relatively high concentration of COD (approximately 250 mg/L). Because of these characteristics, it does not require the same treatment processes as blackwater or mixed wastewater. In existing practice, greywater is often discharged indiscriminately into open drains, onto land or fed into soak pits or infiltration trenches. Greywater treatment and reuse technologies generally consist of a primary treatment to hold back sand, grit and fat followed by a secondary treatment stage. Greywater treatment may generate sludge, which needs further handling/treatment (due to it’s comparatively low volume, this product is not included in the system diagrams). The treated effluent can be infiltrated into the subsurface, discharged into surface waters or reused for irrigation purpose or as service water, following the WHO guidelines.

1.4 Wet urine diversion system

In this system faeces, flushing water and greywater are collected, transported and treated together but urine is kept separate. The diversion of urine from the other flowstreams requires a specific user interface, known as a urine-diverting flush toilet, which, due to the intricate plumbing and construction, is available only as a pedestal. The objective of the urine separation is (usually) to keep the nutrient rich urine free of pathogens and to ultimately facilitate its reuse. In this wet urine diverting system, the faeces are flushed with water (brownwater) to an off-site treatment facility. Sometimes the urine is mixed with a small amount of flushing water, in which case the product is referred to as yellowwater. Because of the novelty of user interface and the complicated infrastructure (plumbing) required for this type of system, it is appropriate only to more experimental settings at this point.

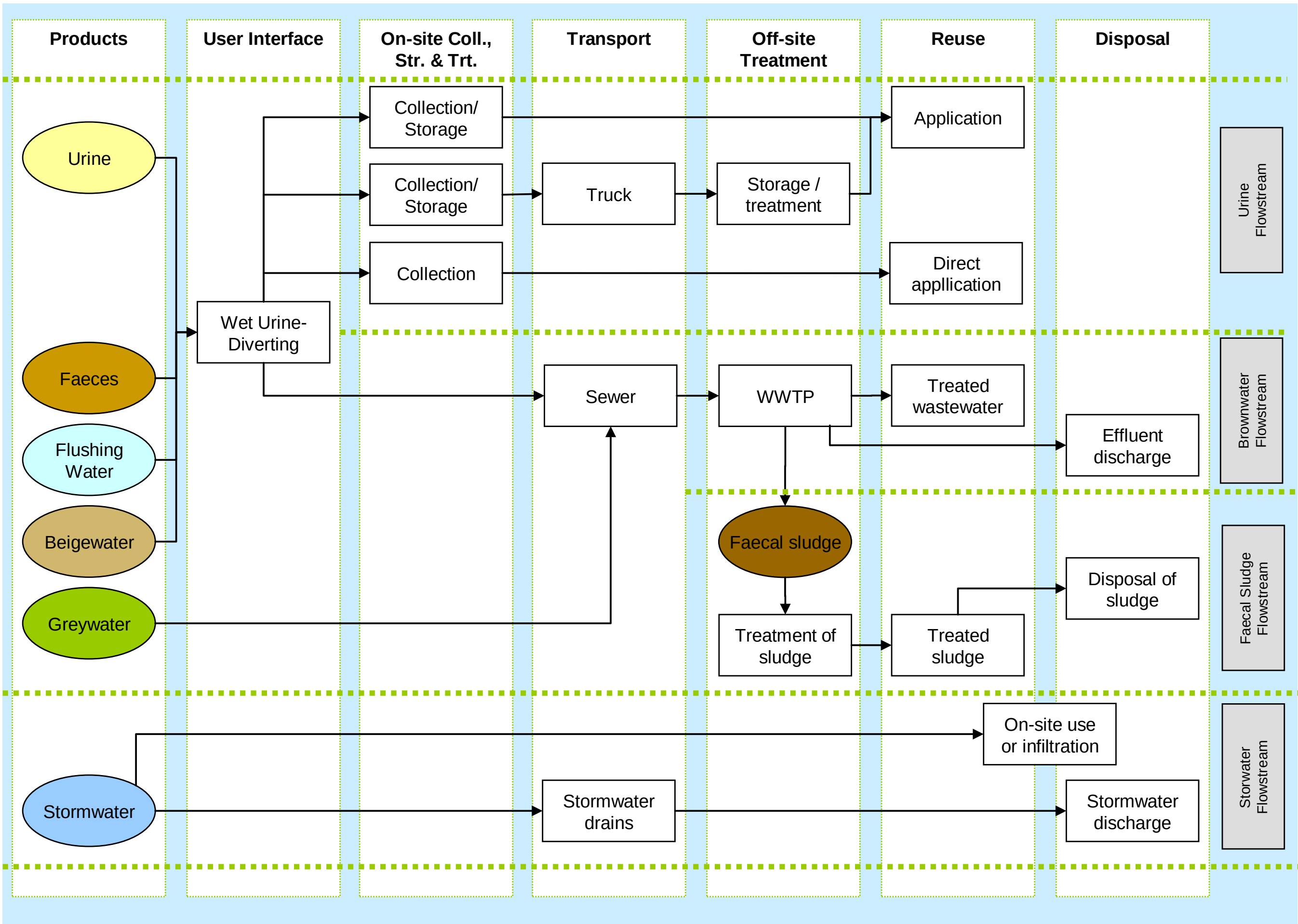


Figure 4: Wet urine diversion system where urine and brownwater (with greywater) are managed separately

Relevant Flowstreams

Urine flowstream

The aim of the urine-diverting system is to prevent urine from coming into contact with faeces, thus minimizing the potential for pathogen contamination and enhancing safe reuse opportunities. Urine is collected separately in a collection vessel and sometimes treated by storage and/or transported before its reuse in crop production. Urine is rich in nitrogen, potassium and phosphorus. The nutrients and minerals, which plants need for growing, are available in a good balance. If uncontaminated by faeces, separately collected urine from a healthy person does not contain pathogens. Where urine is used to fertilize crops eaten by others than the own family it is recommended that the urine be stored for 1-6 months before application (see WHO guidelines on “Excreta and greywater reuse in agriculture”). During the storage, it develops a pungent odour of ammonia, and the pH increases from 6 to around 9. These changes are a result of the bacterial hydrolysis of urea, which produces ammonia and carbon dioxide. The concentration of the urine flowstream is influenced by the amount of flushing water mixed with the urine.

Depending on diet, human urine collected during one year (ca. 500 liters) contains 2-4 kg nitrogen, while faeces (ca. 50-120 kg per year) contain only 0.3-0,6 kg nitrogen.

Brownwater mixed with greywater flowstream

Brownwater consists of faeces and flushing water (although in actual practice there is always some urine, as only 70-85% of the urine is diverted.) In this system, the brownwater is mixed with greywater. By separating urine, the nutrient concentration in the brownwater is greatly reduced. By mixing brownwater with greywater the nutrient concentration is lowered even further.

Faecal sludge flowstream (refer to 1.1)

1.5 Dry excreta and greywater separate system

Excreta is a mix of urine and faeces; there is no flushing water. In this system the greywater collected separately. So although the mixture of urine and faeces may be slightly wet, the system is referred to as 'dry' simply because there is no flushing water. Depending on the cultural habits, beigewater (or anal cleansing water) may or may not be included although smells and flies are minimized if the mixture is kept as dry as possible. This is particularly true for the composting-type systems (Arbor loo, Fossa alterna) that can become flooded/anaerobic if too much water is added. Generally, the system is typically characterised by "drop and store" latrines that can be emptied, reused, or capped and filled.

The separate greywater should be treated as close to where it is generated (on-site-treatment) as possible. The excreta may be further treated off-site. Generally, off-site treatment is only performed to improve hygienisation (especially in the case of single pits that are emptied before the contents can be completely digested). Proper operation and maintenance significantly influence the performance of these facilities. It is possible to either reuse the recovered resources (greywater and/or treated excreta sludge) or to dispose of them when interest in resource recovery and reuse is lacking.

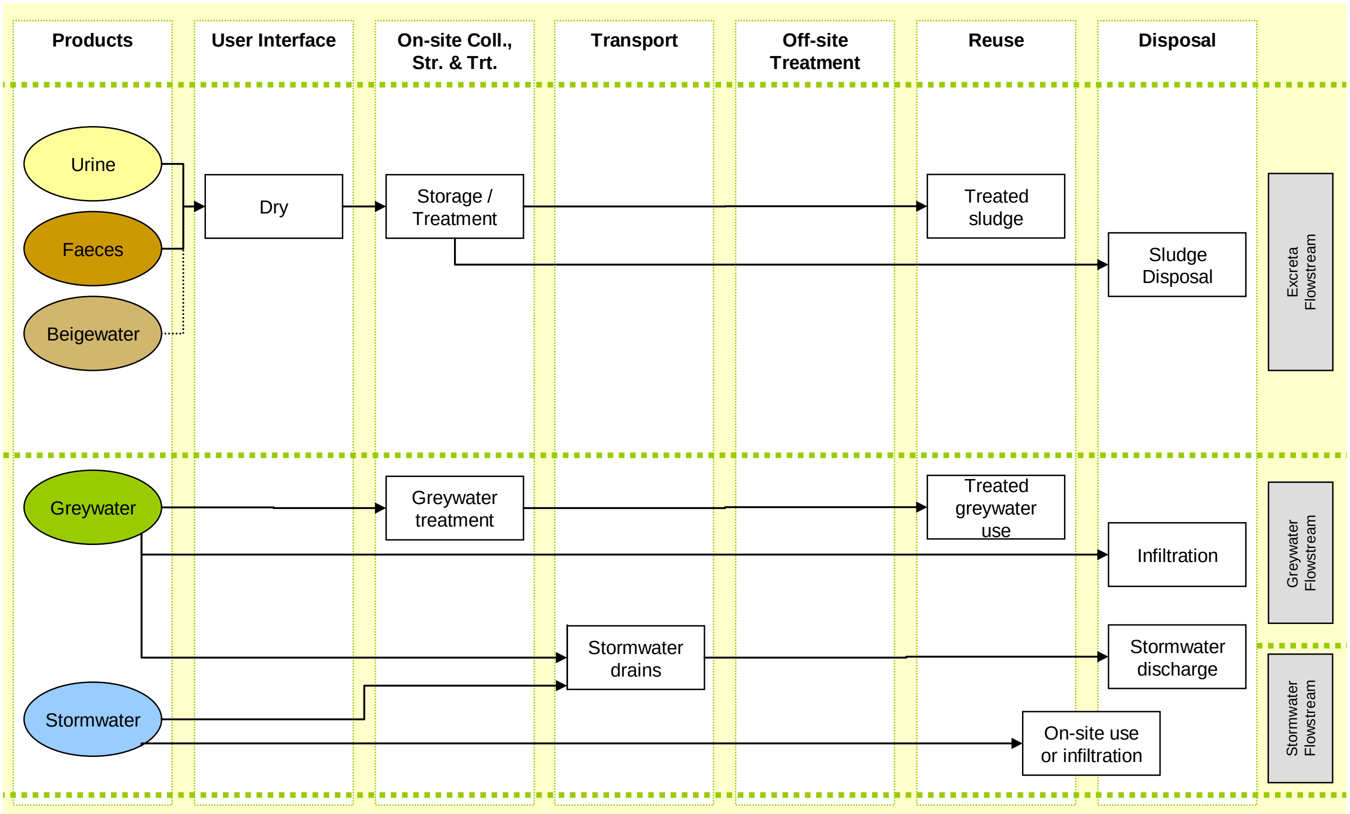


Figure 5: Dry onsite excreta storage with greywater diversion system

Relevant Flowstreams

Excreta flowstream

As a dry system without flushing water this flowstream consists of faeces and urine, and depending on the circumstances, it may also include anal cleansing material or anal cleansing water. In the event that anal cleansing water is included, one must be careful to consider if the type of collection technology is appropriate; some types of on-site technologies (e.g. composting toilets) cannot tolerate excess moisture (other than urine) and should therefore not be chosen. Given the low liquid content (and the fact that it can therefore not be moved in a sewer) On-site Collection, Storage and Treatment technologies are the most appropriate (although mechanical or manual emptying and transport are also possible). In sparsely populated rural areas where the space availability is not an issue, the drop and store facilities are closed when full and new pits are constructed (e.g. Arbor loo). In areas of higher density with scarcity of space, alternating double pits are appropriate although the periodic emptying of excreta must be ensured. Generally, the excreta is removed from alternating pits after it has had sufficient time to mature into a benign, useable humic-like substance and requires no further treatment.

Greywater flowstream (refer to 1.2)

1.6 Dry urine, faeces and greywater diversion system

This system is characterized by the separation of urine, faeces and greywater into three different flowstreams, and where anal cleansing water is used, a fourth flowstream. In this way, each flowstream can be more appropriately managed in terms of its volumetric flow, nutrient and pathogen content and handling characteristics. This diversion facilitates more targeted treatment and end use for the different fractions.

This system requires a urine-diverting user interface. Urine is collected through the front outlet and conveyed to a collection vessel (a tank in larger, more expensive systems or a jerry can in smaller, simpler systems), a garden or possibly a soak pit, if the urine is not brought to use. Through the rear outlet the faeces are collected in a container located underneath the toilet. Dry cleansing material (such as toilet paper) can be dropped through the rear outlet, although it is often kept separate. Some urine-diverting squat pans are also equipped with an additional outlet for anal cleansing water (beigewater), which is then treated, in a separate flowstream.

The urine can be used as a fertilizer for crop production. In larger systems, urine must be sanitized through storage, while at the household level, the urine can be used directly but the time from fertilizing until harvesting should be at least one month. Hygiene and sanitation guidelines on how to safely use urine as a fertilizer for crop production have been published by the WHO.

Dehydration is the simplest way of treating the faecal fraction, although they can also be mixed with organics and composted. By dehydrating the faeces with or without the addition of a drying or pH control agent (e.g. ash, lime, etc.), the faeces can be sanitized and used, or disposed of, safely. Faeces should be kept as dry as possible and covered continually to aid in drying and form a barrier between the faeces and vectors.

Guidelines for the hygienic use of faeces have been published in the WHO Guidelines.

If anal cleansing is practiced, the resulting beigewater should be diverted and either treated separately or with the greywater. Mixing the faeces and the beigewater will result in the continued survival of pathogens and the proliferation of smells and flies.

The greywater can be treated separately or combined with stormwater. The treated effluent can then be reused for irrigation purposes or as service water, following the WHO guidelines.

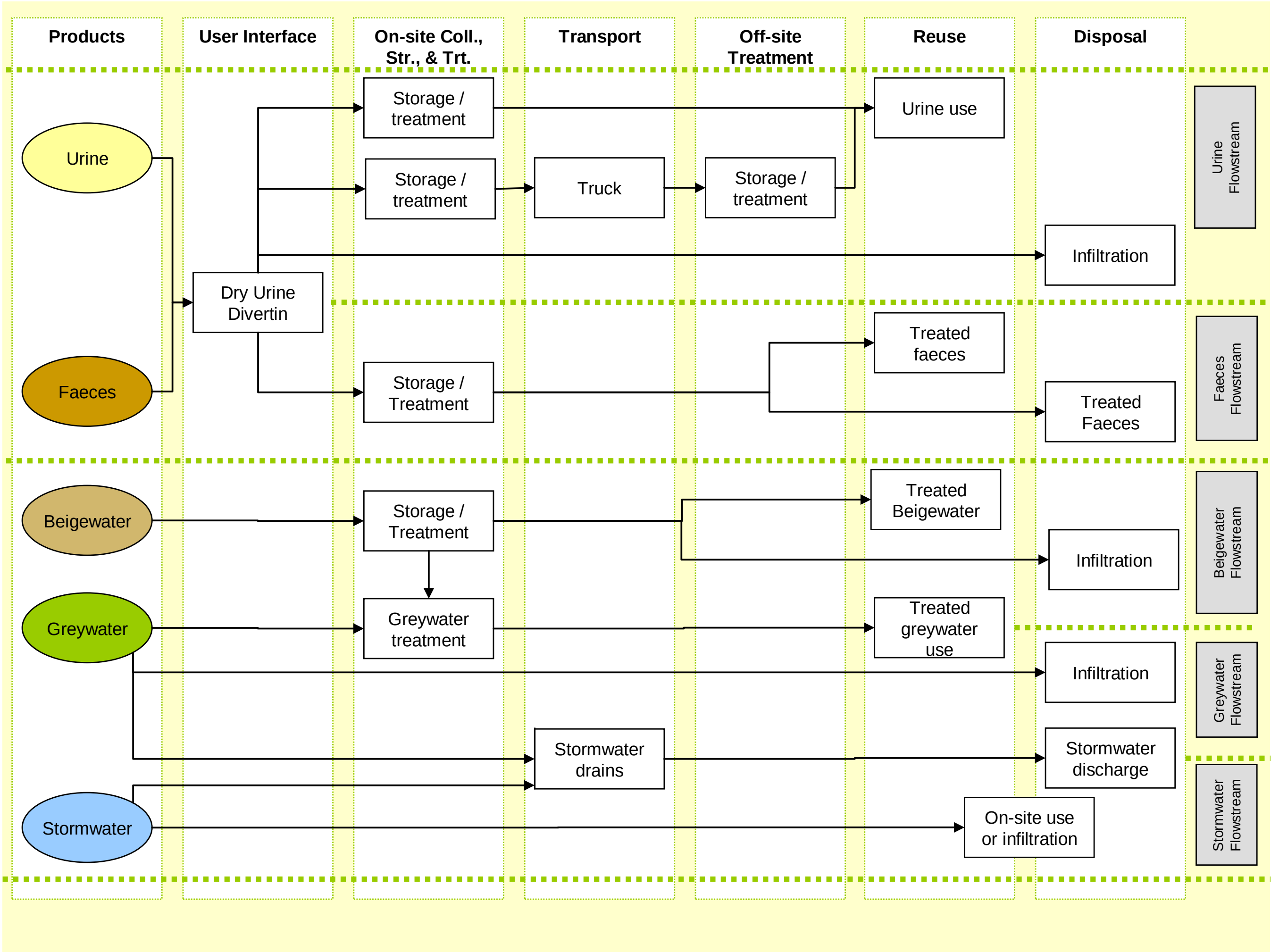


Figure 6. Dry urine, faeces and greywater diversion

Relevant Flowstreams

Urine flowstream (refer to 1.3)

Faeces flowstream

The faeces flowstream consists of only faeces, sometimes anal cleansing material like toilet paper, and in very rare cases a small amount of anal cleansing water, although in general, anal cleansing water should not be included in this flowstream because the faeces must remain as dry as possible to facilitate further treatment (e.g. by dehydration). This flowstream resembles the excreta flowstream however with less liquid content (as urine is missing). The low moisture content of the faeces means that simple technologies such as dehydration and composting can be used to treat the faeces onsite. Extended, moisture-free storage results in dehydration and thus, is characterized as a treatment process. Treatment options may also involve the addition of solid waste which improve the carbon to nitrogen ration (C:N) and facilitate a composting process (e.g. Fossa alterna). Ammonia treatment or digestion (with the addition of water to create a faecal sludge) are emerging secondary treatment options.

Beigewater flowstream

Although beigewater is quite dilute, it is still quite pathogenic and should be treated before it is discharged. Where anal cleansing water is used, this normally forms a separate flowstream. The beigewater flowstream is normally treated separately on site in a small planted filter which, due to the small flow, often does not produce any effluent. It can also be co-treated with the greywater, although in doing so, the pathogen concentration in this mixed flowstream is increased.

Greywater flowstream (refer to 1.2)

1.7 Dry excreta and greywater mixed system

In this system, urine, faeces and greywater are mixed in the same On-site Collection, Storage and Treatment technology. Although this type of system can be frequently observed in rural and peri-urban areas of West Africa, it is not considered to be good practice. The difference between this system and System 5 'Dry excreta and greywater separate system' is the inclusion of greywater. Since the toilet facility often serves as a room for showering and washing also, the washing water (greywater) flows into the same hole/pit where excreta are collected. Most often the facilities consist of "drop and store" collection technologies, where the liquid fraction infiltrates into the subsurface, while the sludge accumulates in the bottom. To prevent the greywater from quickly filling up the pit, the soil must have a good infiltration capacity. Unfortunately, this practice may endanger the groundwater aquifer below. In the case of soils that have poor infiltration capacity, the pits need to be emptied frequently. In sparsely populated rural areas where the availability of space is not an issue, the drop and store latrine facilities are closed when they are full and new pits are constructed. In areas of higher density and where space is scarce, double pits are more often observed as they can be emptied less frequently and used indefinitely. Irrespective of the system, faecal sludge must be managed as a unique flowstream.

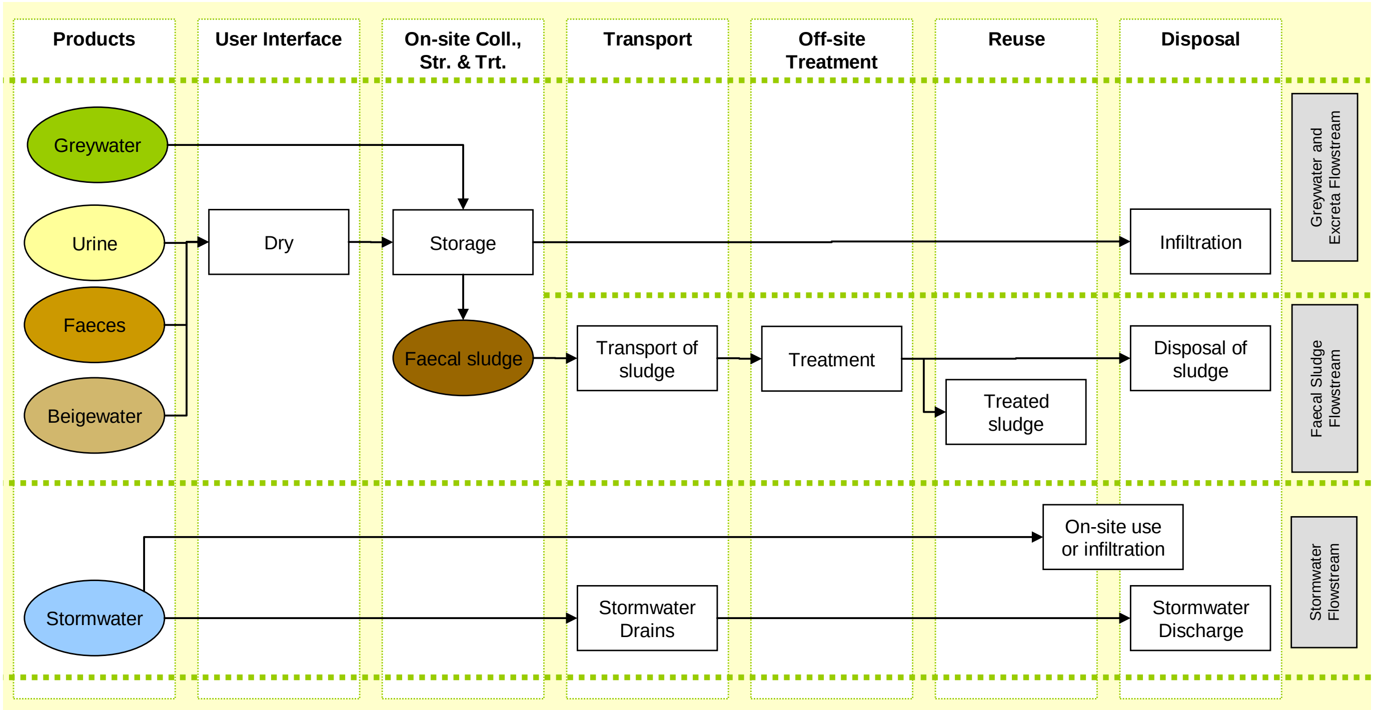


Figure 7. Dry excreta and greywater mixed system

Relevant Flowstreams

Mixed excreta and greywater flowstream

This flowstream consist of urine, faeces, greywater and anal cleansing water if applicable. This system can be very frequently observed in rural and peri-urban areas of West Africa. Drop and store facilities require high infiltration rates to avoid rapid filling and overflowing due to the large flows of greywater, but this also increases the risk of ground water pollution. In areas where the infiltration capacity or ground water contamination is a problem, a change over to systems 1.5 can often be recommended. In areas of higher density with scarcity of space, an emptying service of the pits must be ensured and double pits are frequent as this considerably decreases the need for emptying. To eliminate pathogens before reuse, the faecal sludge can be treated by composting, digestion, dewatering, dehydration, ammonia treatment, or humification. It is often sometimes suitable to co-treat the faecal sludge with organic solid waste.

Faecal Sludge flowstream (refer to 1.1)

1.8 Summary of Flowstreams

The following table summarizes each of the flowstreams that are found in the systems described in this document.

Table 3. Summary and description of relevant flowstreams

Flowstream	Summary
blackwater flowstream	**Products:** urine, faeces, flushing water. It also contains cleaning material or beigewater. **Description:** Lack of greywater in this flowstream may limit the self-cleansing velocity in a sewer network given the reduced liquid content. Blackwater however may be stored or treated on-site in appropriate facilities. Such on-site storage and treatment most often entails settling of the solid fraction, and a partial treatment of the liquid as well as solid fraction. The liquid fraction may then be infiltrated into the subsurface or may be transported further to an offsite treatment plant, and subsequently reused or discharged whereas the solids must be handled separately as faecal sludge flowstream. *In: System 2 (chapter 1.2.)*
greywater flowstream	**Products:** Greywater **Description:** Greywater is used water from the kitchen, bathtub, shower, sinks, laundry and dish washing. Greywater accounts for 50-80% of the outflow produced at household level, although this very much depends on local conditions. It contains few, if any, pathogens and 90% less nitrogen than blackwater and therefore does not require the same treatment processes as blackwater or mixed wastewater. Greywater can be recycled for irrigation, toilet flushing, and exterior washing, which can improve water conservation. In existing practice greywater is often discharged indiscriminately into open drains, onto land or fed into soak pits or infiltration trenches. Greywater treatment and reuse systems generally consist of a preliminary treatment to hold back sand, grit and fat followed by a secondary treatment technology. The treated water can be infiltrated into subsurface, discharged into surface waters or reused for irrigation purpose or as service water, following the WHO guidelines. *In: System 2 (chapter 1.2); System 4 (1.4); System 5 (1.5), System 6 (1.6)*
faecal sludge flowstream	**Products:** faecal sludge **Description:** Faecal sludge can be broadly defined as the thicken solids resulting from the storage and/or treatment of wastewater. Sludge can be mostly biological (e.g. from trickling filters) or mostly raw faecal material (e.g. from pit latrines) To reduce pathogens and vector attraction, sludge can be treated by a variety of methods. However, sludge that originates not only from household wastewater but also from industrial wastewater may contain high levels of toxic chemicals that are not removed during treatment. Depending on the origin of the wastewater the level of treatment and resultant pollutant content, sludge can be used in regulated applications ranging from soil conditioning to fertilizer for food or non-food agriculture. *In: System 1 (chapter 1.1.); System 2 (chapter 1.2); System 3 (chapter 1.3); System 4 (1.4); and System 7 (1.7)*
brownwater flowstream	**Products:** faeces, flushing water. It also contains cleaning material or beigewater **Description:** Brownwater results from wet-urine diversion systems. Typically, brownwater is transported through sewers and is treated offsite. It is very similar to blackwater, however with the urine removed, the nutrient levels are significantly lower.

	In: System 4 (chapter 1.4.)
urine flowstream	**Products:** urine **Description:** Urine diverting systems avoid urine coming into contact with faeces, thus eliminating potential pathogen contamination and enhancing safe reuse opportunities. Urine is collected separately in a reservoir or canister and stored, treated and/or transported before its reuse in crop production. It can also be directly infiltrated in a small soakaway. Urine is rich in nitrogen, potassium, phosphorus and sulphur. The nutrients and minerals, which plants need for growing, are available in a good balance. Separately collected urine from a healthy person does not contain pathogens. However urine may still be contaminated easily by traces of faeces. For safety reasons, in large systems it is recommendable to treat urine by storage for 3-6 months before application. During the storage, urine develops a pungent odour of ammonia, and the pH increases from 6 to more than 9. Both of these changes are a result of the bacterial hydrolysis of urea, which produces ammonia and carbon dioxide. The chemical composition is also influenced by the amount of flushing water in the collection system. *In: System 3 (chapter 1.3); System 4 (1.4); System 6 (1.6)in: System 3 (chapter 1.3); System 4 (1.4); System 6 (1.6)*
excreta flowstream	**Products:** urine and faeces **Description:** The excreta flowstream is collected with a dry user interface, i.e. without flushing water. Given the low liquid content, treatment occurs on-site. In sparsely populated rural areas where space availability is not an issue, drop and store facilities are closed when full and new pits are constructed. In areas of higher density where space is scarce, alternating double pits can be used. Excreta can be co-treated together with solid waste (co-composting), or dried in order to eliminate pathogens before reuse. *In: System 5 (chapter 1.5)*
faeces flowstream	**Products:** Faeces. It may also include toilet paper or other dry materials. **Description:** This flowstream resembles the excreta flowstream but is drier (as urine is missing). The relatively low liquid content of this flowstream means that dehydration or composting are suitable treatment technologies. Given the high solids content, on-site “drop and store” latrines, especially watertight dehydration vaults, are common storage technologies. Onsite treatment in a combined faeces/solid waste system, such as the Fossa alterna, is also possible. To properly compost faeces, the addition of solid waste is required. *In: System 6 (chapter 1.6)*
beigewater flowstream	**Products:** Beigewater (anal cleansing water) **Description:** Beigewater is the water that is used for cleaning by those who do not use dry cleaning materials (e.g. toilet paper). Beigewater, although very dilute, contains a significant amount of faecal material and is therefore pathogenic and should be treated appropriately. Beigewater is most often mixed with blackwater in ‘wet’ systems, but in dry systems, especially when urine is separated from faeces, it is important to also separate beigewater so that the other flowstreams can be treated properly. *In: System 6 (chapter 1.6)*
mixed blackwater and greywater flowstream	**Products:** urine, faeces, flushing water, and greywater (stormwater may or may not be diverted into the sewer and mixed with this flowstream). It also contains cleaning material or beigewater (if anal cleansing is practiced) **Description:** This is the most common flowstream in industrialized

	city systems; a sewer to a centralized treatment plant carries all water that is generated from houses /businesses/industries etc. *In: System 1 (chapter 1.1.)*
brownwater mixed with greywater flowstream	**Products:** faeces, flushing water and greywater. It also contains cleaning material or beigewater. **Description:** This flowstream is similar to the blackwater mixed with greywater flowstream except that the urine has been separated out. Thus, on-site treatment or else transport by a sewer and off-site treatment can be options for treatment before reuse of the effluent. On-site storage/treatment facilities most often entail settling of the solid fraction, and a partial treatment of the liquid as well as solid fraction. The solid fraction (faecal sludge) must then be further managed in the faecal sludge flowstream. By separation of urine, brownwater contains lower concentrations of nutrients (as nitrogen and phosphorous is mainly contained in the urine). This aspect of low nutrient concentrations is further enhanced by the inclusion of greywater, which further decreases the nutrient concentrations. *In: System 3 (chapter 1.3.)*
excreta mixed with greywater flowstream	**Products:** urine, faeces, greywater **Description:** This is a commonly seen flowstream in West Africa. . In dense areas with a scarcity of space, either double pits are used alternately or single pits must be emptied frequently. However, mixing greywater with excreta is not recommended since the greywater shortens the life of the pit, causes odours and cannot be used beneficially. Excreta can be co-treated together with solid waste (co-composting), or dried in order to eliminate pathogens before reuse. *In: System 7 (chapter 1.7)*

PART 2 Technology component descriptions

The following chapter summarizes conventional and innovative sanitation technologies; for each technology there is a brief description and where possible, a reference. The technology components are grouped according to process (i.e. the function that they serve) and sub-divided according to flowstream

User Interface

Toilet technologies can be constructed as pedestals or squatting slabs depending on the socio-cultural preferences. In this chapter the term 'toilet' is used to refer collectively to both pedestals and squatting pans.

High-volume cistern-flush toilets

Flush toilets use water to flush excreta into a subsequent storage, transport or treatment process. After the toilet is used and flushed, water from the cistern automatically fills the bowl, which is then drained away along with the excreta, leaving the bowl clean. Flush toilets normally have a U-shaped conduit partly filled with water (U trap) under the pan. The U trap overcomes the problems of flies, mosquitoes, and odour by serving as a water seal. Conventional cistern-flush toilets use between 10 and 20 litres per flush. The toilet can be constructed as pedestal or squatting pan depending on the socio-cultural preferences.

Low-volume cistern flush toilets

Low-volume (or low flow) toilets are designed to use four to six litres of water per full flush. This reduces water requirements in single-family residences significantly, by at least 20%. Although a low flush toilet looks like a conventional cistern flush toilet, it has several unique features. Most low flush toilets use gravity to speed the course of water through the bowl and trap. The rim wash comes through an open slot rather than small holes. The bowl may have steep sides and a narrow trap opening to decrease volume of the U-bend. Low flush toilets generally have a smaller pool or "water spot" than in conventional toilets. Some toilets also offer the option of a half flush of two to three litres or a full flush, which is twice the size.

A special case of a low volume flush toilet is the so-called simple/light flush toilet. It has been used in Japan and requires 200-500 ml of water per flush to wash the pan and conduct the excreta into a container below (pit or watertight chamber or cesspit). Given this very low flush volume, the toilet water from this toilet cannot be transported by conventional gravity sewers, but needs to be collected underneath the toilet.

Pour-flush toilets

The pour-flush pan/toilet includes both a spot for squatting or sitting and a water seal that helps control odour and flies. Below, or connected to the pan by small diameter pipes, can be single or double leach pits, a cesspit or septic tank. Water, which is poured by hand into the pan, transports the excreta through the water seal and connecting pipes into the collection technology. The flush volume required varies, but can be as low as 2-3 litres. The actual volume used varies with the user. Just as in cistern flush toilets, the pan is cleaned after each use and the water seal is maintained to provide a barrier against odours and insects.

Mara, D. (1985). The Design of Pour-Flush Latrines. TAG Technical Note No. 15. UNDP/ World Bank. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2003/03/14/000178830_98101903445990/Rendered/PDF/multi0page.pdf Accessed 17 July, 2007.

Urine diversion toilet (dry or wet)

The urine diversion toilet differs from an ordinary toilet as it is designed to collect the urine separately from the faeces. This is done to minimize the faecal contamination and the water dilution of the urine flowstream. It can offer the same comfort and functional service as non-diverting toilets. Urine diverting pedestal toilets and squatting plates can be self-constructed (dry systems) or prefabricated (dry and wet systems). Non-flush systems are appropriate technology options for both simple and complex environments. Toilets are commonly constructed of sanitary porcelain, concrete, fibreglass or plastic. These toilets may be introduced with the construction of new sanitation systems or after modifications to an existing system. Variations of the urine diversion toilet designs include: the *urine diversion flush toilet* (similar to the WC), the *waterless toilet with urine collection funnel*, and *vacuum urine diverting toilets*. Careful planning and appropriate design selection is essential for practical application of urine diversion toilets. Metals should be avoided within the urine system as urine is very corrosive. Durable plastics are a viable alternative. Ventilation of urine collection is not recommended, since ventilation increases the loss of volatile nitrogen and the risk of mal-odour. Only a small venting for pressure equalisation of the storage containers should be used. Urine diversion flush toilets come as wall-hung and floor models. Easily accessible and removable connections are recommended to simplify maintenance.

a) Flush toilet with urine diversion

The urine diversion flush toilet has a partition in the toilet bowl to allow for urine collection in the front, and a bowl for faeces collection in the rear. Some designs allow for each bowl to be flushed separately, while in other models they are flushed simultaneously. The dilution of the collected urine with flushwater depends on the toilet and the user. Collection of urine with no or minimal dilution is possible on many models.

Kvarnström, E. et al. (2006). Urine diversion: One step towards sustainable sanitation. Report 2006-1. Ecosanres, Stockholm Environment Institute, Sweden. http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf; Accessed 29 August 2007.

b) Urine diversion waterless toilet- pedestal or squatting pan

The urine diversion waterless toilet is a very simple adaptation of a drop toilet whereby the urine is captured in a bowl or funnel in the front of the toilet and piped to a collection container or leaching pit. Faeces simply fall down the large, open space behind the urine bowl or funnel into a collection pit or container. The waterless toilet requires no water for flushing the faecal fraction, but small doses may be used to rinse the urine bowl at suitable frequencies.

The water-free urine-diverting unit can also be designed as a squatting pan; this design may be especially useful where anal cleansing is practiced, as the plate can be adapted to include a separate hole to dispose of the beigewater.

Morgan, P. (2007) Toilets That Make Compost: Low-cost, sanitary toilets that produce valuable compost for crops in an African context. Stockholm Environment Institute, Sweden.

Urinal

A urinal is a specialized toilet designed to be used only for urination. The most common designs are for used by males, but designs for females are also available. In public toilets, the urinal often includes a mesh above to outlet to prevent solid objects such as cigarette butts and paper from entering the pipe and possibly causing a plumbing problem. Presently, most urinals use water for flushing, but waterless urinals are becoming increasingly more popular.

Squatting-type ladies' urinals are becoming increasingly available in different international and local markets. The variety of styles ranges from prefabricated versions to local designs.

a) Low flush urinals

Urinals, like toilets, use large amounts of water. Low flush urinals are intended to help reduce water consumption by providing a financial incentive to replace high-volume flush toilets and urinals. Before the advent of low-flow models, many urinals required 2-3 gallons of water per flush. Today's low-flow models all require less than 1 gallon per flush. Although designing a low-flush urinal did not present the same problems that manufacturers experienced with low-flush toilets, design changes were required in order to develop a unit that performed successfully. There have not been any significant acceptance problems with waterless urinals for men as they do not call for any change of behaviour on their part

b) Waterless urinals

Waterless urinals have been used for a long time. Their development was particular driven by the needs of arid areas, where water is too vital to waste for urine transport. They have also been used for quite some time in industrialised countries. There, the motivation was mainly economic to reduce the costs of water supply, particularly in highly frequented buildings. Waterless urinals collect undiluted urine, which can then be collected, transported, treated and used. Waterless urinals come in many shapes and materials; squatting slabs and wall mounted bowls are common while materials range from reused plastic vessels, concrete, high-quality plastics, porcelain to stainless steel. Prefabricated urinals are available both as high quality products and as low-cost options. Self-construction of inexpensive waterless urinals is also possible and easy.

From a functional point of view the main distinguishing feature of urinals is the type of odour trap that prevents the emission of gases and odours from urine pipes. Simple and low cost urinals often have no odour trap. Odour problems therefore may occur but can often be prevented by only having one urinal on each pipe and letting the inlet pipe into the collection vessel/container go down almost to the bottom, thus forming a liquid trap there. Four types of odour traps are available: membrane barriers, liquid barriers, electromagnetic and hydrostatic float barriers. In urinals with a membrane stench barrier, the odour trap consists of a flat rubber tube or rubber lips. The urine passes through this membrane, which then closes when the urine flow stops and seals the urine outlet, preventing smell. In urinals with liquid odour traps the urine passes through a liquid odour seal made of oil or aliphatic alcohols. The urine, which is heavier than the liquid, sinks down through the liquid and further down to the drain. The sealing liquid should be environmentally friendly and biodegradable. In urinals with electromagnetic float barrier, the urine passes into the cylindrical inner part of the pan and from there to the overflow chamber, whereby the float rises and seals the inlet opening against a flexible sealing lip. When the urine in the overflow chamber reaches a certain level it flows into the drain. Every time the urinal is used, a sensor activates an electromagnet that draws the float down again to ensure complete emptying of any residual urine. Instead of using a magnetic device driven by electricity, urinals with hydrostatic float barrier are also available. The urine presses down the float and therefore the downflow channel is open and urine flows out. It is designed in a way that the float will move downwards even when the pressure from urine above is very small, to ensure that no urine is blocked and remains outside.

GTZ. (1999). Technical data sheets for ecosan components: Waterless urinals. GTZ, Germany. www.gtz.de/de/dokumente/en-ecosan-tds-01-b2-urine-diversion-waterless-urinals-2005.pdf; Accessed 17 July, 2007.

Austin, A. and L. Duncker. (2002). Urine-diversion. Ecological Sanitation Systems in South Africa, CSIR, Pretoria.

Dry toilet

A dry toilet is simply a toilet without flushing water. The toilet may be raised as a seat (pedestal) or else it is a squat pan over which the user squats. Pedestals and squatting platforms can be made locally using concrete or other materials. Dry toilets do not have odour seals. Therefore, the odour may have to be controlled by other means such as ventilation and/or use of cover material (in the case of dry faecal collection without any urine or water).

Morgan, P. (2007) Toilets That Make Compost: Low-cost, sanitary toilets that produce valuable compost for crops in an African context. Stockholm Environment Institute, Sweden.

Brandberg, B. (1997). Latrine Building. A Handbook for Implementation of the Sanplat System, Intermediate Technology Publications, London. (see also www.sanplat.com)

On-site Collection, Storage &Treatment

Although the technologies listed in the following section are most appropriate for on-site applications, it is important to note that several technologies described below can be applied off-site as well (i.e. at the household level or at the community/regional scale). Usually the main difference is the scale of the technology

Related to excreta

Single pit latrine

The single pit latrine is the most commonly used sanitation technology in developing countries. Pit latrines consist of a superstructure and a hole for defecation. A pit cover slab can be used to reduce odour and hinder flies. The average depth is 3 m. but is usually limited by the groundwater table or bedrock. The walls of the latrine should be water pervious and it is strongly recommended that the guidelines on vertical safety distance between the bottom of the pit and the groundwater be followed. Dry anal cleansing is advantageous to minimise water content and extend the life of the pit.

Brandberg, B. (1997). Latrine Building. A Handbook for Implementation of the Sanplat System, Intermediate Technology Publications, London.

Pickford, J. (1995). Low Cost Sanitation. A Survey of Practical Experience, Intermediate Technology Publications, London.

Arbor Loo Pit

The Arbor loo is a special case of a single pit. The pit is shallow, about 1.0 to 1.5m deep, and the site is temporary. Excreta, soil, ash and leaves are added to the pit to minimize the risk of odour and flies and to facilitate composting. The Arbor loo unit, which consists of a ring beam, slab and structure - moves from one site to the next (i.e. when full) at 6 to 12-month intervals. The full pit is covered with at least 20-30 cm of soil and left to compost. A tree is planted on the old site, preferably during the rains.

Morgan, P. (2007). Toilets that make compost. Low-cost, sanitary toilets that produce valuable compost for crops in an African context. EcoSanRes, Sweden. http://www.ecosanres.org/pdf_files/ToiletsThatMakeCompost.pdf; Accessed 15 August, 2007.

Ventilated improved single pit latrine (VIP)

Ventilated improved pit (VIP) latrines are designed to reduce two problems frequently encountered by traditional pit latrine systems: smells and flies (or other insects). A VIP latrine differs from a traditional latrine by having a vent pipe covered with a fly screen. Wind blowing across the top of the vent pipe creates a flow of air, which sucks out the foul-smelling gases from the pit. As a result, fresh air is drawn into the pit through the drop hole and the superstructure is kept free from smells. The vent pipe also has an important role to play in fly control. Flies are attracted to light and, if the latrine is suitably dark inside, they will fly up the vent pipe to the light. They cannot escape because of the fly screen, so they are trapped at the top of the pipe until they dehydrate and die. Female flies, searching for an egg-laying site, are attracted by the odours from the vent pipe but are prevented from flying down the pipe by the fly screen at its top.

Mara, D.D. (1984). The Design of Ventilated Improved Pit Latrines (UNDP Interreg. Project INT/81/047), The World Bank, Washington + UNDP

Mara, D.D. (1996). Low-Cost Urban Sanitation. John Wiley & Sons- Wiley-Interscience Publications.

Alternating Twin-Pit Latrine

Pit latrines or VIP latrines can also be constructed with a double pit. The latrine has two pits, a superstructure and (optionally) a vent pipe. The cover slab has two drop holes, one over each pit. Only one pit is used at a time. When the first pit becomes full, the drop hole is covered, the superstructure is moved (if applicable) and the second pit is used. Because the material in the pits is left to mature for a year or more, pits can be used wet or dry. After a period of at least one year, the contents of the first pit can be removed safely and used as soil conditioner. The pit can be used again when the second pit has filled up.

Roy, A.K., K.N. Chatterjee, et al. (1984). Manual on the Design, Construction and Maintenance of Low-Cost Pour Flush Water seal Latrines in India (UNDP Interreg. Project INT/81/047), The World Bank+ UNDP, Washington.

D. Duncan Mara (1984). The Design of Ventilated Improved Pit Latrines (UNDP Interreg. Project INT/81/047), The World Bank+ UNDP, Washington.

Fossa alterna

The Fossa alterna combines the concept of a double pit and a composting toilet. For the Fossa alterna there are two permanent, shallow pits, up to 1.5m deep and dug close to each other, which are used alternately (similar to the double pit latrine). For a medium sized family, continuously adding bulking and/or carbon rich material, the pit takes about 12 months to fill up. The material is added to minimize the risk of odour and flies and to enhance the composting process. Every year one pit is excavated whilst the other becomes full. If the pits remain stable this process can continue for years. It is important that water (greywater, flushwater) not be put into the Fossa alterna; urine however is acceptable.

Morgan, P. (2007). Toilets That Make Compost: Low-cost, sanitary toilets that produce valuable compost for crops in an African context. Stockholm Environment Institute, Sweden. www.ecosanres.org/toilets_that_make_compost.htm; Accessed 17 July, 2007.

Alternating Double Dehydration Chambers

In the absence of urine (because it is diverted and collected separated), two vaults can be used for the collection, storage and dehydration of faeces. To allow sufficient time for the faeces to be dehydrated each chamber (vault) should be designed to accommodate a volume of at least six months of excreta. If the faecal matter is to be reused without secondary treatment the chamber should accommodate the faecal matter for the duration of the storage period needed for the safe reuse of the stored faeces. This period depends on temperature and pH (See WHO Guidelines). Often ash or sawdust is added after each defecation to minimize the risk of odour and flies, to improve moisture control and increase pH (and thus pathogen die-off). It is important to bear in mind that in the absence of moisture and organics, the faeces are simply dehydrated, but not composted. The excreta inside the chamber become dry with the help of sun, natural evaporation and ventilation. The toilet must not contain flushing water, anal cleansing water or urine as it will encourage bacterial growth and will cause foul odours. Similarly, it is important that the vaults be constructed to be water tight regardless of surface or ground water.

The product from the dehydration process, a crumbly cake, is not compost but rather a kind of mulch, which is rich in carbon and fibrous material, phosphorous and potassium. Nutrients will be available to plants directly or after further decomposition of the dehydrated material. Much of the nitrogen is lost as ammonia during the dehydration process. In warm environments (20°-35°) storage times of less than 1 year will be sufficient to eliminate most bacterial pathogens and substantially reduce viruses, protozoa and parasites. Some soil-borne ova (e.g. *Ascaris lumbricoides*) may persist. Alkaline treatment, i.e. raising the pH above 9, can reduce the required storage time to about 6 months (Schönning and Stenström, 2004). Further storage, sun drying, alkaline treatment or high-temperature composting may be recommended to further decrease health risks of utilization of the dehydrated faeces.

Dehydration-based treatment technologies are increasingly popular in the developing world. They can be successfully used in various climatic conditions and are most advantageous in arid climates where water is scarce and faeces can be effectively dried. For areas with high groundwater tables or rocky soils, dehydrating toilets with both chambers above ground is oftentimes one of the simplest and most appropriate solutions.

Schonning, C. and T.A. Stenstrom. (2004). Guidelines for the Safe Use of Urine and Faeces in Ecological Sanitation Systems-Report 2004-1.EcosanRes, Stockholm Environment Institute, Stockholm, Sweden. www.ecosanres.org/pdf_files/ESR_Publications_2004/ESR1web.pdf; Accessed 18 July 2007.

Winblad, U. and M. Simpson-Herbert (eds.) (2004). Ecological Sanitation- revised and enlarged edition. Stockholm Environment Institute, Stockholm, Sweden. www.ecosanres.org/pdf_files/Ecological_Sanitation_2004.pdf; Accessed 17 July, 2007.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater- Volume 4: Excreta and greywater use in agriculture. WHO, Geneva. http://whqlibdoc.who.int/publications/2006/9241546859_eng.pdf; Accessed 17 July, 2007.

Dehydrating toilet/latrine

This is similar to the double chamber, however in a dehydration toilet, the processing chambers are constructed in a way to enhance the drying of excreta inside the chamber with the help of sun, natural evaporation and ventilation. They are sometimes called solar toilets and versions with just one chamber are also used. The toilet should not contain flushing water or anal cleansing water but in hot, dry climates urine can be included. This system consists of a one or two-chamber dehydration toilet for the drying, storage and hygienisation of faeces for later reuse. This option is far less common than dehydration vaults which do not include urine, but in some instances, this may be an appropriate option.

GTZ (2005). Dehydration toilets. GTZ, Germany.http://www.gtz.de/en/themen/umwelt-infrastruktur/wasser/9397.htm; Accessed 14 August, 2007.

Winblad, U., and Simpson-Herbert, M. (eds.) (2004). Ecological Sanitation- revised and enlarged edition. SEI, Stockholm, Sweden. http://www.ecosanres.org/pdf_files/Ecological_Sanitation_2004.pdf; Accessed 14 August, 2007.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater- Volume 4: Excreta and greywater use in agriculture. WHO, Geneva. http://whqlibdoc.who.int/publications/2006/9241546859_eng.pdf; Accessed 17 July, 2007.

Composting chamber

The basic principle of a composting chamber is to facilitate the biological degradation of excreta (and toilet paper if included) in a specially designed container. A ventilation system is highly recommended in order to stimulate aeration and prevent odour. The system can either be designed with or without urine diversion.

The decomposition process is called “composting”, which is the degradation of organic matter by thermophilic aerobic bacteria and other microorganisms. These bacteria rely on a good aeration (oxygen), optimal moisture content and a specific carbon to nitrogen ratio. Including urine or even anal cleansing water may result in excessive water content, which will affect the composting process. Since faeces alone have a low carbon content, the addition of organic solid waste can improve the carbon to nitrogen ratio. An additive or so-called bulking agent is recommended to lower the water content, to improve aeration and to increase the carbon content of the material. Wood chips, bark chips, sawdust, paper and other substances are commonly used and their use can also minimize the risk of odour and flies, if they are used after each defecation as cover material. Moreover, with bulking agents, the pore spaces of the composting pile can be increased; hence it will be less compact, leading to better aeration. However, too much airflow can remove too much heat and moisture, therefore the conditions inside the compost chamber should not be too cool or dry. However, even with optimal conditions, the compost temperature seldom is more than 5-10°C above ambient temperature and thermophilic temperatures are essentially only achieved when the chamber is heated (e.g. with an electrical heater). One main effect of the decomposition process in a composting toilet is the considerable volume reduction (10-30% of the original volume, thus allowing the prolonged storage of waste in the container.

The emptying frequency depends on the size of the container, the feeding rate and the composting rate (volume reduction). The pathogen content is reduced considerably in a composting toilet. However, complete pathogen destruction can only be achieved if thermal process conditions can be guaranteed sufficiently long, e.g. by using an advanced toilet design with insulation and perhaps external heating for maintaining a high temperature within the whole composting chamber. The end product should be an odourless, stabilized material: a valuable soil conditioner. It can be used directly for non-food plants. Further treatment such as additional thermal composting or prolonged storage increases the hygienic safety and thus the type of crops for which it can be used.

GTZ (2005). Composting Toilets. GTZ, Germany.

http://www.gtz.de/en/themen/umwelt-infrastruktur/wasser/9397.htm; Accessed 18 August, 2007.

USEPA (1999). Water Efficiency Technology Fact Sheet: Composting Toilets- EPA 832-F-99-066. US Environmental Protection Agency, Washington. www.epa.gov/owm/mtb/comp.pdf. Accessed 17 July, 2007

Related to blackwater[1]

Septic tank

A septic tank generally consists of a watertight tank that is connected to an inlet pipe at one end, and to a leach field, a constructed wetland, or another disposal or treatment technology at the other. Pipe connections are generally made of a T pipe which allows liquid to enter and exit without disturbing any of the crust on the surface. Today, the design of the tank usually incorporates two chambers (each of which is equipped with a manhole cover) which are separated by a dividing wall which has openings located about midway between the bottom and top of the tank. Wastewater enters the upper zone of the first chamber of the tank, allowing solids to settle and scum to float. The settled solids are anaerobically digested thus reducing the volume of solids. The liquid component flows through the dividing wall into the second chamber where further settlement takes place and the relatively clear excess liquid then drains out of the outlet into a subsequent disposal or reuse technology.

Advantages: A properly designed and normally operating septic tank is odour-free. Besides periodic inspection and desludging, the tank should last for decades with no maintenance. A well designed and maintained concrete, fibreglass or plastic tank should last about 50 years

Disadvantages: solids that are not completely decomposed by the anaerobically, occasionally have to be removed otherwise the tank fills up and raw wastewater may discharge directly.

With careful management, many users can reduce emptying to every 3 to 5 years. When emptying a tank, only a small residue of sludge should be left in the tank. Anaerobic decomposition is rapidly re-started when the tank is re-filled. How often the septic tank has to be emptied depends on the volume of the tank relative to the input of solids, the amount of indigestible solids and the ambient temperature (as anaerobic digestion occurs more efficiently at higher temperatures). In general it is rare for a septic tank system to require emptying more than once a year.

A special case of a septic tank is the **interceptor tank**. The interceptor tank is a buried watertight tank with a baffled inlet and outlet. It is designed to detain the liquid flow for 12 to 24 hours and to remove both floating and settleable solids from the liquid stream. Typically, an interceptor tank is used a first step before transport with a small bore (solids free) sewer. Stored solids are periodically removed through an access port. Typically, this can be described as a single-chamber septic tank.

Crites, R. and G.Tschobanoglous (1998). Small and Decentralized Wastewater Management Systems, WBC/McGraw-Hill.

Polprasert, C. and V.S. Rajput (1982). Environmental Sanitation Reviews: Septic Tank and Septic Systems, Environmental Sanitation Information Center, Bangkok, AIT, Thailand.

[1] In fact, the technologies in this section are suitable for several flowstreams, including blackwater mixed with greywater, brownwater, and other combinations therein

Cesspit or Cesspool

In the UK, a cesspit or cesspool is a watertight pit, holding tank, or covered cistern, which can be used for the temporary storage of any kind of wastewater and must be emptied if full. In US, it often means a septic tank with a leach-field.

Because it is sealed, the tank must be emptied very frequently — in many cases as often as weekly. The need for frequent emptying means that the cost of maintenance can be very high.

Given the high cost and necessity for frequent and regular emptying, this technology component will not be assessed further in the subsequent chapters.

Aquaprivy

An aquaprivy is similar to a septic tank; it can be connected to flush toilets and take most household wastewater. It consists of a large tank with a water seal formed by a simple down pipe into the tank to prevent odour and fly problems. Its drawback is that water must be added each day to maintain the water seal, and this is often difficult to do unless water is piped into the home. The tank is connected to a soakaway to dispose of effluent. Unlike a septic tank, the aquaprivy tank is located directly below the house, but it, too, requires periodic emptying and must be accessible to a vacuum tanker. Aquaprivies are expensive and do not offer any real advantages over alternating twin pits.

USAID (1982). Water for the World-Designing Aqua Privies, Technical Note NO. SAN. 1.D.4. www.lifewater.org/resources/san1/san1d4.pdf; Accessed 17 July, 2007.

Pickford, J. (1995). Low-Cost Sanitation. A Survey of Practical Experience, Intermediate Technology Publications, London.

Anaerobic baffled reactor

The anaerobic baffled reactor (ABR) could be described as an upgraded septic tank. The ABR consists of an initial settling compartment followed by a series of baffled reactors (three baffles or more). The baffles are used to direct the flow of wastewater in an upflow mode through a series of simple sludge blanket reactors. This configuration provides for intimate mixing and contact between anaerobic microbes in the sludge and the wastewater, which improves nutrient removal. BOD removal is 70-95 % and is far superior to that of a conventional septic tank. Sludge removal is important for the ABR and must be done regularly. Flow regulation is very important also as flow velocity in the upflow compartments should not exceed the design value, otherwise the anaerobic sludge might follow the effluent out of the reactor. The energy for the mixing of the sludge with the wastewater comes from the small but necessary loss in water level height through the reactor.

Advantages:

- Process simplicity
- No electrical requirements
- Construction material locally available
- Low land space required
- Low capital costs

Disadvantages:

- Needs skilled contractors for construction
- Needs strategy for faecal sludge management (effluent quality rapidly deteriorates if sludge is not removed regularly)

The system requires low to medium capital costs. It may be suitable for relatively wealthy areas with low population density that want to achieve better effluent quality than with conventional septic tank. The effect of the resulting methane emission should be considered.

Sasse, L. (1998). Decentralised wastewater treatment in developing countries. Bremen, BORDA.

Bachmann, A; Beard, VL; McCarty, PL (1985). ''Performance Characteristics of the Anaerobic Baffled Reactor''. Water Research 19 (1): 99-106.

Anaerobic digester

The anaerobic digester is a unit in which organic material is broken down under anaerobic conditions (without oxygen). This process produces biogas (consisting about two thirds - by volume - of methane), which can be used for cooking and lighting. In some countries, the digester is common for households with animal husbandry activities where it can be used to meet or partially meet the daily energy needs. It is also possible to use this technology for domestic wastewater, especially when the user prefers a low flush toilet (since the solids content should be as close as possible to 10%). Since this is not usually achieved, organic solid waste, e.g. manure or market waste is generally needed to supplement the input. Digesters operate best in warm climates, as high temperatures increase the production of biogas. Also, the heat (which is required for themophilic digestion) will in turn, ensure the die-off of pathogens. The effluent from the reactor, a dark slurry, is a nutrient-rich fertilizer for agriculture and aquaculture, due to conservation of nitrogen during the anaerobic process. To assure hygienic quality, especially when human wastes are included, a long retention time (>60 days) should be used, and/or a post treatment step (e.g. wetlands, composting, etc.). Post treatment of the effluent largely means that the fertilizing value of the effluent is lost. This technology can be used to replace existing septic tanks by integrating the septic tanks as an inlet chamber. There are different designs available, especially in the leading countries for household biogas technology, namely China, India and Nepal. The size ranges commonly from 6 to 10 m^3. Larger biogas digesters serving several households or a whole community are also feasible (up to 50 m^3). Biogas digesters are usually built underground to protect them from temperature variations and also to prevent accidental damage. Hence, they use very little space. Operational requirements are low, due to automatic influent feeding and mixing of animal and toilets wastes. Limited operator skill is required (but household members need training to understand the system). The plant needs checking for gas leaks, especially from distribution pipes. Furthermore, desludging is occasionally necessary.

Since urine contains ammonia which easily inhibits anaerobic digestion, separating and not including urine in the digester feedstock improves the digestion process. Thus, urine separation and its exclusion may improve the anaerobic digestion process for the remaining brownwater.

Advantages:

- Provides source of biogas, which results in less dependence on fossil fuels, which may not be readily available to households
- Improves the household overall sanitation by treating blackwater, organic wastes, and animal manure
- Effluent is a nutrient-rich fertilizer, with improved hygiene
- Less frequent / almost no desludging required compared to septic tanks
- Can be built with local material

Disadvantages:

- Requires quality design and construction
- Requires conscientious operation and maintenance
- Skilled, trained contractor and labour is required
- Requires availability of manure or other additional organic solid waste for optimal biogas production
- There are sometimes cultural prejudices against using gas from human waste

The system requires a medium level of capital costs, but additional revenue can be recovered in the form of energy saving and higher agricultural yields. The technology is suitable for rural areas, especially when families also have animal waste, and where there is a need for gas for cooking.

Food and Agriculture Organization (FAO). (January, 1999). Biogas Technology: A Training Manual for Extension. Consolidated Management Services - Kathmandu, 1996. www.fao.org/docrep/008/ae897e/ae897e00.htm; 18 July 2007.

ISAT (1998). Biogas Digest Vols. I-IV. ISAT and GTZ, Germany. www.gtz.de/en/themen/umwelt-infrastruktur/energie/4552.htm; Accessed 18 July, 2007

Related to urine

Long-term storage in different types of containers

If the urine is collected by a urine diversion toilet or urinal, it passes through a separate pipe system to a **collection tank**, which can be connected to just one toilet or to several households. The collection tank can be made of different materials like plastics or concrete. As urine is very corrosive, no metals should be used. The tank size has to be designed according to the number of people using the toilet/urinal and the design of the rest of the systems. Collection in jerry cans should always be considered, since they can be exchanged and can also serve as containers for long-term storage and also as transport vessel.

Large storage tank

When urine is collected and directly reused by the household, no separate storage of the urine is needed (i.e. in systems where the urine is used to fertilise food to the same household which generated the urine). However, in large systems, where the urine is used to fertilise food for people other than those who generated it, a secondary storage container is required to safely sanitise the urine before use. Where the urine is transported by truck, the volume of the collection tank should normally correspond to the truck volume for an economical and ecological transport. If it is a smaller system, dimensioning the tank for emptying once or twice yearly is probably more economical. It should be noted that the time spent in the collection tank must not be included in the time of separate storage, when this is used for sanitation.

Neither the collection tank, nor the collection pipe system, should be ventilated, but they both need to be pressure equalized. If the collection tank is emptied by suction truck, the inflow of air at a sufficient rate has to be ensured, so that the tank does not implode due to the vacuum. Emptying through the manhole is encouraged, as this also enables visual inspection of the tank.

Urine can, bucket or container storage: For smaller flows, urine can be collected, transported and stored in cans, buckets or small containers like jerry cans. This is a cheap and easy-to-handle technology, however small containers must be emptied more frequently or the content has to be brought to and stored in bigger central tank or applied directly (which is safe only for household use).

GTZ (2007). Technical data sheet, Urine diversion: Piping and storage. GTZ, Eschbon, Germany. www.gtz.de/de/dokumente/en-ecosan-tds-01-b3-urine-diversion-piping-storage-2005.pdf; Accessed 23 July, 2007

Related to faecal sludge/excreta

Anaerobic digestion

Similar to the anaerobic digestion of wastewater, faecal sludge can also be digested to obtain biogas and a slurry digestate (which is an excellent fertiliser for energy and industrial crops, but is often not safe enough to be used on food crops). For additional sanitation and reuse on food crops, the digestate can be further composted or dried before reuse, but at the expense of losing ammonium, which is a nitrogen fertiliser. Anaerobic digestion is a bacterial decomposition process that stabilizes 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, which is operated at ambient temperature and which has no mixing. Biogas is collected from the digester and caned be stored 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. After digestion, the sludge is an excellent fertilizer, rich in plant available nitrogen. It is however, bulky. Therefore, it is usually passed to a sedimentation tank where the sludge is thickened. However, ammonium, the plant-available nitrogen, is water soluble and is thus present in equal concentrations in the thickened sludge and in the supernatant. Usually, the thickened sludge is further treated prior to reuse or disposal, but this also means that essentially all plant available nitrogen is lost as ammonia. Anaerobic digestion can also be carried out at a slower rate in ponds, which are usually covered by a UV resistant plastic sheet: biogas is collected from the top of the sheet.

Food and Agriculture Organization (FAO). (January, 1999). Biogas Technology: A Training Manual for Extension. Consolidated Management Services - Kathmandu, 1996. www.fao.org/docrep/008/ae897e/ae897e00.htm; 18 July 2007.

ISAT (1998). Biogas Digest Vols. I-IV. ISAT and GTZ, Germany. www.gtz.de/en/themen/umwelt-infrastruktur/energie/4552.htm; Accessed 18 July, 2007

Ammonia sanitation

In a closed and non-corrosive vessel, faecal material can be mixed with water to form a sludge with a water content of at least 75%. The sludge is then mixed with 2% urea (by wet weight). The degradation of this urea to ammonia and carbon dioxide is facilitated by urease, which is naturally present in the faeces. The ammonia is toxic to viruses, bacteria and helminths. Safe sanitation is then achieved by just storing this sludge in the closed vessel. Bacteria and helminths are reduced some 6 $\log_{10}$ in about 2 weeks at 35°C or 4 months at 24°C. If wood ash or lime has been used as cover material during faecal collection, such that the pH of the faecal material is at least 11, then urea can be saved and the sanitation sped up at 24°C; with just 1% urea addition by wet weight, bacteria and helminths are reduced some 6 $\log_{10}$ in about 2 months at 24°C.

The nitrogen remains in the material after sanitation, which means that there is no risk of bacteria regrowth. This also means that the material is an excellent fertilizer. However, as it is high in ammonia, it is important that it is handled in closed, non-ventilated systems, both to reduce ammonia loss and odour emission. It should, like urine, preferably be incorporated directly into the soil.

Related to faeces

Co-composting

In special circumstances, where there is an abundance of space, and organic matter, excreta may be co-composted on site. It is a contentious issue however, about whether or not to collect, carry, and dump the excreta as this could increase the chances of pathogen transmission.

Onsite, outdoor, above ground excreta co-composting is a combination of the Fossa alterna (below ground) a composting chamber (indoor), and large scale faecal sludge composting (offsite). Still, the same composting principles apply (i.e. the presence of a carbon rich bulking material and adequate moisture). Typically, some sort of cover material (e.g. rice husks or saw dust) are used to cover the excreta after each deposit, until the receptacle is full and can be transported to the onsite composting area. Here again, the excreta/bulking mixture should be covered again with hay, grass or another material to limit pathogen transmission and smell.

Worm composting (vermicomposting). Vermicomposting is the process by which organic materials are converted into humus with the use of specific types of earthworms that breakdown the organic materials.

Edwards, C.A. (1995). Historical overview of vermicomposting. Biocycle, 36 (6), 56-58.

Jenkins, J. (1999). The Humanure Handbook: a Guide to Composting Human Manure.(2nd ed.). Jenkins Publishing, Grove City, Pa.

Related to greywater

Pre-treatment- grease trap and grit trap

In general, all greywater treatment processes should be preceded by some kind of pre-treatment to remove heavy settleable solids and remove the floatable fraction-- both of which could interfere with subsequent treatment. Flotation is a physical process by which light components, such as grease, oil and fat, accumulate on the surface of the water. Grease traps are typically used as primary treatment units in greywater irrigation systems and as a low-cost alternative to sedimentation or septic tanks. They are used for greasy and oily water (e.g. kitchen greywater, restaurant greywater) and should be installed high up in the system, close to the wastewater source, where the wastewater is still hot and where it has a low risk of clogging the pipes. While their function is simple, grease traps are difficult to maintain, as frequent emptying is needed to ensure good functioning and the contents are very odorous. Thus, emptying by suction truck is highly recommended, otherwise daily emptying should be considered, as this considerably decreases the odour.

Morel A., Diener S. (2006). Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods, Eawag, Switzerland.

Given this necessity for this technology component in all subsequent treatment technologies the grease/grit trap will not be assessed further in the following chapters.

Slow sand filtration

The treatment of water by slow sand filtration combines biological, chemical and physical processes when the water slowly passes downwards through a bed of sand. As the water passes through the filter, fine particles are filtered out, and an active biological layer removes bacteria, viruses and organic matter. Pre-treated greywater slowly enters the filter through an inlet at the top, and an outlet leads the clean water from the drains to the clean-water mains. During operation, the sand filter is covered with a water layer of 0.3–1.0 m. For the filter to work well, water must flow continuously at a rate of 0.1–0.3 m/hour. For community use, filter reservoirs can be made of concrete, bricks, ferro-cement, etc. At least two filters are needed if treated greywater is to be provided continuously. When the quality of the greywater is poor, it is recommended that appropriate pre-treatment steps be added (e.g. upflow roughing filter along with the standard grease and grit trap). Sometimes, the water is chlorinated after filtration to prevent recontamination. Under good operation and maintenance conditions, a slow sand filter produces water virtually free of harmful organisms.

Brikké, F. and Bredero, M. (2003). Linking technology choice with operation and maintenance in the context of community water supply and sanitation. WHO, Switzerland.

Horizontal subsurface-flow constructed wetland (HSSF CW- planted horizontal flow filter)

Horizontal-flow constructed wetlands consist of a bed lined with impermeable material (clay packing, plastic or gum liner) and filled with sand and gravel. The greywater entering the filter bed through an inlet zone devoid of vegetation flows horizontally through the bed. The water line lies below the filter surface and is controlled by an outlet level control arrangement. While the top surface of the filter is kept horizontal to prevent erosion, the bottom slopes preferably 0,5 – 1% from let to outlet. The grain size of the filter media should allow continuous flow without clogging. To guarantee an even distribution of water input, the grain size at the input and output zones should be coarser than the rest of the bed. As the water flows, it comes into contact with aerobic, anoxic and anaerobic zones. The aerobic zones are found around the roots and rhizomes of the wetland plants (e.g. *Phragmites australis*). The mechanisms of bacterial treatment are the same as in conventional wastewater treatment processes i.e. oxidation of organic matter by heterotrophic bacteria, oxidation of ammonium nitrogen to nitrate and nitrite by autotrophic nitrifiers and under anoxic conditions, the breakdown of nitrate through nitrite to nitrogen gas by heterotrophic bacteria. The treatment level is determined by the hydraulic retention time in the filter. Horizontal-flow planted wetlands are very efficient in removing organic matter and suspended solids. Operation and maintenance activities focus on proper pre-treatment, maintenance of the vegetation and the control of the water level.

Cooper, P.F. et al (1996). Reed beds and constructed wetlands for wastewater treatment, WRc, United Kingdom.

Morel A., Diener S. 2006. Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods, Eawag, Switzerland.

Horizontal surface-flow constructed wetland (HSF CW)

In this type of wetland, wastewater is fed in at the inlet and flows slowly over the surface of the plant bed in a horizontal path until it reaches the outlet of zone before leaving via the level control arrangement at the outlet. In a HSF CW, the plants can contribute to treatment through uptake of nutrients and other wastewater constitutes, but the most important parts are the submerged portion of leaves, stalks, and litter, which serve as a substrate for attached microbial growth. The wetland tends to be oxygen-limited since the reeds cannot supply the oxygen at the rate required by the wastewater load and is not very efficient for nitrogen removal. The problem with freestanding water is the potential for mosquito breeding and infestation. If there are not enough natural predators and/or an undeveloped ecosystem, mosquitoes will thrive in the still water. This technology is interesting not only due to its purification effects but also for its ability to bring back natural habitats and to a certain extent, for its flood control properties. However, it is difficult to adopt this technology in urban areas or places where land is insufficient or limited.

Crites, R. and G.Tschobanoglous (1998). Small and Decentralized Wastewater Management Systems, WBC/McGraw-Hill, pp 582-599.

Bendoriccio, G., L. Dal Cin & J. Persson (2000). Guidelines for free water surface wetlands design. EcoSys 8: 51-92. www.ecology.uni-kiel.de/~michael/wet/design.pdf; Accessed 17 July, 2007.

Vertical flow constructed wetland (VF CW)

Vertical flow constructed wetlands are shallow excavations or above ground constructions with an impermeable liner, either synthetic or clay. The layer structure of a VF CW comprises a flat bed of gravel (min. 20 cm) topped with a layer of sand (min. 60 cm), which is again topped by a layer of gravel (min. 15 cm). The reeds, which are planted in the top layer of gravel, are the same sort (e.g. *Phragmites australis*) as in horizontal-flow constructed wetlands. However, these systems are fed intermittently four to six times a day, to ensure aerobic conditions. The frequency of dosing should be timed such that the previous dose of liquid has had time to percolate through the bed so that the void spaces are refilled with air.

During a flush phase the greywater percolates down through the unsaturated bed, undergoes filtration, comes into contact with the dense microbial populations on the surface of the filter media and roots and is finally collected by a drainage network at the base. The design and size of a VF CW is dependent on hydraulic and biological loads. As for HF CW an efficient mechanical primary treatment for the removal of solids is important to prevent clogging of the filter media.

Cooper, P.F. et al (1996). Reed beds and constructed wetlands for wastewater treatment, WRc, United Kingdom.

Morel A., Diener S. (2006). Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods. Eawag, Switzerland.

Greywater garden (mulch trench)

Greywater gardens are simple greywater management systems that allow for the direct utilisation of the water, facilitate the breakdown of organic compounds and recover nutrients. If site conditions (e.g. available space, soil conditions, etc.) are favourable, the easiest way to apply greywater for subsurface irrigation purposes is to drain it to swales or trenches, which are filled with mulch material. Distribution and application may be done either below the mulch or above the surface. When the greywater is discharged 5 cm above the surface of mulch, it quickly disappears; this method is much simpler to construct and maintain. Decomposing mulch has to be replaced periodically by locally available mulch material such as wood chips, bark chips, rice husk, etc.

Green walls

Developed by a Swedish horticulturist, green walls/vertical gardens are a container gardens for intensive horticulture for dry tropical areas. They are based on walls with built-in growth boxes made of hollow concrete blocks.

Greywater is pumped into the top box of the green wall and from there, it slowly trickles down through to the bottom box via filtering materials that progressively treat and ‘polish’ the water. Water is stored in a tank underneath the lowest box. Plants in each box are selected partially to enhance the treatment process but mostly on the basis of being able to survive in a nutrient rich sand base. The sand filter does most of the water treatment work.

When building the wall some of the blocks are turned 90 degrees and the protruding hollow part is provided with a floor and a small hole for drainage. The core of the wall is filled with a weak concrete mixture. In the tropics, the containers may face any direction and the walls can be quite closely spaced (1.2 -1.5 metres). A variety of vegetables and ornamentals can be grown in the containers.

Esrey S et al. (1998). Ecological sanitation. SIDA, Sweden.

Tower garden

Tower gardens are a user-friendly, low-cost and low-tech greywater reuse system, where gardening does not have to rely on rainfall and where nutrients are derived from the greywater. The external structure of the greywater garden consists of poles (iron bars or fence posts) and shading material surrounding soil and a central stone-packed drain. The purpose of the stones is to spread the water flow throughout the column. Greywater is poured daily with buckets on top of the central stone core. The water trickles through the stone core and is more or less evenly distributed within the soil column. Leafy vegetables (such as spinach) are planted into slits of the shading material surrounding the soil column. The slits are offset to one another, which gives more space for root development. Tomatoes or onions may be planted on top of the column. The most appropriate filling material mix for the tower should be composed of three parts soil, two parts animal manure and one part wood ash. Tower gardens are best located in the courtyard so as to minimise transport distance of greywater.

Morel A., Diener S. (2006). Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighbourhoods. Eawag, Switzerland.

Anaerobic filtration

Anaerobic filters are widely used as secondary treatment step in household greywater treatment systems. They have been successfully used when placed after a grease trap or septic tank. The anaerobic filter is an attached biofilm technology (fixed-film reactor) that aims at removing non-settleable and dissolved solids. It comprises a watertight tank filled with submerged media, which provide surface area for bacterial growth. As the wastewater flows through the filter – usually from bottom to top (up-flow) – it comes into contact with the biomass on the filter and is subjected to anaerobic degradation. Primary treatment in a septic tank is usually required to eliminate solids of larger sizes before greywater is allowed to pass through the anaerobic filter. Studies have shown that the hydraulic retention time is the single most important design parameter influencing filter performance; 0.5–1.5 days is a typical retention time. A maximum surface-loading (i.e. flow per area) rate of 2.8 m/d has proven suitable. Suspended solids and BOD removal can be as high as 85–90% but is typically between 50–80%. Nitrogen removal is, however, limited and normally does not exceed 15% in terms of total nitrogen (TN). Good filter material provides a specific surface area of 90–300 m^2 per m^3 of filled reactor volume. Gravel, rocks, crushed cinder block or specially formed plastic pieces are used as filter material. With up-flow systems, filter material size decreases from bottom to top. Typical filter material sizes range from 12 to 55 mm. Finally, the water level should cover the filter media by at least 0.3 m to guarantee an even flow regime through the filter. Anaerobic filters produce flammable gases (methane) and foul odours that need to be controlled and evacuated. The filters may be constructed above ground, but most often they are below the ground surface to provide insulation and protection against severe climates. Access to the inlet and outlet should be provided to allow for cleaning and servicing. Cleaning is required when the bacterial film on the filter media becomes too thick. The filter mass can be removed and cleaned outside the reactor but more frequently the filter is not removed and is cleaned by backwashing.

Sasse, L. (1998). Decentralised wastewater treatment in developing countries. Bremen, BORDA.

von Sperlin, M. and C.A. de Lemos Chernicharo (2005). Biological Wastewater Treatment in Warm Climate Regions. Volume One, IWA, DESA.

Vegetated leachfield

A vegetated leachfield is an open system in which pre-treated greywater (or primary-treated wastewater) is evenly distributed through a horizontal, perforated pipe laid in a gravel bed. The gravel bed is covered with sand then densely planted with fast-growing plants, which 'harvest' nutrients, the main pollutants found in ground and surface waters. Horizontal flows in the leachfield distribute greywater over a large area for treatment by the roots and the microbes in the gravel. The standard of treatment by leachfields is hard to measure empirically. It is, however, clear that horizontal flows, which distribute greywater evenly over a large area, achieve better results.

Vegetated leachfields should be densely planted with moisture and nutrient-loving plants. A variety of species should be planted since different species take up nutrients at different rates. Fast growing plants such as bananas are recommended for domestic, on-site treatment gardens.

GTZ et al. (2007). Guidelines for the Selection and Implementation of Sustainable Sanitation Systems for the Reconstruction in Aceh and Nias.http://www.humanitarianinfo.org/sumatra/reliefrecovery/watsan/docs/important/Sanitation_Guidelines_Seminar/2_Draft_Sanitation_Guidelines_31%20Jan%2007.pdf; Accessed 14 August, 2007.

Transport Technologies

Related to blackwater/greywater

Conventional gravity sewers

Conventional gravity sewers convey raw, untreated wastewater through pipelines to a treatment facility or lift station. A conventional gravity sewer network consists of individual houses connected to a central reticulation pipe (truck). The reticulation systems normally include a series of pump stations to convey the sewage through the system, especially on atoll and coastal communities due to flat topography and high groundwater levels. Manholes and other access chambers are required to maintain and clean the pipes. The sewer lines are straight and installed on a specific horizontal and vertical alignment, with interspaced manholes placed at set intervals, at pipe intersections and at changes in pipeline direction. The pipes are installed with uniform gradients sufficient to create a minimum self-cleansing velocity (0.6-0.75 m/sec). Thus, a reliable supply of sufficient water is required. Manholes allow access for inspection, cleaning, and repair. Construction of these systems on flat terrain typically requires deep excavations (1.5 - 3.8 meters below grade) and proper preparation and bedding materials are also needed in the pipeline trenches. The excavation of trenches for pipes may be difficult where the ground is rocky, the groundwater table is high, or where pipes and cables have previously been installed, particularly where their location is not accurately documented. The sewers and manholes are most typically installed along the centreline of roadways and have service collection laterals extending perpendicular to the roadway alignment. If required, a lift/pump station collects the wastewater transported by the collection piping. Due to the high degree of operation and maintenance, especially for pumping devices, skilled personnel is required. This may be suitable for wealthy, high-density areas, e.g. the central business districts of major towns but is usually not suitable for rural or poor communities.

Advantages: Convenient for household members since maintenance is performed by trained workers (not users)

Disadvantages: High costs (operation & maintenance); sophisticated technology requiring skilled engineers, contractors and operator; Reliable piped water supply required; adequate treatment and/or disposal/reuse required for a large point source discharge.

ASCE (1992). Gravity Sanitary Sewer Design and Construction, Joint Task Force of ASCE and WPCF, ASCE Manuals and Reports on Engineering Practice No. 60, WPCF MOP No. FD-5, American Society of Civil Engineers, New York.

Tchobanoglous, G. (1981). Wastewater Engineering: Collection and Pumping of Wastewater, McGraw-Hill, New York.

Small-bore sewers

This technology is also known as settled sewerage or solids-free sewerage. Small-bore sewers convey domestic sewage that has been settled in a septic tank (sometimes referred to, in this context, as a solids interceptor tank). Consideration of the self-cleansing (or other) velocities is not necessary with settled sewerage since all the solids which would block the sewer are retained in the interceptor tank, provided it is adequately maintained. This technology may also involve *inflective gradients* where the design of settled sewer roughly follows ground contours and the flow in the sewer is allowed to vary between open channel flow and pressure (full-bore) flow. There must be an overall fall from the upstream end of the sewer to its downstream end. The sewer is divided into sections over which, the flow is of the same type (i.e. open channel or pressure flow) and reasonably uniform (i.e. the sewer can be laid at a more or less constant gradient). When choosing a pipe diameter (at least 75 mm), the actual peak flow in each section must be less than the "just full" flow (if it is not, the next larger sewer diameter is selected). In sections where there is pressure flow, the hydraulic gradient cannot rise above the level of the invert of any interceptor tank outlet (if it does, then either select the next larger pipe diameter or increase the depth at which the sewer is laid). Given that existing septic tanks are at the rear of properties, the settled sewer can be laid there, rather than in the road (as in normal with conventional sewerage), which results in considerable cost savings (and is analogous to the backyard or condominal variant of simplified sewerage). Manholes are not required at every junction or change of direction; simple cleanouts suffice. Lift stations are only required in very flat areas, but these are simple structures with a water pump, rather than a more expensive sewage pump since there are no solids to be pumped. Small-bore sewers have the following characteristics compared to conventional sewers:

- Smaller pipe diameters
- Flatter pipe gradients
- Shallower pipe depths
- Fewer access chambers (no manholes)

Settled sewerage construction costs are typically 20–50 percent less than those of conventional sewerage in the rural USA. In areas with existing septic tanks, the cost reduction will be higher, 40–70 percent.

Advantages:

- Lower capital cost than conventional sewerage, more flexible and adaptable to local conditions

Disadvantages:

- Smaller diameter pipes may result in a higher risk of blockages and thus increased maintenance;
- Reliable maintenance (emptying) of the solids interceptor tanks;
- Requires skilled engineers, contractors and operators;
- Reliable piped water supply required.

Mara, D. D. (1996). Low-Cost Sewerage, John Wiley & Sons- Wiley Interscience Publications.

Otis, R.J. and D. Mara (1985). The Design of Small Bore Sewer Systems (UNDP INterreg. Project INT/81/047), The World Bank+ UNDP, Washington.http://www.wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2000/01/06/000178830_98101903445889/Rendered/PDF/multi0page.pdf; Accessed 17 July, 2007.

Simplified Sewerage

Simplified sewerage (also known as condominial sewerage) collects all household wastewaters in small-diameter pipes laid at fairly flat gradients. For example, a 100 mm diameter sewer laid at a gradient of 1 in 200 (0.5 percent) will serve around 200 households of 5 people with a wastewater flow of 80 litres per person per day. The sewers are often laid inside the housing block, or in the front garden or under the pavement (sidewalk), rather than in the centre of the road as with conventional sewerage. It is suitable for existing unplanned low-income areas and new housing estates with a more regular layout. Plastic pipes are best used as they can be joined correctly easily, and this essentially eliminates wastewater leakage from the sewer and minimized groundwater infiltration. With simplified sewerage there is no need to have large expensive manholes of the type used for conventional sewerage—simple brick or plastic junction chambers are used instead. Simplified sewerage is most widely used in Brazil. It has also been used in other South American countries and some Asian countries. Currently, construction costs of simplified sewerage (in Brasília) are around US$ 22–34 per person and condominial sewerage has been shown to be cheaper than on-site systems at the quite low population density of *ca.* 160 people per hectare. Good operation and maintenance is essential for the long-term sustainability of simplified sewerage, since the small diameters pipes may sometimes become blocked with sediment. In rural villages in northeast Brazil good results have been obtained by having the village Residents Association employ with one of the villagers to maintain the sewers and the wastewater treatment plant. In urban areas the sewerage company undertakes operation and maintenance itself or contracts small local contracting firms to do this on its behalf.

Bakalian, A., A. Wright, et al. (1994). Simplified Sewerage: Design Guidelines, The World Bank, Washington + UNDP.

HABITAT (1986). The design of Shallow Sewer Systems, Habitat United Nations Centre for Human Settlements (HABITAT), Nairobi, Kenya.

Mara, D.D. (1996). Low-Cost Urban Sanitation, John Wiley & Sons- Wiley-Interscience Publications.

Watson, G. (1995). Good Sewers Cheap? Agency-Customer Interactions in Low-Cost Urban Sanitation in Brazil. UNDP-World Bank Water & Sanitation Program, The World Bank, Washington, UNDP.

Vacuum sewerage

In contrast to conventional gravity sewerage systems with intermediate pumping stations, the pressure within the vacuum system is maintained below atmospheric pressure. Vacuum sewerage systems consist of i) the vacuum station, where the vacuum is generated, ii) the vacuum pipeline system; iii) collection chambers with collection sumps and; iv) interface valve units. To minimize water use, vacuum toilets can be used. Batches of wastewater are driven by air streaming from the collection chambers/vacuum toilet towards the vacuum station. Vacuum systems can, in certain circumstances, significantly reduce investment costs and/or operating expenses, as compared to conventional sewerage systems. Vacuum technology can reduce water consumption considerably, enabling flexible installations regardless of topography. In addition, it allows for the use of alternative wastewater handling (black/grey water separation). It is sometimes used in conjunction with urine or blackwater diverting systems. The vacuum sewerage system can have advantages over conventional sewerage systems especially for the following applications:

- Insufficient natural slope, i.e. flat countryside
- Poor subsoil conditions (i.e. unstable soil or rock, high groundwater table)
- Seasonal operation (e.g. in holiday resorts)
- Frequently flooded areas

However a high degree of operation and maintenance as well as skilled personnel is required

Advantages:

- No manholes required, due to maintenance free sewer lines
- Leaking is impossible, thus ideal for water protection areas
- Installations of water supply and vacuum sewer in the same trench allowed
- Small diameter pipes of PVC or PE reduce piping costs
- Reduced installation costs, due to narrow and shallow trenches

Disadvantages:

- Specialised equipment required; may not be locally available
- High cost for vacuum stations, energy, and specialized repairs
- Technology requires highly skilled engineers, contractors and operators, among others for quick detection and repair of leaks.
- Reliable piped water supply and electricity required
- Energy use of the vacuum pump can be high

This technology requires high capital costs but it can, under special circumstances, be less than for conventional sewerage systems.

GTZ (2005). Vacuum Technology. GTZ, Germany. http://www.gtz.de/en/themen/umwelt-infrastruktur/wasser/9397.htm; Accessed 18 August, 2007.

Given the high cost, and especially the required regular and reliable power supply and highly skilled maintenance and operation, this technology component will not be assessed further in the subsequent chapters.

Related to urine

Urine pipes

In general, urine should be transported as little as possible in pipes as calcium and phosphate minerals can easily precipitate, causing blockages. Urine pipes must be cleaned with acid and/or chipped clean; in the case of long, inaccessible pipes, they may even need to be replaced or removed so that they can be cleaned. Urine pipes should be as short as possible and storage tanks should be placed as close to the point of collection as possible. For inspection and cleaning the pipes should have frequent access points.

When there is more than one household using a urine-diverting toilet, the toilets can be connected to a semi-central collection tank with a pipeline. This is practical however, only for very dense housing, such as apartment blocks or townhouses. For frequent and high loads of urine in dense areas, it can be transported either by gravity, pressure or vacuum pipes. The minimum recommended diameter of the urine gravity sewer is 75 mm, but 110mm is preferable outside and inside houses, and 50 mm where the pipe is easily accessible for cleaning (at the expense of more maintenance). To allow the necessary flow, the slope must be at least 1 % to help transport some of the organics and precipitates that accumulate. It is essential that the piping is tight against ground water. Underground joints should be avoided, but if this is not possible they should be welded or glued since infiltrating groundwater can quickly fill up the collection vessel/container. To minimize the risk of odour and ammonia loss, it is also important that, to avoid nitrogen losses, the pipes are not ventilated, only pressure equalized.

If the toilet does not have any odour seal (i.e. in small systems with one toilet on each urine pipe), the pipes can be thinner (e.g. 25 mm), but should have a minimum slope of 4% and sharp bends should be avoided. This type of piping system should be short, preferably less than 10 metres, to limit the time the urine is in the piping system and thus the degradation of urea and the associated risk of precipitation in the system.

GTZ (2005). 01.B3 Urine diversion - Piping and storage. GTZ, Germany. http://www.gtz.de/de/dokumente/en-ecosan-tds-01-b3-urine-diversion-piping-storage-2005.pdf; Accessed 14 August, 2007.

Kvarnström et al. (2006). Urine diversion: One step towards sustainable sanitation. Report 2006-1. Ecosanres, Stockholm Environment Institute, Sweden. http://www.ecosanres.org/pdf_files/Urine_Diversion_2006-1.pdf; Accessed 29 August 2007.

Manual urine transport

Containers of urine can be transported by animals (e.g. donkeys) or by people with the aid of a pull-cart, bicycle, or other manual device. This means of transport is suitable when the amount of urine is small and when the use of a truck is not profitable or for locations that are not easily accessible by truck. The user can carry or roll the container to a reuse site or to a further storage facility. The same type of cart used for the distribution of water in jerry cans is well suited for transporting urine. Manual transport is possible only when the reuse facility is not far away from the collection point.

Truck for urine transport

A tank truck can transport urine that is collected on- or off-site. However, an access road for trucks is necessary. The truck is expensive for small urine loads or short distances. If the urine is transported over longer distances and high volumes are transported, an additional trailer can make trucking more feasible.

Related to faecal sludge

Human powered faecal sludge emptying and transport

This can mean one of three things: i) manual emptying of liquid sludge using buckets, ii) manual emptying of composted and matured faecal sludge by use of spades and shovels, or iii) MAPET: a portable manually operated pump (MAnual Pit Emptying Technology). Manual emptying with buckets is highly hazardous for the waste workers who must often enter into the pit. Although it is often practiced this is not to be recommended and should be phased out by introducing other technologies. When the faecal sludge has composted and matured in the pit, it strongly resembles a good soil, is solid and easy to handle. This emptying is not risk free, but the risk has been greatly reduced due to the pathogen reduction during the composting/maturing period. The MAPET technology consists of a hand pump connected to a vacuum tank. Depending on the consistency of the sludge, the MAPET can pump up to 3 m in height. The transport vehicle can be human or animal powered. Often the MAPET is the only solution that, due to narrow or non-existent roads, can be used in slums or dense, informal settlements.

Eales, K. (2005). Bringing pit emptying out the darkness: A comparison of approaches in Durban, South Africa, and Kibera, Kenya. Building partnerships for Development in Water and Sanitation. http://www.bpd-waterandsanitation.org/bpd/web/d/doc_131.pdf?statsHandlerDone=1; Accessed 17 July, 2007.

Muller, M. and J. Rijnsburger (1994). MAPET. Manual Pit-latrine Emptying Technology Project. Development and pilot implementation of a neighbourhood based pit emptying service with locally manufactured handpump equipment in Dar es Salaam, Tanzania. 1988-1992., WASTE Consultants, Netherlands.

Faecal sludge emptying and transport by vacuum tanker

A vacuum truck or tanker is a motorized vehicle equipped with a pump and a storage tank. The pump is connected to a hose that is lowered down into a septic tank or pit, and the sludge is pumped up into the tank. Generally the storage capacity of a vacuum tanker is between 4-6m^3 so large septic tanks may require a truck to return more than once to fully empty the tank.

Although smaller more mobile pump systems have been developed, large vacuum trucks are still the norm. Unfortunately, the large trucks often have difficulty accessing pits/septic tanks in areas with narrow or non-driveable roads.

Depending on the system, the material that needs to be pumped can sometimes become so compacted that it cannot be easily pumped. In these situations it is necessary to thin the solids with water so that they can flow more easily. Often emptying services with typical suction pumps are only able to collect the more liquid fraction at the top part of the pit/tank. Where the sludge is thick and dense, the pumps cannot perform. If water is not available, it may be necessary remove the sludge manually.

In 1997, with the sponsorship of UN-HABITAT, the Vacutug was developed and put into practice in Nairobi, Kenya. The aim was to develop a pit-latrine exhauster that was suitable for areas which were previously inaccessible. The design was based on the estimated volume of excreta that a family of 10 would produce in 1 year: 500L. The simple design consisted of a small gasoline engine, a 500L tank and a 4 m PVC hose that can suck up to 1700L/min. The vacuum can then be reversed to allow the excreta to be discharged at a centralized facility or collection point.

The Vacutug requires 2 operators and although it can move at speeds up to 5 km/h it is really only efficient if the point of discharge is within 1 km of the service area.

Boesch, A. and Schertenleib (1985). Pit Emptying On-Site Excreta Disposal Systems. Field Tests with Mechanized Equipment in Gaborone (Botswana), IRCWD, Switzerland. www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_sandec/general_sandec_publications/IRCWD_news_21_22; Accessed on 17 July, 2007.

UN-HABITAT(*2003)* Bringing relief to slums – a novel way to remove human waste safely and economically *http://staging.unchs.org/vacutug.asp*. Accessed 13 August, 2007

Treatment Technologies Off-Site

Related to blackwater

Pre-treatment

Prior to the treatment technologies listed below, wastewater should first be subjected to preliminary or pre-treatment to reduce larger objects, oils, grease, fats, sand, grit, and coarse (settleable) solids of the influent of sewage water. First, the influent is strained to remove all large objects (rags, sticks, condoms, sanitary towels etc.). This is most often done with a manual or mechanically raked screen. Sand or grit channels (detritor, sand catcher) then remove sand, grit and stones as they settle. Grease and floating plastics should be separated and removed with a grease trap, scrapers and skimmers. The target is a homogeneous liquid for further treatment steps.

Advantages:

- after correct treatment the wastewater can easily further processed

Disadvantages:

- potential for high investment costs for technical equipment, however, manually raked screens and manually cleaned constant-velocity grit channels can keep costs low.

Given this necessity for this technology component in all subsequent treatment technologies the pre-treatment grease/grit trap will not be assessed further in the following chapters.

Trickling filter

The trickling filter is filled with a high-surface area medium such as rocks, gravel, shredded PVC bottles, etc. (the higher the surface area to volume ratio, the better). Organisms that grow in a thin biofilm over surface of the media oxidise the organic pollution in the wastewater to carbon dioxide and water (and new biomass). Oxygen is obtained by direct diffusion from air into the thin biological film. After preliminary settlement the wastewater is “trickled” over the surface of the filters, often by rotating distribution pipes. Typically, 80 % BOD removal can be achieved with a correctly sized trickling filter. Some nitrification can also be achieved, depending on the organic loading rate to the filter. Skilled labour is required to keep the trickling filter running trouble-free i.e. to prevent clogging, ensure adequate flushing, control filter flies.

Advantages:

- High effluent quality in terms of BOD and suspended solids removal;
- Low operational costs (low electricity requirements);
- Simpler process compared to activated sludge process or some package treatment plants

Disadvantages:

- High operation and maintenance requirements;
- Needs electrical power;
- More space required compared to some other technologies;
- Potential for odour and filter flies
- Relative capital costs (compared to similar techniques) are moderate to high.

EPA, (2000). Wastewater Technology Fact Sheet- Trickling Filters, 832-F-00-014. US Environmental Protection Agency, Washington. www.epa.gov/owm/mtb/trickling_filter.pdf; Accessed July 17, 2007.

Tchobanoglous, G., Burton, F.L. and Stensel, H.D., 2003. Wastewater Engineering: Treatment and Reuse, 4th Edition. Metcalf & Eddy, New York.

UASB reactor

The Upflow Anaerobic Sludge Blanket (UASB) Reactor is a tank filled with anaerobic granular or flocculant sludge with good settling properties (the bacteria may spontaneously agglomerate to form granules). Influent wastewater is distributed at the bottom of the UASB reactor and travels in an upflow mode through the sludge blanket. Anaerobic degradation of organic substrates occurs in this sludge blanket and biogas is produced. The gases produced under anaerobic conditions (methane and carbon dioxide) mix the contents of the reactor as they rise to the surface. Critical elements of the UASB reactor design are:

- Influent distribution system

- Gas-solid separator
- Effluent withdrawal design
- Flow rate

Modifications to the basic UASB design include adding a settling tank or the use of packing material at the top of the reactor. The presence of a settler on the top of the digestion zone enables the system to maintain a large sludge mass in the UASB reactor, while an effluent with low concentrations of suspended solids is discharged. The UASB reactor has the potential to produce higher quality effluent than septic tanks, and can do so in a smaller reactor volume. Whilst it is a well-established process for large-scale industrial effluent treatment processes, its application to domestic sewage is still relatively new. Effluent from the UASB will usually still require further treatment prior to discharge to the environment (similar to septic tanks). Skilled personnel are required for construction and maintenance, and the monitoring and control are critical during the start-up period.

Advantages:

- Low production of stabilised sludge (and thus, infrequent desludging required)
- Higher treatment efficiency than septic tanks and less space required;
- No energy required for treatment;
- Biogas can be used for energy (but usually requires scrubbing first)
- Relative capital costs (compared to similar techniques) are low to medium. Operational costs are low.

Disadvantages:

- Application to on-site domestic sewage is still relatively new;
- Requires continuous wastewater flow with little flow variation to ensure floating sludge blanket
- Requires trained staff for operation and maintenance
- Performance depends on temperature

Lettinga, G; Roersma, R; Grin, P (1983). Anaerobic Treatment of Raw Domestic Sewage at Ambient Temperatures Using a Granular Bed UASB Reactor . Biotechnology and Bioengineering Vol. 25, No. 7, p 1701-1723.

von Sperlin, M. and C.A. de Lemos Chernicharo (2005). Biological Wastewater Treatment in Warm Climate Regions. Volume One, IWA, DESA, pp 741-804

Waste stabilization ponds (WSP)

WSPs are one of the main natural wastewater treatment methods. They are man-made earthen basins, which can be designed to work independently or as a sequence of several anaerobic, facultative and maturation ponds, depending on the effluent quality required. Primary treatment is carried out in anaerobic ponds, secondary treatment in facultative ponds, and tertiary treatment in maturation ponds. The type, number and sequence of ponds depend on what is to be done with the effluent. Effluent may be used for restricted or unrestricted irrigation; for fish or aquatic vegetable culture; or discharged into surface water or groundwater. Prior to treatment in the WSPs, the wastewater is first subjected to preliminary treatment.

Advantages: WSPs are particularly suited to tropical and subtropical countries since sunlight and ambient temperature are key factors in their process performance. Anaerobic and facultative ponds remove organic matter, *Vibrio cholerae* and helminth eggs. Maturation ponds remove faecal viruses, faecal bacteria, and nutrients (nitrogen and phosphorus). Due to their high removal of excreted pathogens, WSPs produce effluents that are very suitable for reuse in agriculture and aquaculture.

Disadvantages: The land required for a WSP system is one of the primary cost factors and can sometimes be a constraint, especially close to big cities. Lower temperatures mean that a greater land area is required. The ponds site should be at least 500 m downwind of the nearest settlement, although properly designed WSPs produce no offensive odours. Still, it is not easy to convince local residents ahead of any planned scheme. Sites prone to high winds can also cause difficulties, since hydraulic short-circuiting is a common factor in the underperformance of WSPs. Though pond depths can be varied to suit available land area, and there is flexibility in the choice of length-to-breadth ratios, a WSP site needs to be reasonably flat to keep down construction costs. Low permeability is a big advantage, as it avoids the need for an impermeable lining, and the soil needs to be suitable for building embankments with slopes of 1 in 3 externally and 1 in 2 internally. Although they are essentially a simple technology, they must be carefully designed, and so should not be attempted by inexperienced engineers simply because they ‘appear’ to be simple.

Advanced integrated pond systems (AIPS)

A special type of WSPs are the Advanced Integrated Pond Systems (AIPS). AIPS were developed from high-rate algal ponds (HRAPs). They are comprised of "advanced" facultative ponds with a submerged anaerobic digestion pit, a paddle-stirred HRAP, algal sedimentation ponds and one or more maturation ponds. The original purpose of HRAPs was to maximize the production of algae to recover and use the algal protein (algae are 50−60 percent protein and HRAPs can produce up to 80 tonnes of algal protein/ha year). However, with AIPS no attempt is made to recover the algal protein.

Disadvantages: HRAPs, which are the key component of AIPS, are complex and sensitive reactors which are much more difficult to operate correctly than conventional WSPs (and indeed activated sludge processes). In the real world of wastewater treatment in developing countries, AIPS are too complicated a technology to be considered a viable and sustainable treatment option.

This technology component is not assessed in the following chapters.

Arthur, J.P. (1983). Notes in the design and operation of waste stabilization ponds in warm climates of developing countries- World Bank technical paper No. WTP7. World Bank. http://go.worldbank.org/BVSSYN5G10; Accessed 14 August, 2007.

Peña Varón, M and D. Mara (2004). Waste Stabilization Ponds. http://www.irc.nl/page/14622; Accessed 15 August, 2007.

Floating macrophyte ponds

These are ponds that are covered in floating plants. The plants float on the water with their leaves close to the surface and their roots hang down into the pond water column to absorb nutrients. Some plant types commonly used are *Eichhornia* sp. (water hyacinth), *Lemna* sp. (duckweed), *Pistia* sp. (water lettuce or water cabbage) and *Cyperus* sp. (papyrus).

In particular, water hyacinths are perennial, freshwater, aquatic macrophytes that grow especially fast in wastewater. The plants can grow large: between 0.5-1.2 m from top to bottom. The long roots provide a fixed medium for bacteria, which in turn degrade the organics in the water passing by.

The plants shade out the algae, thus reducing effluent BOD_5 and suspended solids; however, this has the disadvantage that disinfection is reduced, which causes effluent *E. coli* numbers to be higher. Consequently, floating macrophyte ponds should only be used as a final treatment stage (for nutrient and algal removal) after conventional maturation ponds have reduced *E. coli* numbers to the required level. However, if the final effluent is used for crop irrigation, nutrient and algal removal is unnecessary and floating macrophyte ponds are therefore not required. A major disadvantage with floating macrophyte ponds is that they encourage mosquito breeding. The still water with infrequent perturbations provides the perfect safe habitat for mosquitoes to lay eggs and develop as larvae. There are few natural predators in these 'engineered' systems and thus, few controls on mosquito breeding; furthermore *Culicine* mosquitoes, the vector of *Bancroftian filariasis*, are the principal problem, but *Eichhornia* ponds also permit the breeding of anopheline mosquitoes, the malaria vector. The main benefit of the ponds is that the harvested macrophytes can be used for food, fodder, or as a raw resource for the production of rope, furniture and other cottage industries.

Rose, G.D. (1999). Community-Based Technologies for Domestic Wastewater Treatment and Reuse: options for urban agriculture. Ottawa, IDRC: 75. http://idrinfo.idrc.ca/archive/corpdocs/117783/cfp27.pdf; Accessed 17 July, 2007

Skillicorn, W., Journey, K. & Spira, P. (1993). Duckweed aquaculture: A new aquatic farming system for developing countries. Washington, DC.: World Bank. www.p2pays.org/ref/09/08875.htm; Accessed 17, July 2007.

Constructed Wetlands

There are two basic types of constructed wetland: subsurface-flow and surface-flow wetlands. Subsurface-flow wetlands can be further classified as horizontal flow and vertical flow constructed wetlands. Subsurface-flow wetlands allow wastewater to flow through a gravel or sand medium onto which plants are rooted. Surface-flow wetlands allow wastewater to flow above the soil in a planted marsh or swamp. Vegetation in a wetland provides a substrate (roots, stems, and leaves) upon which microorganisms (that break down organic materials) can grow. Microorganisms and natural chemical processes are responsible for approximately 90 percent of the pollutant removal and waste breakdown. The plants remove about 7 to 10 percent of pollutants, and act as a carbon source for the microbes when they decay. Different species of aquatic plants have different rates of heavy metal uptake, which should be taken into account depending on the source of the wastewater. In subsurface-flow systems, the effluent may move horizontally, vertically, or parallel to the surface. Subsurface-flow systems have the advantage that they require less land area for water treatment, but are not generally as suitable for wildlife habitat as surface-flow constructed wetlands. Subsurface horizontal-flow wetlands are less hospitable to mosquitoes, whose populations can be a problem in constructed wetlands (carnivorous plants have been used to address this problem). The key advantage is that they tend to be inexpensive to construct, simple to maintain, and environmentally friendly.

Crites, R. and G.Tschobanoglous (1998). Small and Decentralized Wastewater Management Systems, WBC/McGraw-Hill

Polprasert, C., S. Veenstra, et al. (2001). Wastewater Treatment II, Natural Systems for WAstewater Management, IHE Delft, The Netherlands. Chapter 6.

Reed, S.C. (1993). Subsurface Flow Constructed Wetlands For Wastewater Treatment, A Technology Assessment, United States Environmental Protection Agency: 87. www.epa.gov/owow/wetlands/pdf/sub.pdf; Accessed 17 July, 2007.

Conventional activated sludge

The Activated Sludge Process is an engineered process in which microorganisms are 'activated' or encouraged to rapidly degrade organic material. In the presence of oxygen, microorganisms break down complex organic molecules into their simple constituents such as carbon dioxide and water: the oxygen can be supplied from air or pure oxygen. By supplying the microorganisms with excess oxygen, the time for degradation is reduced to hours instead of days. The Activated Sludge Process has a number of variants in terms of design and layout. The Activated Sludge Process has a number of variants in its design and layout, including Extended Aeration and Sequencing Batch Reactor (SBR) technologies. This is an example of a suspended growth technology (as opposed to attached growth, or fixed-film).

Advantages: Since it is a suspended growth process, the concentration of microorganisms can be varied to match the concentration and nature of pollutants of the incoming wastewater. This intensification of the process enables the Activated Sludge Plant to be smaller than those for other processes.

Disadvantages: an air source is required which in turn requires expensive, high-maintenance equipment and a continuous energy supply. Costs tend to be high.

Integrated Fixed-film Activated Sludge (IFAS)

IFAS systems involve the addition of inert media into existing (activated sludge) basins to provide active sites for biomass attachments. This conversion results in a combination of attached growth and suspended growth biomass.

Advantages: a high density of biomass population is maintained, and the efficiency of the system can be increased without the need for increasing the mixed liquor suspended solids (MLSS) concentration.

Disadvantages: high costs

Small-scale modular activated sludge systems

Different companies have developed, and are promoting, small-scale domestic wastewater treatment units which are often combined with a submerged membrane unit. Although they are gaining popularity in Europe and North America for locations which can not connect to a sewer systems, these units are still at high cost and are not affordable the poor in Africa

Crites, R. and G.Tschobanoglous (1998). Small and Decentralized Wastewater Management Systems, WBC/McGraw-Hill. pp 451-504.

Tchobanoglous, G., Burton, F.L. and Stensel, H.D., 2003. Wastewater Engineering: Treatment and Reuse, 4th Edition. Metcalf & Eddy, New York pp. 659-789

Given its high costs and power requirements this technology component will not be assessed further in the subsequent chapters.

Membrane biological reactors

A Membrane Biological Reactor (MBR) is a special process that can be used in water reclamation facilities to remove nearly all bacteria. MBRs include a semi-permeable membrane barrier system either submerged in, or following, an activated sludge process. The performance of MBR systems is directly proportional to nutrients reduction efficiency of the activated sludge process. The microscopic holes in the membrane are smaller than bacteria so that they are filtered. The extremely effective treatment means that: (1) effluent (reclaimed, clean water) leaving the facility is treated to a higher level than the standard reclamation process; and (2) the MBR eliminates the need for some of the processes used during treatment, so MBR facilities have a much smaller footprint. The application of membranes in anaerobic treatment processes still has some limitations due to severe membrane scaling and fouling, although they have been proven to achieve superior COD removal and biomass retention.

Advantages:

- Guarantees removal of all suspended and some dissolved pollutants,
- Very compact and space saving,
- High reuse potential of effluent

Disadvantages:

- High investment and operation costs (higher than conventional WWTP).

Given its high costs and power requirements this technology component will not be assessed further in the subsequent chapters.

Related to urine

Off-site urine storage

In large systems, where the urine is used to fertilise food crops eaten by other than those who generated the urine, a secondary storage process is required. In urine, bacteria, protozoa and viruses die-off as a function of storage time. An environment with high temperature, low dilution and high pH promotes the sanitisation. Therefore, in large systems (more than one household) storage is often used as a convenient and cheap way to treat urine before it is applied to plants. Guidelines for the safe use of urine recommend that for reuse in agriculture, urine should be stored at 4-20°C for 1-6 months depending on the types of crops. With average temperatures > 20°C, 1 month of storage is sufficient, except for vegetables eaten raw. Urine collected from individual households can be used directly on crops (which have fruit above ground) that are intended for the household’s own consumption. In both cases, one month between urine application and crop harvesting is recommended. Recommendations that describe the recommended storage time, as a function of temperature and crop, are found in the WHO Guidelines for the safe use of wastewater, excreta and greywater (see references). It should noted that the time of separate storage is the time from the last filling of the tank (i.e. the last time any pathogens could enter) until the content can be safely used. Thus, the retention time in a collection vessel cannot be included in the time calculated to properly sanitize the urine before application.

Storage tanks, which should closed and non-ventilated, but pressure equalized, can be made of concrete or plastic. Since urine is very corrosive, metals should be avoided. They can also be made in the same way as simple rain water tanks or dams, with a sturdy plastic, rubber or bitumen liner dug into and supported by the soil around it. The tank should be covered with a sturdy plastic liner to avoid odour and loss of ammonia.

Maurer, M. (2007). Urine treatment- Absolute Flexibility. Eawag, Switzerland. http://www.eawag.ch/services/publikationen/eanews/news_63/en63e_maurer.pdf; Accessed 14 August, 2007

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater- Volume IV: Excreta and Greywater use in Agriculture. World Health Organization, Geneva.

Struvite precipitation from urine

Precipitation of $MgNH_4PO_4*6H_20$ as the white mineral struvite (also called magnesium ammonium phosphate, MAP) is a nutrient recovery option, which has been used in full-scale wastewater treatment for over 20 years. More recent research has focused on its recovery from animal manure and human urine. The production of struvite would be possible anywhere that there are sufficient, and continuous quantities of urine. Struvite is precipitated from urine by adding a magnesium source (e.g. magnesium oxide, MgO; magnesium chloride, $MgCl_2*6H_20$). In this way more than 90% of the phosphorus can be recovered in the form of struvite. MAP production is a simple technology that is capable of producing dry phosphorus-based fertilizer although it does not optimally make use of the potassium, sulphur, or the full amount of nitrogen present in urine. Because struvite is a concentrated source of nutrients that can be easily handled and shipped, transport and energy costs are reduced and nutrients can be redirected from where they are generated to where they are needed most. The precipitation of MAP from urine removes only a part of the ammonia content from the urine and thus, the nutrient-reduced urine must still be dealt with in an adequate matter. Struvite production at the community-scale has not been implemented to our knowledge, however because of the environmental, sanitation, agricultural, and economic benefits, it is foreseen that the technology could be promising in the right circumstance.

Ronteltap, M., M. Maurer, W. Gujer (2007) Struvite precipitation thermodynamics in source-separated urine. Water Research 41(5): 977–984.

Related to faecal sludge

Settling ponds

Faecal sludge can be either high strength (e.g. from unsewered public toilets) or low strength (e.g. from septic tanks). High strength sludge is still very high in organics and has not undergone significant degradation, which makes it difficult to dewater. Low strength sludge has undergone significant anaerobic degradation and is more easily dewatered. Consequently, each type of faecal sludge has very different settling properties; sludge-specific settling tests should be done prior to designing any settling pond to determine how, and if the sludge will settle.

In order to be properly dried then, high strength sludges must be first stabilised: this can be done by allowing them to degrade anaerobically in settling/thickening ponds. The same type of pond can be used to thicken low-strength sludge, although it undergoes less degradation and requires less time to settle well. However, the degradation process may actually hinder the settling, because the gases produced may resuspend solids. To achieve maximum efficiency, the loading and resting period should not exceed 4-5 week, although much longer cycles are common.

In settling ponds, removal efficiencies of suspended solids (SS) can achieve 96 % with two alternating, batch-operated sedimentation ponds (e.g. a 4-week loading/ 4-week resting cycle). The accumulated sludge is let to dewater until a total solids concentration of 20-25 % and, hence, spreadability is attained.
As the sludge settles and digests, the supernatant can be decanted and treated separately. The thickened sludge can then go on to be dried or composted further.

Settling ponds are an adequate treatment method when there is space available that is far from homes and businesses. The sludge however is not effectively treated, and requires further treatment before disposal.

Ideally this technology should be coupled with an onsite drying/co-composting facility to generate a hygienic product. This is a simple, low-cost option that can be installed almost anywhere there is space, however the technology must be considered along with the final use of the dry solids, even if it is just surface application or landfilling.

Heinss, U., S.A. Larmie, M. Strauss (1999). Characteristics of Faecal Sludges and their Solids-Liquid Separation. EAWAG/SANDEC Report, Duebendorf, Switzerland. www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/ewm_settling; Accessed 14 August, 2007.

Heinss, U., S.A. Larmie, M. Strauss (1998). Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics-Lessons Learnt and Reccomendations for Preliminary Design. Second Edition. Sandec Report 05/98. EAWAG/SANDEC, Duebendorf, Switzerland. www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/ewm_settling; Accessed 14 August, 2007.

Unplanted drying beds

A sludge drying bed is a simple, permeable bed that collects percolated leachate and allows the sludge to dry by evaporation. About 50-80% of the sludge volume drains off as liquid. The sludge however, is not stabilized or treated.

Sludge should be settled in settling ponds beforehand to thicken it and to remove as much water as possible before it is applied to the drying beds. Unplanted drying beds can be used for dewatering and drying sludge mixtures of low and high strength sludges at volumetric ratios higher than 2:1. They can also be used for primary pond sludge with an initial TS content varying from 1.5 to more than 7%. Dewatering performance varies with the initial TS and TVS content and the applied loads.

The thickened sludge is pumped onto the drying beds. A splash plate should be used to prevent erosion of the sand layer and to allow the even distribution of the sludge.

The bottom of the drying bed is lined with perforated pipes that drain away the leachate. On top of the pipes are layers of sand and gravel that support the sludge and conduct the liquid to the collection pipe.

The top sand layer should be 25-30 cm thick as some sand will be lost each time the sludge is manually removed.

The fresh sludge should not be applied in layers that are too thick (maximum 20 cm), or the sludge will not dry effectively. The final moisture content after 10-15 days of drying should be about 60%.

It has been found that 5 to 15 days of dewatering were necessary to reach a TS content of 25% when the initial solids loading rates varied between 70 and 475 kg TS/m^2*year and with a loading depth of 20 cm.

Sludge drying is an effective way of decreasing the sludge volume, which is especially important when it must be transported elsewhere for direct use, co-composting or disposal. It is not however, effective at stabilizing the organic fraction or decreasing the pathogenic content.

Sludge drying beds are appropriate for small to medium communities that have fewer than 20,000 people.

Crites, R. and G.Tschobanoglous (1998). Small and Decentralized Wastewater Management Systems, WBC/McGraw-Hill.

Montangero, A and M. Strauss (2002). Faecal Sludge Treatment Lecture Notes, IHE Delft.
www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/ewm_options; Accessed 17 July, 2007.

Planted drying beds/ reedbeds

A planted drying bed is similar to an unplanted drying bed but with the benefit of increased transpiration. This technology has the benefit of dewatering as well as stabilizing the sludge. Also, the roots of the plants create pathways through the thickening sludge to allow water to escape more easily.

The sludge should be pre-settled to thicken it before spreading it.

The appearance of the bed is similar to a subsurface flow constructed wetland. Beds are filled with sand and/or gravel to support the vegetation, but the biosolids are applied to the surface and the filtrate flows down through the subsurface to collection drains. A general design for layering the bed is:

- 25 cm coarse gravel (d=20mm)
- 25 cm fine gravel (d=5 mm)
- 10-15 cm sand

One metre of free space should be left above the top of the sand layer to account for about 10 years of accumulation.

Once constructed, the plants (generally reeds, banana trees, papaya trees or any other water and nutrient tolerant plant) should be planted evenly and allowed to establish themselves before the sludge is applied.

Application rates up to 100 kg/m^2/year have been reported. Sludge should be applied in layers between 75-100 mm and should be reapplied every 7-10 days.

In Thailand, beds were planted with *Typha angustifolia* (narrow-leaved cattail), had a surface area of 25 m^2 and were loaded at a rate of 8 m^3 /week. Ponding periods of 6 days were found to be optimum. The beds were able to accumulate 70 cm of sludge after 4 years of operation while maintaining their full permeability. In general, the sludge should be removed after 5 years and used for agriculture.

A planted drying bed system can be used on a fairly large scale: up to 20 million litres a day.

Heinss, U. and T. Koottatep (1998). Use of Reed Beds for Faecal Sludge Dewatering - A Synopsis of Reviewed Literature and Interim Results of Pilot Investigations with Septage Treatment in Bangkok, Thailand, UEEM Program Report, AIT/EAWAG., Duebendorf, Switzerland. www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/ewm_drying; Accessed 18 July, 2007.

Koottatep, T., et al. (2004). Treatment of septage in constructed wetlands in tropical climate – Lessons learnt after seven years of operation. Water Science & Technology, 51 (9) pp 119–126.
www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/ewm_drying; Accessed 18 July 2007.

Co-composting

Co-Composting is the same as composting in that it is the controlled aerobic degradation of organics; the difference is that co-composting incorporates more than one feedstock. Faecal sludge has a high moisture and nitrogen content but a low carbon content. The carbon to nitrogen ration (C:N) of sludge is between 5-10, while a bulking material such as wood chips has a C:N around 500. As well, solid waste has good bulking properties (i.e. it allows air to flow and circulate). Thus, by combining the two, the benefits of each can be harnessed to optimize the composting process.

For dewatered sludges, a ratio of 1:3 (dewatered sludge: solid waste) should be used. Liquid sludges should be used at a ratio of 1:5-1:10 depending on how thin the sludge is.

There are two types of co-composting systems: open systems and in-vessel systems. In open systems, the mixed material (sludge and solid waste) is piled into long heaps and left to decompose. Windrow piles are turned periodically to provide oxygen and ensure that all parts of the pile are subjected to the same heat treatment. Windrow piles should be at least 1 m high, and should be insulated with compost or soil to promote an even distribution of heat inside the pile.

In-vessel composting requires controlled moisture and air additions, as well as mechanical mixing; it is not generally appropriate for decentralized facilities. Depending on the climate and space available, the facility may be covered to prevent excess evaporation or rain.

A co-composting facility is only appropriate when there is an available source of clean solid waste. Mixed solid waste with plastics and garbage must first be sorted.

Co-composting, when done carefully, can produce a very clean, pleasant, beneficial product that is safe to touch and work with, since the heat generated during the composting process sanitizes the faecal matter.

Faecal sludge treatment by worm composting

Vermicomposting is the process by which organic materials are converted into humus by specific types of earthworms that breakdown the organic materials. There are some species that can consume organic materials very rapidly. Verimicomposting can increase the rate at which finished compost is produced, although the operating costs are usually higher than regular composting. Worms are, however, sensitive to heat. Most species die at temperatures above 38-40°C, which means that most types of waste have to be applied in thin layers to avoid temperature build up. Furthermore, there is no agreement about criteria for deciding whether vermicomposted faecal sludge has been safely sanitized or not.

Montangero, A., et al (2002). Co-composting of Faecal Sludge and Soil Waste. Sandec/IWMI, Duebendorf, Switzerland.

Strauss, M., et al. (2003). Co-composting of Faecal Sludge and Municipal Organic Waste- A Literature and State-of-Knowledge Review. Sandec/IMWI, Duebendorf, Switzerland.

Tanner, M. (2003). Nitrogen in Co-compost and other chemical compost analyses. Field Report from Ghana, Sandec, Dubendorf, Switzerland.

(All reports are avilable at www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/ewm_cocomposting)

Reuse Technologies

Related to urine

Application

The application of urine to arable land is an option that is being piloted on different scales in various countries. Directly applying urine (i.e. without prior storage) is a practical approach when (i) urine is collected from a household, (ii) only the family consumes the fertilized crops and (iii) storage capacity is limited. The WHO fertilizing guidelines for direct use of urine should be followed in order to minimize health risks. Urine must not be applied closer than 100 metres from a water source or 50 meters from a watercourse. Urine should be applied as close as possible to the soil, and then be harrowed down immediately. The application should be done in periods when the plants can utilise the nutrients. In order to avoid odours, potential health risks and nitrogen losses, the stored urine should be harrowed down as soon as possible. Urine must not be applied to grazing pasture or to fields that are used for fodder crops that will be harvested in less than ten months. Moreover, for food intended for human consumption, at least one month should elapse from fertilization to harvest.

There are strong indications that pharmaceutical substances are well degraded in the topsoil of arable fields, as negative effects due to pharmaceutical substances present in manure are extremely rare, even though the concentrations of many pharmaceuticals are higher in manure than in human urine. One advantage of source separation of urine is however, that the pharmaceutical substances can be degraded before application to soil, if this is prioritized.

If enough water is available, multiple harvests can be obtained in the West African context.

On-site reuse

Urine is applied on agricultural fields close to the the toilet; this option is most common in rural areas and areas with urban agriculture where the urine can be applied with simple tools like watering cans, to the fields. Additionally, urine can be collected with greywater so that the mixture can be used in a greywater garden.

Off-site reuse:

After collection, urine can be applied to fields on a larger scale with machinery like slurry spreaders. This option would be applicable when there is a collection service or a central collection tank.

Off-site reuse demands an organisational and logistical framework for collection, sanitization and application, and is therefore, not applicable to all West African settings.

Schonning, C. and T.A. Stenstrom. (2004). Guidelines for the Safe Use of Urine and Faeces in Ecological Sanitation Systems-Report 2004-1.EcosanRes, Stockholm Environment Institute, Stockholm, Sweden. http://www.ecosanres.org/pdf_files/ESR_Publications_2004/ESR1web.pdf; Accessed 14 August, 2007.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater- Volume 4: Excreta and greywater use in agriculture. WHO, Geneva. http://whqlibdoc.who.int/publications/2006/9241546859_eng.pdf; Accessed 14 August, 2007.

Related to sludge

Use in agriculture

To reduce worker and consumer exposure to pathogens in sludge used for agriculture, the WHO recommends 5 areas for control: (1) crop restriction, (2) application techniques, (3) fieldworkers, (4) the withholding period and (5) food preparation.

Crop restriction dictates that treated sludge be restricted to non-food crops, crops that are processed before consumption or crops that must be cooked. In all cases however, the sludge must be treated and raw excreta should not be used.

Treated sludge and excreta can be applied in the same way that animal manure is applied locally. To improve the benefit to the plant and to reduce contact between the crop and humans, the material should be worked into the soil.

Agricultural workers should wear appropriate protective clothing (e.g. boots) to reduce the risk of exposure to helminth eggs, and adequate water and sanitation facilities should be provided in conjunction with hygiene programs.

Crops should not be fertilized within the month prior to harvesting. This withholding period allows time for pathogens to die due to solar radiation, dehydration or predation.

Finally, the preparation of foods grown with sludge can dramatically affect the presence of pathogens. Washing with tap water, disinfectant solutions, or detergent and peeling can reduce pathogens by up to 2 log units, and cooking can provide near complete removal.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Excreta and greywater use in agriculture- Vol. IV. World Health Organization. http://www.who.int/water_sanitation_health/wastewater/gsuweg4/en/index.html; Accessed 15 August, 2007.

Related to blackwater and greywater

Application in agriculture

Waste waters of varying qualities can be used for irrigating agricultural land although appropriate precautions should be taken. Generally however, only waters that undergone secondary treatment (i.e. physical and biological treatment) should be used (to limit the risk of crop and worker contamination).

To reduce risk to the consumer and the agricultural worker, multi-barrier strategies are key and may include combinations of the following: (a) on-site storage and treatment to reduce pathogens to a level that presents a tolerable risk; (b) off-site additional treatment for further pathogen reduction; (c) crop restrictions: growing crops that either are not eaten or are processed (cooked) prior to consumption; (d) application techniques of wastewater, excreta and greywater that reduce exposure of workers and contamination of crops (including withholding periods, buffer zones); (e) exposure control methods: limiting public access; workers wearing protective clothing; (f) pathogen die-off before consumption and (g) food preparation measures such as washing, disinfecting and/or cooking food properly prior to consumption.

Depending on the geography, infrastructure and resources available there are a variety of irrigation options.

Flood and furrow irrigation systems are still one of the most popular methods of crop irrigation. Water is pumped or brought to the fields and is allowed to flow along the ground among the crops. This method is simple and cheap, and is widely used by societies in less developed parts of the world, but the problem is that about one-half of the water used ends up not getting to the crops.

Spray and sprinkler irrigation have the highest potential to spread contamination onto crop surfaces and effect nearby communities. Where spray or sprinkler irrigation is used with wastewater, it may be necessary to set up a buffer zone (e.g. 50-100 m from houses and roads) to prevent adverse health impacts on local communities.

Localized irrigation techniques (e.g. bubbler, drip, trickle) offer farm workers the most health protection because the wastewater is applied directly to the plants. To minimize evaporation and contact with pathogens, drip irrigation is usually the most effective option. Surface irrigation is prone to large losses from evaporation but requires little/no infrastructure and may be appropriate to some situations. Crops such as corn, alfalfa (and other feed), fibres (cotton), trees, tobacco, fruit trees (mangos), and foods requiring processing (sugar beet) can be grown safely with treated effluent. More care should be taken when growing fruits and vegetables that may be eaten raw (e.g. tomatoes) that could come in contact with the water.

Cessation of irrigation with wastewater for one to two weeks prior to harvest can be effective in reducing crop contamination by providing time for pathogen die-off. Enforcing withholding periods is likely to be difficult, because many vegetables need watering up until harvesting to increase their market value. Alternatively, crops could be irrigated from non-contaminated water sources (where available) after the cessation of wastewater use until harvest.

Ayers, R.S. and D.W. Westcot (1994). FAO Irrigation and Drainage Paper 29 Rev. 1. Water Quality for Agriculture. FAO, Rome. www.fao.org/DOCREP/003/T0234E/T0234E00.HTM; Accessed 17 July 2007.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Vol. II: Wastewater use in agriculture. World Health Organization. http://www.who.int/water_sanitation_health/wastewater/gsuweg2/en/index.html; Accessed 14 August, 2007.

Aquaculture

Aquaculture refers to the controlled cultivation of aquatic plants and animals. As a treatment stage for wastewater, fish can be grown in ponds where they feed on algae and other organisms until they are eventually harvested. Alternatively, plants such as duckweed, lotus, water mimosa, water spinach, etc. can be grown as food for fish or for humans. Care should be taken not to overload the ponds: BOD should not exceed 1 $g/m^2.d$ and oxygen should be at least 4 mg/L. Fish introduced to aerobic ponds can effectively reduce algae and help control mosquito populations.

The fish themselves do not dramatically improve the water quality, but because of their economic value they can offset the costs of a treatment facility. Under ideal operating conditions, up to 10,000 kg/ha of fish can be harvested. If the fish are not acceptable for human consumption, they can be a valuable source of protein for other high-value carnivores (like shrimp) or converted into fishmeal for pigs and chickens.

A floating plant (macrophyte) pond is essentially a modified aerobic pond. The aerobic pond is populated with floating plants such as water hyacinths or duckweed that float on the surface and have roots that hang down into the water.

Duckweed is a fast growing, high protein plant that can be used fresh or dried as a food for fish or poultry. It is also very tolerant of a variety of conditions and can remove significant quantities of nutrients from water.

To provide extra oxygen to a floating plant system, the water can be mechanically aerated but at the cost of increased power and machinery. Aerated systems can withstand higher loads and can be built with smaller footprints. Non-aerated systems should not be too deep otherwise there will be insufficient contact between the bacteria-harbouring roots and the wastewater.

To ensure year-round function, aquaculture systems are generally restricted to warm climates.

Skillicorn, W., Journey, K. & Spira, P. (1993). Duckweed aquaculture: A new aquatic farming system for developing countries. Washington, DC, World Bank. www.p2pays.org/ref/09/08875.htm; Accessed 17, July 2007.

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Wastewater and excreta use in aquaculture- Vol. III. World Health Organization.

Infiltration trench/field

Infiltration may be seen as reuse option if the objective is groundwater recharge, i.e. the natural or intentional infiltration of surface water into the zone of saturation. There are a variety of structures that conduct surface water into the ground such as dug or constructed spreading basins, pits, ditches, furrows, streambed modifications, or injection wells.

An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives effluent. The effluent is stored in the void space between the stones and infiltrates through the bottom of the trench into the soil matrix. Infiltration trenches perform well for removing fine sediment and associated pollutants. Pre-treatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment entering the trench which can clog and render the trench ineffective.

Disposal Technologies

Related to faecal sludge

Surface Disposal

Surface disposal is simply the stockpiling of biosolids for non-beneficial use. Surface disposal is the final disposal site; the biosolids are not used later.

When there is no demand, or acceptance for the beneficial use of biosolids, they can be placed in monofills, which are biosolids-only landfills or heaped into permanent piles. The main difference between surface disposal and land application is the application rate. There is no limit to how much biosolids can be applied to the surface, since there are no concerns about nutrient loads or agronomic rates. There is however, concern related to ground water contamination and leaching. More advanced surface disposal systems may incorporate a liner and leachate collection system to prevent nutrients and contaminants from infiltrating the groundwater.

Landfilling biosolids along with Municipal Solid Waste (MSW) is not advisable since it reduces the life of a landfill that has been designed for the containment of more noxious materials. Also, as opposed to more centralized MSW landfills, surface disposal sites can be situated close to where the faecal sludge is treated, thus limiting the need for long transport distances.

Since there are no benefits gained from this type of disposal system, it should not be considered as a primary option. However, where there is no acceptance towards biosolids, the contained and controlled stockpiling of biosolids is far preferable to uncontrolled dumping.

Since the surface disposal site is away from and protected from the public, there is no risk of contact or nuisance. Care should be taken to protect the disposal site from vermin and from pooling water, both of which could exacerbate smell and vector problems.

Maintenance staff should ensure that only appropriate materials are disposed of at the site, and must thus maintain control over the traffic and hours of operation.

U.S. Environmental Protection Agency (1999). Biosolids Generation, Use, and Disposal in the United States, EPA-530/R-99-009. U.S. Environmental Protection Agency: Washington, D.C. http://www.epa.gov/epaoswer/non-hw/compost/biosolid.pdf

U.S. EPA (1994). A Plain English Guide to the EPA Part 503 Biosolids Rule, EPA832-R-93-003. USEPA, Washington, DC. http://www.epa.gov/owm/mtb/biosolids/503pe/index.htm; Accessed 7 August, 2007.

Incineration

Before sludge can be incinerated, it must be dewatered using filters, drying beds, or centrifuges. It can then be dried and then combusted in a special incinerating plant. This occurs often in areas where the reuse of sludge is forbidden due to legislation or when the sludge is highly contaminated (by industrial inputs) or when no reuse is possible.

An incineration system consists of a furnace (or incinerator) and some type of air pollution control device (APCD). The APCD is required to filter out the fine, and potentially toxic particles that are vaporized and escape with the smoke.

Fuel, such as natural gas, oil, coal, wood or municipal solid waste is also required to enhance the burning of biosolids. If municipal solid waste is added however, extra precautions must be taken to ensure that the mixture burns correctly and cleanly.

Incineration is most appropriate for non-degraded sludge, i.e. sludge that still retains a high quantity of volatile solids. Digested sludge, or biosolids (e.g. from an anaerobic digester), is more difficult to incinerate because of the lower quantity of volatile solids. In either case however, dewatering is required and thus incineration is only an option when a dewatering facility also exists.

U.S. EPA, (1994). A Plain English Guide to the EPA Part 503 Biosolids Rule. EPA832-R-93-003, EPA, USA. http://www.epa.gov/owm/mtb/biosolids/503pe/index.htm; Accessed 7 August, 2007

Given its high costs and power requirements this technology component will not be assessed further in the subsequent chapters.

Related to blackwater and greywater

Soak pit

The soak pit (or trench) allows effluent/wastewater to percolate down into the surrounding subsoil. Soak pits should be sufficiently large to avoid flooding and overflowing. The capacity of the pit should accommodate all the wastewater produced during one day. An important consideration is the soil permeability; if the percolation rate is too high, the wastewater might drain into the nearby watercourses before it can undergo any (natural) treatment. If soil permeability is too low, the pit/trench might clog and backup. Although sometimes a site percolation test is recommended, it is actually ineffective because the percolation test gives the percolation rate of clean water into virgin soil, and not an indication of how settled wastewater infiltrates into soil which becomes increasingly clogged over time.

Discharge of treated wastewater through percolation/leach-pits into sub-soil layers is a common practice of wastewater disposal. The average depth of the pit is 4 m although the groundwater table or bedrock usually limits the depth. Sub-soil layers should be water permeable to avoid the rapid saturation of soils. Soil infiltration of effluents becomes a public health hazard if dug- or bore-wells are located less than 10 m away from infiltration pits, as effluents will leach into the catchment area of the well.

Infiltration of untreated wastewater should be seen as temporary solution as it can lead to groundwater pollution and moreover, valuable resources (water and nutrients) are lost through this practice.

Ahrens, B. (2005). A Comparison of Wash Area and Soak Pit Construction: The Changing Nature of Urban, Rural, and Peri-Urban Linkages in Sikasso, Mali. www.cee.mtu.edu/peacecorps/reports/Brooke_Ahrens_Final_Report.pdf; Accessed 18 July, 2007.

Mara, D.D (1996). Low-Cost Urban Sanitation. John Wiley & Sons- Wiley-Interscience Publications.

Leach field (sub-soil wastewater infiltration)

After proper primary treatment to remove suspended solids (e.g. a septic tank) the wastewater is distributed over large area through perforated pipes that allow the water to 'leach' down into the soil. The pipes are embedded in a layer of gravel to enhance distribution and absorption. Rather than simply 'disposing' of the wastewater, the leach field has the benefit of providing some additional biological treatment. A biomat (i.e. a layer of biological growth) develops on the distribution layer/soil interface. To effectively degrade the wastewater, the interface should stay unsaturated so that the biomat layer can remain aerobic. BOD and nitrogen are consumed by organisms, while phosphorus is removed by absorption in the soil. The size of the leachfield depends on the infiltration capability of the soil, which is much reduced by the biomat.

If the hydraulic conductivity is very high, e.g. if the soil is coarse gravel, the flow will be too fast for a good biomat to develop, in which case the technology more closely resembles a soak pit (i.e. no additional treatment).

Depending on local conditions, the infiltration surface can raised above the original ground in a mound or even be at the top surface. Many other adoptions to local conditions are also available.

Advantages: A properly designed and normally operating system should be odour free

Disadvantages: The leachfield is prone to clogging if the previous treatment technology is inefficient. Also, the efficiency of the leachfield depends on the infiltration capacity of the soil; heavy clay is not suitable, nor is coarse gravel.

USEPA (1980). Design manual- on-site wastewater treatment and disposal systems. EPA-625/1-80-012. Office of Research and Development, Municipal Environmental Research Laboratory, Cincinnati, Ohio. www.epa.gov/ordntrnt/ORD/NRMRL/Pubs/625180012/625180012chap7.pdf; Accessed 18 July, 2007.

Discharge into receiving water body

The discharge of treated wastewater into receiving water bodies (such as rivers, lakes, etc.) is an acceptable option if certain conditions are met. First, it is necessary to ensure that the self-purification capacity of receiving streams is not overloaded by the discharged wastewater. Secondly, efficient pre-treatment must ensure that health of local populations who use river-water downstream is not negatively affected. Local authorities should be consulted to determine the discharge limits for the relevant parameters (e.g. BOD, nitrogen, phosphate, faecal coliform counts etc.) as they can vary widely. For especially sensitive areas, chlorination may be required to meet certain guideline limits.

Related to urine

Urine soakaway pit

A urine soakaway is a small soakaway (soak pit), loaded only with the urine. Since the flow is so small, it can be much smaller than normal soakaways. The low flow also means that the retention time of the urine will be long, which promotes a good reduction of nitrogen and phosphorus. However, the electrical conductivity of the urine is high. Therefore, in dry areas, plants close to the pit might suffer if their main liquid supply is from the urine. This risk can be decreased by irrigation with other water sources, thus diluting the electrical conductivity of the liquid available to the plants.

Related to faeces

Incineration

Dried faeces with a moisture content of less than 10% can be incinerated with limited emissions of smoke and odour; higher moisture content leads to increased emissions. During the burning, the plant-available nitrogen and the sulphur are lost, while the phosphorus and the potassium remain in the ash. However, the indications are that the phosphorus that remains is not plant-available. Nevertheless, incineration can be of interest in areas with high densities since it can minimize mass transport. Furthermore, the process minimizes the risk for pathogen transmission and aesthetically, the ash is visibly treated, which can be important in promoting the technology as part of a sanitation system.

PART 3 Technology assessment

For each flowstream, the following tables list and rank the technologies that are appropriate to the given flowstream. Since some flowstreams are similar in terms of volume, composition, etc. they have been grouped together to simplify the assessment. (There are of course instances when one technology is marginally better or worse for a given flowstream and this is not reflected in the rankings since some flowstreams are grouped). The technologies that are assessed for each flowstream (or group of flowstreams) are grouped according to the process that they perform (i.e. transport, etc.), although it should be noted that only the relevant technologies, and thus the relevant processes are included. The tables are meant to not only summarize the appropriate technologies but to give an indication about the effectiveness and appropriateness of each technology in regards to a diverse and comprehensive set of criteria.

Assessment by eliciting expert judgement

In the planning and selection process for sanitation systems and technologies, the wide range of stakeholders have an equally wide range of interests and differing objectives regarding the type of, and goals of, an improved sanitation system. During the decision making process it is extremely important to understand the drivers for improved sanitation for each of the respective. For instance, individual residents and households typically want improved sanitation not primarily to improve their health, but more importantly, to improve privacy, safety, comfort, cleanliness, to improve their status/image or even to make better use of the nutrient or water resources.

The ranking tables that follow are an attempt to identify the different areas of importance to which stakeholders may assign meaning, and in turn, critically assess the feasible technologies, based on these criteria. Each technology, for each criterion, was assigned a ranking on a five-point scale. The ranking scale is summarized in Table 4.

Table 4: Definition of descriptors used for the assessment:

Qualitative Descriptor	Meaning
+ +	the criterion is very well fulfilled by this technology
+	the criterion is fulfilled by this technology
o	the criterion is neutral to this technology
-	the technology does not well fulfil this criterion
- -	the technology does not at all fulfil this criterion
shaded	the criteria is not applicable for this technology

The ranking tables that follow are not exhaustive but they reflect an expert-driven decision process about which technologies to include and exclude. Where the NETSSAF consortium of experts agreed that a technology was unlikely to be feasible and practical for the West African context of rural and peri-urban poor, it was not included.

Technologies applicable for:

- **Blackwater**
- **Blackwater + Greywater**
- **Brownwater**
- **Brownwater +Greywater**

		User Interface			**Onsite Collection, Storage and Treatment**					**Transport**			**Offsite Treatment**					**Reuse**		**Disposal**		
		High-volume cistern flush toilets	**Low-volume -flush toilets**	**Pour-flush toilets**	**Alternating Twin Pit Latrine**	**Septic Tank**	**Aquaprivy**	**Anaerobic baffled reactor:**	**Anaerobic digester**	**Conventional Gravity sewers**	**Small bore sewers**	**Simplified Sewerage**	**Trickling filter**	**Waste stabilization ponds**	**Floating macrophyte ponds)**	**Constructed wetlands**	**UASB reactor**	**Application in Agriculture**	**Application in aquaculture**	**Infiltration trench/field**	**Soak pit**	**Discharge into water body**
Health issues																						
reduces exposure	of users	++	++	+	+	+	+	+	o									-	-	+	+	+
	of waste workers				+	+	-	-	+	+	-	-	o	-	-	o	-	-	-	o	o	o
	of resource recoverers /reusers				+	-	-	+	o				o	-	+	o	o	-	-	o	o	o
	of “downstream” population				+	o	o	+	++				+	+	o	+	+	o	o	o	o	-
hygienization rate					+	o	-	-	++				-	+	o	o	+	o	o	-	-	--
increases health benefits		+	+	+	+	o	o	+	+	+	+	+	+	+	+	+	+	+	+	-	-	--
Impact to environment / nature																						
use of natural resources	needs low land requirements	+	+	o	o	+	o	+	-	-	o	o	o	--	--	-	-	o	o	-	-	o
	needs low energy requirements	++	++	+	+	+	+	+	++	o	++	++	-	++	+	+	-	+	+	+	+	+
	uses mostly local construction material	-	--	++	++	+	o	+	+	o	+	++	+	++	+	+	-	+	+	+	+	+
	low water amounts required	--	+	+	+	o	o	-	--	--	-	-	o	+	--	o	o	++	++	++	++	++
low emissions and impact to the environment	surface water				+	+	+	o	++	o	o	o	o	+	+	+	+	o	o	+	+	--
	ground water				-	+	+	o	++	-	-	-	+	-	-	+	+	o	o	-	-	-
	soil / land				-	+	+	o		-	-	-	o	-	o	-	o	o	o	-	-	-
	air				o	o	o	--		o	o	o	o	-	o	o	o	o	o	+	+	+
	noise, smell, aesthetics	+	+	o	o	o	o	--	o	+	o	o	-	-	-	+	+	o	o	+	+	+
good possibilities for recovering resources	nutrients	-	-	+	+	-	-	--	++				o	+	o	-	-	++	++	-	-	-
	energy	-	-	-	-	-	-	--	++				--	o	-	--	++	o	o	-	-	-
	organic matter	-	-	+	+	-	-	o	o				o	+	++	--	+	o	o	-	-	-
	water	--	-	-	-	+	o	+	+				+	++	+	-	o	o	o	-	-	-

Technologies applicable for: ▪ Blackwater ▪ Blackwater + Greywater ▪ Brownwater ▪ Brownwater +Greywater	User Interface			Onsite Collection, Storage and Treatment					Transport			Offsite Treatment					Reuse		Disposal		
	High-volume cistern flush toilets	Low-volume -flush toilets	Pour-flush toilets	Alternating Twin Pit Latrine	Septic Tank	Aquaprivy	Anaerobic baffled reactor:	Anaerobic digester	Conventional Gravity sewers	Small bore sewers	Simplified Sewerage	Trickling filter	Waste stabilization ponds	Floating macrophyte ponds)	Constructed wetlands	UASB reactor	Application in Agriculture	Application in aquaculture	Infiltration trench/field	Soak pit	Discharge into water body
Technical Characteristics																					
allows simple construction and low level of technical skills required for construction	-	+	+	+	+	-	-	--	--	+	+	--	+	+	+	--	+	+	+	+	+
has high robustness and long lifetime/high durability	+	+	++	+	+	+	+	o	++	-	-	-	+	+	+	-	+	+	o	o	+
enables simple and low operational procedures and maintenance and low skills required	-	-	+	+	+	+	-	--	+	o	o	--	+	o	o	--	+	+	+	+	+
Economical and financial issues																					
has low construction costs (unit cost per household)	-	o	+	+	+	-	-	--	-	+	+	--	+	+	o	--	+	+	+	+	++
provides benefits to the local economy (business opportunities, local employment, etc.)	+	+	+	o	o	o	o	o	+	+	+	o	o	o	o	o	++	++	o	o	o
has low operation and maintenance costs	-	-	o	+	+	o	o	-	-	-	-	--	+	+	+	--	o	o	+	+	+
provides benefits or income generation from reuse				o	-	o	o	++				-	o	o	-	+	+	+	o	o	o
Social, cultural and gender																					
delivers high convenience and high level of privacy	++	+	+	+	+	+	+	o	+	+	+	o	+	+	+	+					
requires low level of awareness and information to assure success of technology	+	+	+	+	+	+	+	-	+	-	-	o	+	+	+	--	-	-	+	+	+
requires low participation and little involvement by the users	+	+	+	+	+	+	+	-	+	-	-	--	+	+	+	+	-	-	+	+	+
takes special consideration issues of women, children and elderly	++	++	++	o	o	o	o	+	o	o	o						-	-	o	o	o

		Onsite C, S & T		Trans.		Offsite Treatment				Re-use	Disp.	
Technologies applicable for: ▪ **Faecal sludge flowstream**		**Anaerobic digester**	**Ammonia sanitation**	**Human powered**	**Motorized emptying**	**Co-composting**	**Planted Drying beds**	**Unplanted drying beds**	**Settling ponds**	**Application in agriculture**	**Surface Disposal**	**Incineration**
Health issues												
reduces exposure	of users											
	of waste workers	-	o	--	-	-	-	-	o	+	-	-
	of resource recoverers /reusers	++	+	--	-	+	+	+	+	-	-	-
	of "downstream" population	+	+	-	--	+	+	+	-	+	o	o
hygienization rate		+	++			++	+	+	o	-	o	++
increases health benefits		+	o			+	+	+	+	+	o	o
Impact to environment / nature												
use of natural resources	needs low land requirements	o	++	+	+	+	-	--	--	-	--	o
	needs low energy requirements	++	++	++	--	+	+	++	++	+	+	--
	uses mostly local construction material	+	--	++	--	++	+	+	+	++	++	--
	low water amounts required	+	-	o	o	--	+	o	o	++	++	++
low emissions and impact to the environment	surface water	+	+			o	-	-	-	-	-	o
	ground water	+	+			+	-	+	-	o	-	o
	soil / land	+	+			+	+	+	-	++	-	o
	air	+	+			o	o	o	o	o	o	-
	noise, smell, aesthetics	+	-	--	--	-	+	-	-	-	-	-
good possibilities for recovering resources	nutrients	+	+			++	--	++	+	++	-	-
	energy	++	o			--	--	o	o	o	-	+
	organic matter	++	+			++	--	+	+	++	-	-
	water	-	o			-	+	+	+	++	-	-

	Onsite C, S & T		Trans.		Offsite Treatment				Re-use	Disp.	
Technologies applicable for: ▪ **Faecal sludge flowstream**	**Anaerobic digester**	**Ammonia sanitation**	**Human powered**	**Motorized emptying**	**Co-composting**	**Planted Drying beds**	**Unplanted drying beds**	**Settling ponds**	**Application in agriculture**	**Surface Disposal**	**Incineration**
Technical characteristics											
allows simple construction and low level of technical skills required for construction	o	-	++	+	++	+	+	+	+	+	--
has high robustness and long lifetime/high durability	o	+	-	--	+	+	+	+	++	+	--
enables simple and low operational procedures and maintenance and low skills required	o	o	++	+	+	+	+	+	+	++	--
Economical and financial issues											
has low construction costs (unit cost per household)	o	o			++	-	+	-		++	--
provides benefits to the local economy (business opportunities, local employment, etc.)	+	o	+	+	+	+	+	o	++	o	o
has low operation and maintenance costs	++	-	++	--	+	+	o	--	+	+	--
provides benefits or income generation from reuse	++	+			+	+	+	o	++	o	o
Social, cultural and gender											
delivers high convenience and/ or high level of privacy	++	o									
requires low level of awareness and information to assure success of technology	o	-	--	+	+	+	+	+	+	+	--
requires low participation and little involvement by the users	o	-	-	+	-	+	+	+	+	++	++
takes special consideration issues of women, children and elderly											

		Onsite Collection, Storage and Treatment									Reuse		Disposal		
Technologies applicable for: ▪ **Greywater flowstream** ▪ **Beigewater flowstream**		**Slow sand filtration**	**Horizontal subsurface flow CW**	**Horizontal surface flow CW**	**Vertical flow CW**	**Greywater garden (mulch trench)**	**Green walls**	**Tower garden**	**Anaerobic filtration**	**vegetated leachfield**	**Application in Agriculture**	**Application in Aquaculture**	**Discharge into receiving water**	**Soak Pit**	**Leach field**
Health issues															
reduces exposure	of users	+	++	-	++	+	+	+	+	o			+	+	+
	of waste workers										-	-			
	of resource recoverers /reusers										-	-			
	of "downstream" population	o	o	o	o	o	o	o	o	o	o	o	o	-	o
hygienization rate		++	++	+	++	+	+	+	++	+	o	+	-	o	o
increases health benefits		++	++	+	++	+	+	+	+	+	+	+	-	o	O
Impact to environment / nature															
use of natural resources	needs low land requirements	+	-	-	-	o	++	++	+	-	-	-	+	++	-
	needs low energy requirements	++	++	++	++	++	+	+	++	++	+	+	+	++	+
	uses mostly local construction material	++	++	+	++	++	++	++	++	++	+	+	++	++	+
	low water amounts required	+	++	++	++	++	++	++	++	++	+	--	+	++	+
low emissions and impact to the environment	surface water	++	+	+	++	--	o	o	++	+	-	-	+	--	+
	ground water	+	+	+	+	+	+	+	++	o	-	-	-	-	-
	soil / land	o	o	o	o	-	-	-	o	o	-	-	-	o	-
	air	o	o	o	o	+	+	+	+	+	o	o	o	o	o
	noise, smell, aesthetics	-	+	-	+	-	-	-	o	+	+	+	+	o	+
good possibilities for recovering resources	nutrients	-	-	+	+	++	++	++	--	+	++	++	-	-	-
	energy	o	o	o	o	o	-	-	-	o	-	-	-	-	-
	organic matter	-	+	+	+	++	++	++	-	+	++	++	-	-	-
	water	++	++	++	++	o	o	o	+	-	++	++	-	-	-
Technical characteristics															
allows simple construction and low level of technical skills required for construction		o	+	+	+	+	++	++	+	+	+	+	++	+	+
has high robustness and long lifetime/high durability		o	+	+	+	++	++	++	+	o	+	+	++	o	O
enables simple and low operational procedures and maintenance and low skills required		-	+	+	+	++	++	++	-	+	+	+	++	++	+

Technologies applicable for: ▪ Greywater flowstream ▪ Beigewater flowstream	Onsite Collection, Storage and Treatment									Reuse		Disposal		
	Slow sand filtration	**Horizontal subsurface flow CW**	**Horizontal free flow CW**	**Vertical flow CW**	**Greywater garden (mulch trench)**	**Green walls**	**Tower garden**	**Anaerobic filtration**	**vegetated leachfield**	**Application in Agriculture**	**Application in Aquaculture**	**Discharge into receiving water**	**Soak Pit**	**Leach field**
Economical and financial issues														
has low construction costs (unit cost per household)	-	-	-	-	++	++	++	+	o	++	++	++	++	+
provides benefits to the local economy (business opportunities, local employment, etc.)	o	o	o	o	++	++	++	+	o	++	++	-	-	-
has low operation and maintenance costs	+	+	+	+	++	++	++	+	+	+	+	++	+	+
provides benefits or income generation from reuse	o	o	o	o	++	++	++	+	+	++	++	-	-	-
Social, cultural and gender														
delivers high convenience and high level of privacy	+	+	+	+	+	+	+	+	+	o	o	++	++	++
requires low level of awareness and information to assure success of technology	+	+	+	+	--	--	--	+	+	-	--	++	++	++
requires low participation and little involvement by the users	-	-	-	-	--	--	--	+	+	+	+	++	++	++
takes special consideration issues of women, children and elderly														

Technologies applicable for: **Urine flowstream**		**User Interface**			**Onsite C,S,T**	**Transort**			**Offsite Treatment**		**Reuse**		**Disp**
		Urine diverting toilets wet	**Urine diverting toilets dry**	**Urinal**	**Storage tank**	**Urine pipes**	**Manual urine transport**	**Truck for urine transport**	**Off-site urine storage tank**	**Struvite precipitation**	**On-site application**	**off-site application**	**Soakaway pit**
Health issues													
reduces exposure	of users	o	o	o	o	++	-	++	o	o			o
	of waste workers				o	+	--	-	0	0	o	o	
	of resource recoverers /reusers				+				+	-	o	-	
	of “downstream” population				+				+	+	0	0	o
hygienization rate					+				+	+			o
increases health benefits					0				0	+	++	+	o
Impact to environment / nature													
use of natural resources	needs low land requirements				0	o			0	-	-	-	+
	needs low energy requirements	++	++	++	++	++	+	--	++	--	++	-	+
	uses mostly local construction material	-	o	+	+	-		--	+	--	+	-	+
	low water amounts required	-	++	+	+				+	+	+	+	+
low emissions and impact to the environment	surface water				++			-	++	++	+	+	-
	ground water				++			-	++	++	+	+	-
	soil / land				+			-	++	++	0	0	-
	air				++			-	++	++	0	0	o
	noise, smell, aesthetics	0	0	0	0	o	0	-	0	0	-	-	+
good possibilities for recovering resources	nutrients	++	++	++	++				++	++	++	++	o
	energy	0	0	0	0				0	-	o	o	o
	organic matter	++	++	0	0				0	0	o	o	o
	water	+	+	+	+				+	0	o	o	o

	User Interface			Onsite C,S,T	Transort			Offsite Treatment		Reuse		Disp
Technologies applicable for: Urine flowstream	**Urine diverting toilets wet**	**Urine diverting toilets dry**	**Urinal**	**Storage tank**	**Urine pipes**	**Manual urine transport**	**Truck for urine transport**	**Off-site urine storage tank**	**Struvite precipitation**	**On-site application**	**off-site application**	**Soakaway pit**
Technical characteristics												
allows simple construction and low level of technical skills required for construction	-	-	0	+	-			+	--	++	0	++
has high robustness and long lifetime/high durability	-	0	0	+	0	+	-	+	--	++	-	++
enables simple and low operational procedures and maintenance and low skills required	-	0	0	+	+	+	-	+	--	++	-	+
Economical and financial issues												
has low construction costs (unit cost per household)	-	0	+	-	--	+	-	-	--	++	-	+
provides benefits to the local economy (business opportunities, local employment, etc.)	+	+	+	0	+	+	+	0	+	+	+	+
has low operation and maintenance costs	-	0	+	+	-	++	--	-	-	++	-	++
provides benefits or income generation from reuse	++	++	++	++				++	++	++	++	--
Social, cultural and gender												
delivers high convenience and high level of privacy	++	++	++	0								++
requires low level of awareness and information to assure success of technology	--	--	+	+	++	-	0	+	--	-	-	+
requires low participation and little involvement by the users	-	-	+	0	++	-	-	0	0	0	0	+
takes special consideration issues of women, children and elderly	0	0	0									

Technologies applicable for: ▪ Excreta flowstream ▪ Faeces flowstream		User Interface		Onsite Collection, Storage and Treatment											Trans.	Reuse		Disp
		Dry toilet	Dry urine diversion toilet	Single Pit latrine	Ventilated improved single pit	Alternating Twin Pit	Fossa Alterna	Arboor Loo	Urine diverted dehydration chamber	Composting chamber	Dehydration chamber	Co-composting	Anaerobic digestion	Ammonia sanitation	Human-powered emptying, transport	Application in aquaculture	Application in agriculture	Incineration
Health issues																		
Reduced exposure	of users	0	+	-	o	o	+	+	+									
	of waste workers			--	--	-	o	o	o	o	+	+	o	-	o	-	-	o
	of resource recoverers /reusers			-	-	o	o	o	o	o	+	+	o	-		-	-	o
	of "downstream" population			-	-	-	+	+	+	+	o	+	o	o	o	+	+	-
hygienization rate				-	-	-	+	+	0	+	o	+	+	+		+	+	+
increases health benefits		+	0	o	o	o	+	+	+	+	+	+	+	o		+	+	o
Impact to environment / nature																		
use of natural resources	needs low land requirements	0	0	-	-	-	o	-	++	+	o	+	-	+		-	-	-
	needs low energy requirements	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--
	uses mostly local construction material	++	+	+	+	+	+	+	+	+	+	+	+	--		+	+	-
	low water amounts required	++	++	++	++	++	++	++	++	+	+	-	+	+		+	+	+
low emissions and impact to the environment	surface water			o	o	+	+	+	+	+	o	+	+	+		+	+	+
	ground water			-	-	-	o	+	+	+	+	o	+	+		+	+	+
	soil / land			-	-	+	o	o	+	+	+	+	+	+		+	+	+
	air			o	o	o	o	o	o	o	o	+	+	+	+	+	+	--
	noise, smell, aesthetics			--	o	+	+	+	o	+	-	+	+	o	+	+	+	-
good possibilities for recovering resources	nutrients			-	-	o	++	+	+	++	-	++	+	+		++	++	+
	energy			-	-	-	o	o	0	+	o	--	++	o		o	o	+
	organic matter			-	-	o	++	+	+	++	o	++	+	o		++	++	-
	water			-	-	-	-	-	-	-	-	--	o	o		o	o	-
Technical characteristics																		
allows simple construction and low level of technical skills required for construction		++	+	+	+	+	+	++	o	o	+	+	o	-		+	+	--
has high robustness and long lifetime/high durability		+	+	-	o	+	+	++	+	+	+	-	+	o	+	+	+	O
enables simple and low operational procedures and maintenance and low skills required		+	+	+	+	+	+	+	+	o	-	-	+	-	+	+	+	-

	User Interface		Onsite Collection, Storage and Treatment											Trans.	Reuse		Disp
Technologies applicable for: ▪ **Excreta flowstream** ▪ **Faeces flowstream**	**Dry toilet**	**Dry urine diversion toilet**	**Single Pit latrine**	**Ventilated improved single pit**	**Alternating Twin Pit**	**Fossa Alterna**	**Arboor Loo**	**Urine diverted dehydration chamber**	**Composting chamber**	**Dehydration chamber**	**Co-composting**	**Anaerobic digestion**	**Ammonia sanitation**	**Human-powered emptying, transport**	**Application in aquaculture**	**Application in agriculture**	**Incineration**
Economical and financial issues																	
has low construction costs (unit cost per household)	++	+	++	+	o	+	++	0	+	+	o	o	-		+	+	--
provides benefits to the local economy (business opportunities, local employment, etc.)	+	+	+	+	+	o	o	+	o	+	o	o	o	-	+	+	--
has low operation and maintenance costs	+	+	+	+	+	++	++	+	+	+	++	+	--	+	+	+	--
provides benefits or income generation from reuse	o	++	-	-	-	+	++	+	+	+	++	++	+		++	++	-
Social, cultural and gender																	
delivers high convenience and high level of privacy	+	+	++	-	-	+	+	+	+	o	+	+	o	-	o	o	O
requires low level of awareness and information to assure success of technology	+	-	+	+	+	o	o	--	o	--	-	-	--	o	-	+	--
requires low participation and little involvement by the users	+	-	+	+	+	-	-	-	-	-	--	o	o	+	+	+	+
takes special consideration issues of women, children and elderly	o	o	-	-	-	-	-	o	o	-							