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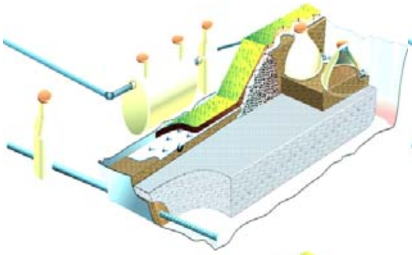
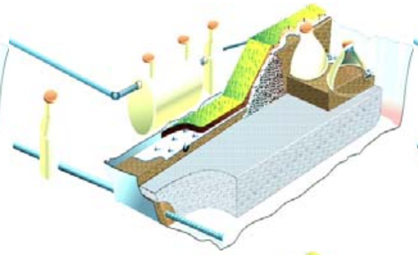
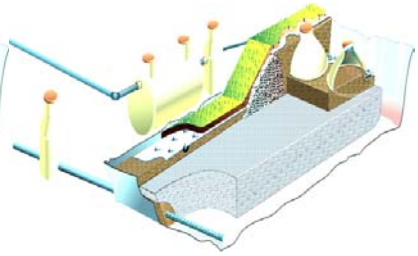
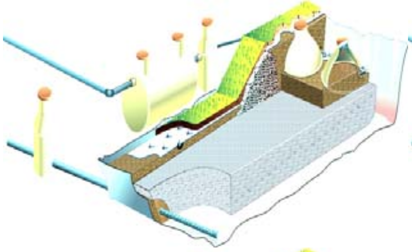
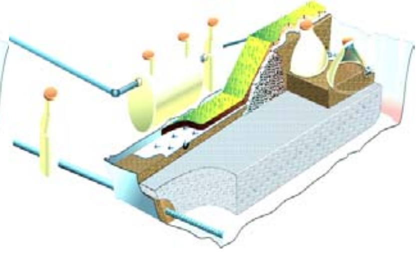
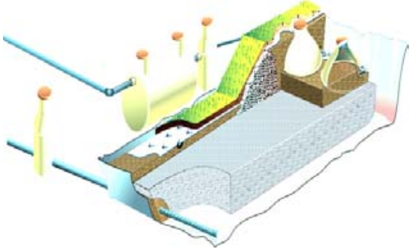
Konzeptionen dezentralisierter Abwasserreinigung und Stoffstrommanagement

Kapitel 4

Sustainable wastewater management in urban areas

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4.1 Introduction

Potable water is one of the world's most precious resources

Present sanitary systems use large amounts of potable water (GARDNER 1997). Potable water is rapidly becoming one of the world's most precious resources and even parts of central Europe are facing water deficits (HAALAND 1994).

While it is important to evaluate the possibilities for conserving and reusing the water resource, it is crucial to remember that wastewater contains mineral nutrients and organic matter that are valuable resources in agriculture. The organic matter is also a potential source for energy production.

Municipal wastewater contains waste heat, which can be extracted with heat pumps, and organic matter, whose energy can be extracted through digestion and biogas production. The combined theoretical potential of heat pumping and methane production in Swedish wastewater, for example, is 10 TWh, or 15% of the country's nuclear electricity production (8% of total electricity production) (GUTERSTAM 1991).

The per capita annual domestic discharge to the sewage system in Norway is 4.5 kg of nitrogen, 0.7 kg of phosphorus and 35 kg of organic matter (HOLTAN and ÅSTEBØL 1990). The amount of nutrients from the total population is equivalent to about 15% of the input of artificial fertilizer to Norwegian agriculture (JENSSEN and VATN 1991a). This has a commercial value of about 25 million EUR.

A century ago these resources were recycled

A century ago these resources were recycled. In cities, the night soil was collected, sometimes mixed with peat or lime, and used as fertilizer (TORSTENSON 1994). With the invention of the water toilet and development and installation of subterranean gravity sewer systems, these resources began being discharged to water, causing pollution.

Today we can treat the sewage and avoid water pollution, but the logistics of first diluting the resource and then reconcentrating and capturing the nutrients at a treatment plant can be questioned, especially if the system is costly and causes environmental problems such as eutrophication. During transport to the treatment plant, domestic wastewater is often mixed with street runoff and wastewater from industries. A sludge containing harmful substances like heavy metals and organic micropollutants may result.

Over the last decade sustainable wastewater treatment has been an issue at several conferences (HENZE et al. 1997, GRAF 1999). The first international conferences of "Ecological engineering for wastewater treatment", was held in Sweden in 1991 (ETNIER and GUTERSTAM 1991), addressing sustainable wastewater treatment systems. The focus was on natural or ecologically engineered systems, that optimize resource gains and minimized resource use, hence, recycling and energy aspects were in focus. Later several conferences on ecological engineering for wastewater treatment or ecological sanitation have been held (STAUDENMANN et al. 1996, KLØVE et al. 1999, JANA et al. 2000, WINBLAD 2001) and the last conference was held in Lübeck in April 2003.

Constructing wastewater treatment systems based on a sustainable approach can minimize environmental problems

Constructing wastewater treatment systems based on a sustainable approach can minimize environmental problems and facilitate utilization of the resources in wastewater. Measures for optimising nitrogen and phosphorus reuse often result also in decreased water consumption or water use. Better nutrient management can also mean dramatic changes in the way the sewage pipe system is built and used, changes which require cooperation between urban hydrologists and engineers.

The emphasis of the chapter is given to systems where wastewater is source separated

This chapter discusses briefly some sustainable solutions to the wastewater treatment problem in urban areas. The emphasis is given to systems where wastewater is source separated. Systems with source separation opens the possibility of producing fertilizer and energy from wastewater and organic waste, hence, near complete recycling of wastewater and waste resources is made feasible. The water use can also be greatly reduced. These are all important factors when evaluating sustainability. Source separating systems have a decentralized structure (section 4.5). This gives a technical and economical flexibility that is beneficial both when rehabilitating old- and building new city sections. With the latest developments in technology source separating systems offer the same comfort to the user as traditional systems. Source separating systems are therefore an option worth evaluating when investments in sewer systems are planned.

4.2 Sustainability analysis of wastewater treatment systems

holistic approach

In order to develop sustainable wastewater treatment it is needed to view the wastewater treatment systems using a holistic approach. A holistic approach implies considering the primary and secondary environmental effects and costs that the systems produce. Examples are the pollution produced at the power plant (generating electricity for wastewater treatment) and the energy cost of producing treatment chemicals. Designing or selecting a treatment system based on sustainability criteria involves a multidisciplinary approach where engineers cooperate with social scientists, economists, biologists, health officials and the public.

simple cost/benefit analysis

In earlier times and even to day, engineers and politicians nearly always use a simple cost/benefit analysis when choosing a wastewater system. This means that, for instance, only the discharge of organic matter (BOD) or phosphorus and the cost is looked upon. However, the quest for sustainability is necessary because many problems are approaching: global warming, acidification of freshwater, diminishing of the ozone layer, organic micro-pollutants and other toxic chemicals in the environment as well as eutrophication and diminishing the fossil resources of phosphorus and oil. The complexity of the problems show that many indicators must be used when deciding what type of wastewater systems to implement. And we should choose the wastewater system that contributes most to an overall sustainable future.

ecology, economy, sociological aspects

The notion sustainability should include ecology, economy and sociological aspects and the sustainability must also perform on three different stages:

1. Local, where hygienic and health aspects are of concern in time scales of hours or days.
2. Regional, where classic environmental problems operate in time scales of months or years.
3. Global, where sustainability matters in a time scale of decades or centuries.

To compare two wastewater alternatives the following indicators may be considered as relevant for a sustainability analysis (LINDHOLM and NORDEIDE 2000):

- Discharge of pollution to local recipients and major recipients. For instance: phosphorus, nitrogen and organic matter (BOD).
- The amount of micro-organic pollutants and heavy metals in the sludge going to agriculture.
- Amount of phosphorus, potassium and nitrogen recirculated for plant production.
- Discharge of climate gases like methane and CO^2.

- Use of electric energy and fossil energy.
- Use of products with hazardous components.
- Use of finite or critical resources.
- Costs as present value of investments, operation and maintenance.
- The use of area, influence on the landscape, aesthetic- and recreational values.
- The service levels like clogging of sewers and flooding of basements.
- Noise, smell, insects and other disturbances in the operation and construction period.
- Safety for children.

Indicators that are approximately the same for both alternatives may be eliminated.

The system borders for the analysis of the sustainability of a wastewater system are very important for the assessment. A wider or narrower definition of the system studied may alter the result of the assessment completely. The assessment may be studied on a global scale, on a regional/city scale or on a block/neighbourhood scale. The two last ones are appropriate for studies of infrastructure systems, even if the global context should be considered at all times. The system borders should be large enough to include not only the infrastructure itself (the hardware of the system), but also the city area it serves and the productive land and waters that enable the cycles of nutrients to be closed (the extended system).

However, up to now we have realised that the municipalities nearly always choose the well known, and cheapest alternative that complies with the minimum regulations and absolute demands from the authorities. We must hope that in the future this will change. The municipalities should achieve a minimum acceptable level of sustainability for their wastewater systems.

4.3 Resources in wastewater and organic waste

Substantial amounts of plant nutrients and organic matter are present in household waste and waste from food processing industries (JENSSEN and SKJELHAUGEN 1994). Theoretically speaking, the nutrients in domestic wastewater and organic waste are nearly sufficient to fertilize crops to feed the world population (WOLGAST 1992). This, however, requires that people turn to a vegetarian diet. It also requires that appropriate technologies are available for safe recycling of the wastewater resources.

Practically speaking 20-40 % of the water consumption in sewered cities is used to flush toilets (GARDNER 1997). In order to evolve towards a sustainable society we need to recycle nutrients, reduce the water consumption, and minimize the energy needed to operate waste treatment processes.

Practically speaking 20-40 % of the water consumption in sewered cities is used to flush toilets

Figures for the amount of mineral fertilizer that can be substituted for organic fertilizer sources vary and depend on several factors, one being whether a country has a net import or export of food. In countries belonging to the Organisation for Economic Cooperation and Development (OECD) the nutrients in wastewater average 8 % of the applied mineral fertilizer and the nutrients in household and yard waste constitute another 7 % (GARDNER 1997). If all the nitrogen and phosphorous in Norwegian wastewater was reclaimed and recycled into agriculture, application of mineral fertilizer could be reduced 15-20 % (JENSSEN and VATN 1991). The corresponding figures for Sweden are 16-17 % (GUTERSTAM 1991). In most developing countries these levels are higher (GARDNER 1997), and according to ETNIER and JENSSEN (1997) more than 40 % of the nutrients present in chemical fertilizers could, theoretically, be substituted with nutrients from wastewater. Organic matter accounts for one third of the input to landfills in industrialized countries and as much as two thirds, in developing countries (GARDNER 1997).

While recycling domestic organic waste can not replace mineral fertilizer entirely, it can reduce pollution from domestic waste, reduce excessive fertilizer use and develop healthier soils.

Tertiary treatment facilities can be designed to remove both nitrogen and phosphorous, but recycling of the nitrogen is difficult unless nitrogen is precipitated as Struvite (an ammonium-magnesium-phosphate mineral also called urine stone) or removed using ammonia stripping with adsorption (VRÅLE 1992). The most common method of nitrogen removal in conventional treatment plants today are biological processes. However, with these methods most of the removed nitrogen is discharged to atmosphere. Phosphorus is most commonly removed by chemical precipitation using either Fe- or Al-salts as precipitating agents. However, the plant availability of phosphorus precipitated as Fe- or Al-phosphates can be very limited due to very low solubility under normal soil conditions

(UGLAND et al. 1998). With lime precipitation the phosphates are easier dissolved and available to the plants. Since industries, households, and street runoff discharge to the same sewer system, there is a risk of heavy metals and other contaminants. In Scandinavia, this threat has reduced the farmer's motivation to recycle sewage sludge.

Urine is the most nutrient rich fraction in wastewater, but contributes less than 1% of the total amount of wastewater produced (see Fig. 4.1). Because of the high nutrient concentrations, urine can be beneficially collected and reused as a plant fertiliser. Faeces and organic household waste contain fewer nutrients than urine; however, due to their content of organic material they may also be recycled to plant production as soil improvers.

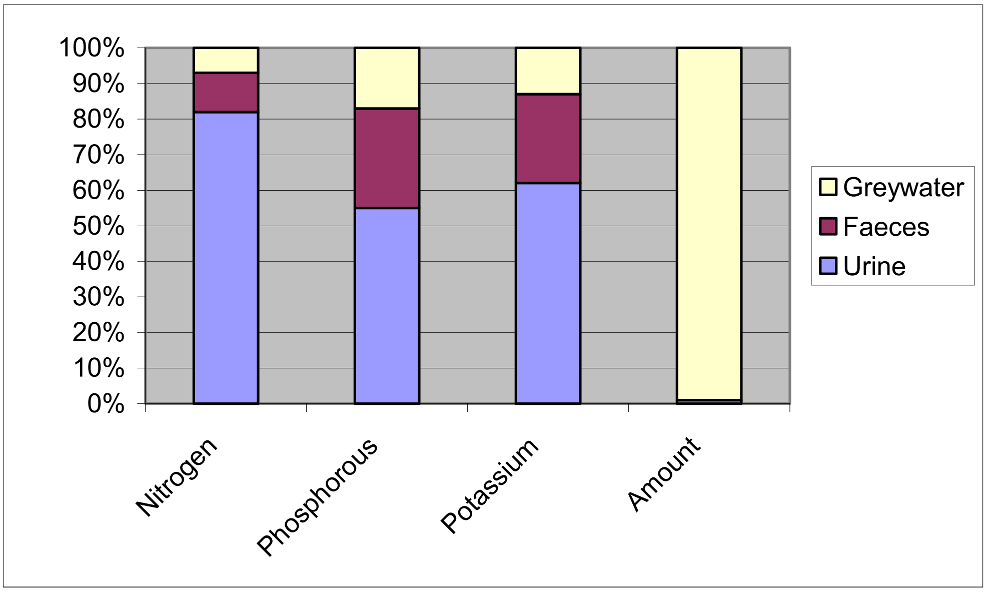

Fig. 4.1 Percentage content of nutrients in domestic wastewater and amounts of wastewater fractions produced (JÖNSSON et al., 1999).

4.3.1 Content of nutrients in urine

diversion of human urine: the collection of urine separately from other wastewater fractions

The Swedish University of Agricultural Sciences has undertaken a considerable amount of research on the diversion of human urine, i.e., the collection of urine separately from other wastewater fractions. The composition of urine collected from 3 apartment blocks has been analysed for nutrient composition (JÖNSSON et al., 1999). These are: Understenshöjden (44 apartments), Palsternackan (51 apartments) and Hushagen (8 apartments).

Sampling was carried out over a period of 28 days at Understenshöjden, 29 days at Palsternackan, and 42 days at Hushagen. Detailed descriptions of the sampling procedures for Understenshöjden and Palsternackan are available in JÖNSSON et al. (1998), and for Hushagen in VINNERÅS (1998).

The composition of diverted urine has been investigated at ”Miljöhuset” a block of 30 apartments in Hallsberg, Sweden (LINDGREN, 1999). VINNERÅS (2002) describes two studies of urine diversion at Ekoporten (an apartment block with 35 inhabitants in the town of Norrköping) and Gerbers (a residential area with 32 apartments and 81 inhabitants in the town of Skarpnäck near Stockholm. Sampling was carried out over a total of 35 days at Ekoporten and 21 days at Gerbers.

The results from these six studies are summarised in Tab. 4.1. In addition, the Swedish norm values for N, P and K in human urine, as given by the Swedish Environmental Protection Agency, are presented (NATURVÅRDSVERKET, 1995).

Tab. 4.1 Summary of nutrient contents in diverted urine from Swedish apartment blocks compared with norm values (g per person per day)

	N [g/p/d]	P [g/p/d]	K [g/p/d]
Location			
Understenshöjden	4.9	0.4	1.3
Palsternacken	4.2	0.3	1.1
Hushagen	5.3	0.3	1.1
Hallsberg	3.4	0.3	0.8
Ekoporten	10.1	0.9	3.3
Gerbers	10.5	0.7	2.2
Mean	6.4	0.5	1.6
Swedish norm value	11.0	1.0	2.5

The results from Ekoporten and Gerbers are significantly higher than the other results because they have been corrected for urine which has been lost, i.e., has contaminated the faecal fraction in the urine diverting toilet.

The data for Ekoporten and Gerbers has also been corrected for a daily presence of the residents in their apartments of 24 hours. At the other locations the data were corrected for a daily presence of 15 hours. The norm values also assume a daily presence of 24 hours.

In Denmark, measurements of nutrient composition in diverted urine have been taken in 4 projects (WRISBERG et al., 2001) at the following locations: Hjortshøj (8 households), Hyldespjældet (9 apartments), Kolonihaverne (toilets associated with 10 allotment gardens), and Møns museum farm (4 public toilets and 1 personnel toilet).

Tab. 4.2 shows the nutrient content in urine from the 4 locations. The ratio between the N, P, K contents are approximately 18:1:4, which corresponds reasonably well to the nutrient requirements of plants (WRISBERG et al., 2001). The relative concentration of P is somewhat lower than that found in Swedish studies where the typical N: P: K ratio is 10-13:1:3-4.

Tab. 4.2 Nutrient contents in diverted urine measured at four different locations.

Nutrient	unit	Hjortshøj	Hyldespjældet	Kolonihaverne	Møns museum farm
Total N	mg/l	2000	2000	5400	1900
Total P	mg/l	130	100	360	90
Total K	mg/l	800	420	1100	680

The N, P, K concentrations at Kolonihaverne are higher than the other locations because of lower dilution by flush water. In Tab. 4.3 the Swedish results from Table 1 have been converted to mg/l so that they may be compared with the Danish results. There is considerable variation between results, but it is clear that the Swedish norm values are much higher than the data collected from the different locations. This is because the norm values give the concentrations in undiluted urine, whilst the urine analysed at the different experimental locations contained varying amounts of flush water.

Tab. 4.3 Summary of results for nutrient concentrations in diverted urine (mg/l).

Location	**N**	**P**	**K**
	mg/l	mg/l	mg/l
Understenshöjden	3 631	313	1 000
Palsternacken	3 310	308	888
Hushagen	2 350	143	477
Hallsberg	2 800	223	683
Ekoporten	6 650	590	2 170
Gerbers	5 915	388	1 270
Hjortsøj	2 000	130	800
Hyldespjældet	2 000	100	420
Kolonihaverne	5 400	360	1 100
Møns Museum farm	1 900	90	680
Mean	3 755	276	979
Swedish norm value	11 000	1 000	2 500

4.3.2 Nutrient content in blackwater and faeces

A number of studies have been made of the composition of blackwater[1]. At the Agricultural University of Norway, measurements have been made over several years of blackwater from an apartment block where blackwater and greywater[2] are treated separately (LARSEN, 2000). This apartment block at Kaja, adjacent to the Agricultural University, has 48 student residents. SKJELHAUGEN and SÆTHER (1999) have investigated the composition of blackwater in a detached residence at Ringebu in Norway. In Lund,

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[1] blackwater: toilet waste water

[2] greywater: from baths, washing machines, showers and sinks

Sweden, Blom (2001) studied the composition of blackwater collected from toilets in a holiday park. Tab. 4.4 presents mean data for the studies at these 3 locations.

Tab. 4.4 Chemical analyses of blackwater (g/kg dry matter).

Location	N-total	NH_4-N	P-total	K-total	Organic material
Kaja	217	--	23	40	421
Ringebu	150	134	29	41	670
Lund	141	114	22	43	783

Nitrogen was highest in the blackwater from Kaja, presumably because of the low use of flush water in the vacuum toilets used at this site (low-flush toilets were used at the other sites). There is little variation in the P and K results but large variation in the amount of organic material collected.

composition of faeces

VINNERÅS (2002) analysed the composition of faeces from Ekoporten and Gerbers (see Tab. 4.5). The large differences in wet matter can be explained by the fact that the faeces at Gerbers were collected without flush water.

Tab. 4.5 Concentrations of nutrients in faeces compared with Swedish norm values.

Parameter	**Ekoporten**	**Gerbers**	**Swedish norm value**	**Suggested norm value**
Wet matter, kg/p/year	18 700	72	36.5	51
Dry matter, kg/p/year	12.6	10	12.8	11
N, g/kg dry matter	50.0	71	43.0	50.0
P, g/kg dry matter	10.0	25	14.3	16.6
K, g/kg dry matter	42.9	28	28.5	33.2

VINNERÅS (2002) has suggested new norm values since the existing norms (NATURVÅRDSVERKET, 1995) underestimate the amount of water in faeces. It should also be noted that the Results in Tab. 4.4 and Tab. 4.5 show that blackwater contains more N than faeces (due to the inclusion of the urine fraction).

4.3.3 Nutrient content in organic household waste

The Agricultural University of Norway has undertaken a study of the composition of source separated food waste from 8 restaurants in Etnedal, Norway (SÆTHER, 1996). The nutrient concentrations analysed are presented in Tab. 4.6.

Tab. 4.6 Chemical analyses of food waste from 8 restaurants in Etnedal.

Parameter	**g/kg Dry matter**
Dry matter (%)	28.8
Organic matter	926
pH (pH)	4
Kjeldahl-N	42
Ammonium-N	2.5
P	5
K	9
Mg	1
Ca	17

In Sweden, EKLIND et al. (1997) analysed 12 tonnes of source separated organic household waste from Uppsala municipality. The mean results of 92 representative samples taken from these 12 tonnes of material are presented in Tab. 4.7. The results are compared with data from a literature study carried out by EKLIND et al. (1997) on the composition of organic household waste.

Tab. 4.7 Nutrient contents in source separated organic household waste (after EKLIND et al., 1997). Referanser: 1. EKLIND et al. (1997). 2. WIDÉN (1993) (Uppsala). 3. SNV (1993) (Borlänge). 4. SNV (1993) (Borås). 5. SNV (1993) (Södertörn). 6. LUNDKVIST (1997) (Skultuna). 7. T. JARLSVIK (Styrsö).

Parameter g/kg TS	**Reference no.**							
	1	2	3	4	5	6	7	**Mean**
pH	4.9	5.1	5.0	5.1	5.8	4.5	--	5.1
TS (%)	34.2	40.6	32.5	28.5	36.0	29.8	32	33.4
VS(%TS)	25.2	36.6	32.5	22.0	30.5	13	20	25.7
C	368	249	370	425	385	470	398	380
C/N	16.9	12	18	19	16	20	17	17.0
N	21.7	21.1	21	22	24	23.5	23.4	22.4
P	4.1	4,6	3.1	3.0	3.3	5.4	3.6	3.9
K	8.0	11.3	8.5	8.7	7.5	9.2	--	8.9
Ca	24.3	30.1	20.8	22.3	25.5	20.5	--	23.9
Mg	2.2	4.0	2.2	1.9	2.5	1.6	--	2.4

Note: TS refers to dry matter content, i.e., Total Solids.
VS refers to Volatile Solids.

There is good agreement between the results for the Swedish studies, even though they have been carried out at different locations. The difference between the results from Etnedal and Sweden can be explained by the organic household waste in the Swedish studies containing more nutrient poor materials (e.g., spent (potting compost, bones and vegetable peelings) than the food waste.

Comparing the nutrient compositions for organic household waste with those for blackwater in Tab. 4.4, it is clear that organic household waste contains less N, P and K. The mean amount of organic material in household waste, as determined from the VS content in Tab. 4.7, is around 740 g/kg dry matter. This is about the same level as that in blackwater, but more studies of the composition of blackwater would be required to confirm this.

4.4 The toilet system options

4.4.1 Compost toilets

Compost toilets are traditionally used in rural environments, both in developing and industrialized countries. In developing countries they often serve as the basic toilet facility for year-round residential homes, and, to a lesser extent, as a public facility. In industrialized countries, they are typically associated with seasonal vacation homes. In the former case, compost toilets tend to be home-built or prefabricated assemblages from local material; in the latter case, they are generally manufactured units, which may (or may not) be required to meet regulatory standards.

The use of compost toilets in urban areas is debatable. Generally speaking, compost toilets are not popular for a variety of reasons, e.g.: the end product is rarely if ever used directly by the urban dweller; transport of the compost material to agricultural areas is often impractical; and, municipal authorities often do not permit waterless toilets for concerns of public health (NADKARNI 2003). Nevertheless, they do exist in urban settings. Compost toilets were used in Germany's first ecological settlement (established in 1986 in Hamburg-Allermohe) to demonstrate alternative, decentralized wastewater treatment solutions. Other composting toilet systems followed in Kiel, Berlin, Bielefeld, and Hamburg-Braamfeld, totaling about 500, with some designed for four-story housing (BERGER 2003). We also see recent substantial increase of compost toilets in developing countries. In Dar-es-Salaam City, Tanzania, for example, 110 compost toilets were installed in 2002-2003 (MASHAURI et al. 2003). But we should keep these facts in perspective. Although urban compost toilets exist, their use and acceptance is more limited than in rural areas. An explanation is in order.

Compost toilets were used in Germany's first ecological settlement to demonstrate alternative, decentralized wastewater treatment solutions

Although urban compost toilets exist, their use and acceptance is more limited than in rural areas

Compost toilets offer marked advantages over conventional flush toilets, the two most notably being (1) they are waterless, which reduces the expense of plumbing fixtures as well as water-supply and disposal costs, and (2) nutrients can be recycled rather than wasted, or worse yet, pollute surface waters. However, there are disadvantages:

- One must accept the fact that at some time the composted waste must be handled.
- There are inherent health risks with collecting and storing human excrement.

- Space is required for processing the waste, which, in addition to installing ventilation shafts, may require structural changes to the home.
- There are potential nuisances such as odours, flies and cleaning the toilet.
- Building codes can restrict if not prohibit the use compost toilets.
- Users must modify their lifestyles.

voluntary acceptance of a compost toilet demands voluntary acceptance of all of the above

As a result, voluntary acceptance of a compost toilet demands voluntary acceptance of all of the above. Equally important for urban dwellers, the public in general – and neighbours in specific – will be affected by the motivations of private individuals to use compost toilets.

4.4.1.1 Motivations for Using Compost Toilets

The motivations for adopting a compost toilet need careful consideration. To begin with, one must realize that motivations vary considerably, both in industrialized and developing countries. Motivations include better hygiene, financial gain, improved soil conditions, and increased comfort and status (FRANCEYS et al. 1992). In some cases, especially in developing countries, the motivation is none of the above. That is, the decision to install a compost toilet is made by default rather than intent, e.g., there are no other alternatives due to environmental constraints. Generally speaking, however, a compost toilet is adopted after deliberate comparison with alternative systems. Sometimes the motivation is merely a straightforward choice between a compost toilet and, say, a pit privy. In other cases, predilection stems from a complex comparison between alternative toilet systems (e.g., compost, dehydration, vacuum, urine-separating, etc.). In urban settings, the decision-making process becomes more complex, because the issues of installation, maintenance, waste reuse, and regulation are more complex.

The prospective role of composting toilet systems in urban settings is uncertain. When one balances the basic benefits of a compost toilet with its inherent disadvantages, one can understand why composting systems are more suited to sparsely populated, agrarian sites where water is limited than to densely populated urban settings where water is readily available. Nevertheless, one cannot overlook the potential of adapting composting toilet principles to urban environments.

4.4.1.2 Public Compost Toilets

One promising application is public toilets. Public (rather than private) toilets hold promise for two fundamental, related reasons: (1) the processes of composting excreta favour large volumes of material over small, and (2) sustaining the processes requires structured management. Let's examine these points in greater detail.

the processes of composting excreta favour large volumes of material over small

sustaining the processes requires structured management

Composting is a biological process. In contrast to dehydration toilets, which are based on physical processes, composting systems make the nutrient-rich excreta plant available. Essentially the process aerobically decomposes the matter into a safe soil conditioner. Pathogens are destroyed various ways, but generally speaking, composting relies upon high temperatures (> 45°C) to sanitize the waste (Fig. 4.2).

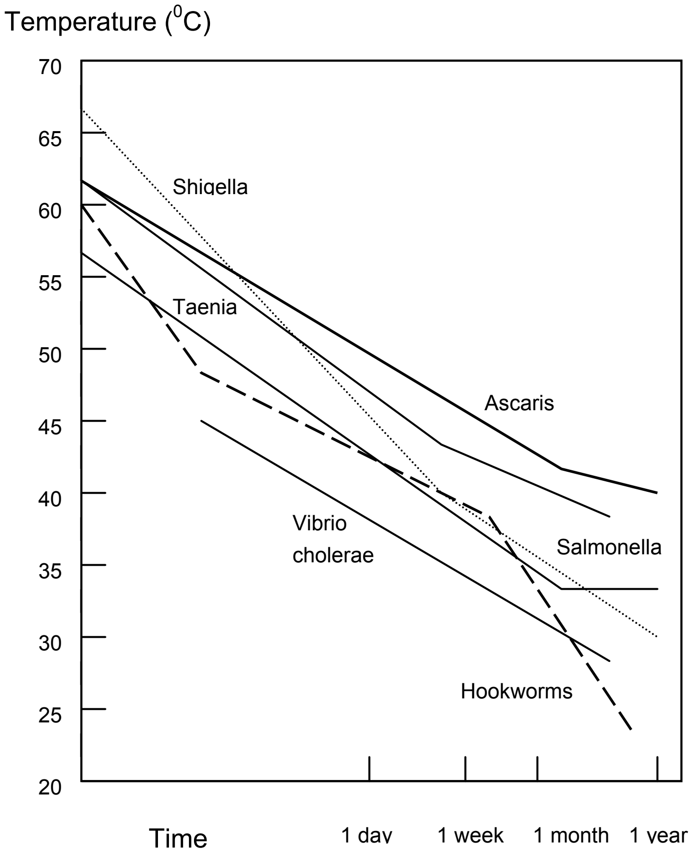


Fig. 4.2 Influence of time and temperature on the destruction of selected pathogens in excreta (FEACHEM et al., 1983).

Admittedly, merely containing excreta long enough, say two years, will produce a safe product. But the efficiency of composting depends upon (1) the volume of mass, and (2) managing environmental factors, including: aeration, moisture, temperature, the carbon to nitrogen ratio, and a large numbers of diverse organisms (such as bacteria to decompose faeces, fungi to decompose paper, and, to a lesser degree, arthropods and worms to help aerate). In essence, composting toilets require more maintenance than dehydration toilets. And composting large volumes of excreta requires managed operating procedures.

Volume is a basic concern to compost toilets, both from the standpoint of performance and capacity. Whether the system is manufactured or self-built, a self-contained single toilet or a multi-chamber unit, active (fitted with mixers) or passive (no mixing)… volume issues exist. Consider a self-contained continuous toilet system that has reached capacity over, say, six months. The material at the bottom might be stabilized and safe, the material in the middle stabilized but not safe, and the material at the top neither stabilized nor safe. Thus, how does one determine the efficiency of the system, much less compare it with a different system handling the same volume over the same time? Manufactures use different formula to estimate capacity (volume), with some based on daily capacity (persons/ 24 hours), others seasonal (persons/30-60 days/year), and still others annual (persons/year). But the straightforward numbers are often misleading. Take, for example, a public compost toilet designed for 3000 persons annually. What if 2000 people use it over two-months? Thus, the speed of composting is predicated, in part, on volume over time.

Properly managed, high quality compost will yield balanced nutrition

Equally important, management determines compost efficiency. In addition to the environmental factors above, managing the material's composition and structure is vital. Since excreta is low in carbon (a necessary element for all life forms), carbon additives (e.g. kitchen waste, bark, or chips) are recommended. If the nitrogen-rich urine is diverted, less carbon is needed. Nevertheless, additives, sometimes called bulking agents, are required to absorb excess moisture and help aerate the mass. Properly managed, high quality compost will yield balanced nutrition (C:N ratio of 20-30:1), adequate humidity (40-50%), ample oxygen supply, and sustain high temperatures (50-60°C) long enough to destroy pathogens (DEL PORTO and STEINFELD 1999). Of course, proper management takes time and a concerted effort, both based upon a basic understanding of composting processes.

Primarily because of volume and management issues, composting human waste appears suitable for public toilets. Scaling up composting toilets from many, small residential systems to a few, large public facilities is not only logical, it's practical. The intrinsic advantages of public compost toilets are three-fold.

First, public facilities reduce per capita installation costs compared with private toilets. And by being waterless, they afford the possibility of pre-fabricated units assembled on-site at minimal expense, both in time and money. In fact, by eliminating piped water, the public toilets could be portable, and thus serve multiple purposes, e.g. toilet provision for commuters, shoppers, residents, ad hoc public events, and emergency relief for victims of natural disaster.

developing countries

In some cases, strategically located public compost toilets might not only supplement but also supplant residential facilities

Second, since most urban areas, especially in developing countries, lack proper toilet provisions (KIRA 1995), the addition of auxiliary pubic facilities reduces the use of private toilets linked to centralized wastewater treatment. In some cases, strategically located public compost toilets might not only supplement but also supplant residential facilities. And, as demonstrated in a Banaglore, India slum project, public compost toilets can provide primary sanitation for those who have no toilet facilities at all.

Third, public compost toilets imply system management. Toilet maintenance and recycling excreta would be neither ad hoc nor voluntary. Operations would be monitored, structured, continuous and regulated. Of course, operation management would require trained (and supervised) personnel, but the benefits would be far-reaching: improved sanitation, comfort, and convenience for many; fertilizer would be available for periurban agriculture; water consumption would be reduced; and organic waste (e.g. food waste from restaurants) would be recycled. Since the volume of human waste in urban areas far exceeds any method of depleting it, composting appears a sustainable way of exploiting this rich natural resource.

4.4.1.3 Regulatory Barriers

These positive points must be balanced with the negative, not the least of which being public acceptance, especially by health regulators. While composting toilets are used as public facilities in North America, Asia, Australia and Africa, they are not common in Europe. Even in Germany – which has several well-established urban communities with compost toilets –only 50 public toilet projects exist, and these are limited primarily to rural recreation areas (BERGER 2003). One of the reasons for this is that public building and health codes are more rigid than those for private households. For example, the authorities of Rostock, Germany issued a limited (7-year) approval permit for a proposed public compost toilet project, pending review of bacterial results (for their hygiene standards) (BERGER 2003). Another example is in Israel, where ECONET (ENVIRONMENTAL TECHNOLOGIES AND PROJECTS LTD.) had to file 25 permits to install six Clivus Mulstrum compost toilets in a single project: it took six years to obtain the first seven permits alone (PRUGININ 2003).

In the USA, onsite wastewater treatment systems, including compost toilets, are regulated by each State. Permits for compost toilets are usually issued by the local health authority, which tends to be either a municipal or county agency. Having said that, there are two regulatory concerns that advocates of compost toilets should be aware of (WARNBERG 2003):

- In most States, permits are given only for commercially manufactured compost toilets that have been certified by the National Sanitation Foundation (NSF); and there are no certified compost toilets on the market for less than $2000 US.
- Applying compost from a toilet to the landscape around a residence is not well defined under current Federal guidelines; however, there is a US Environmental Protection Agency restriction that defines organic product from a compost toilet as material that must be treated in an approved sewage treatment facility.

Admittedly, not all regulatory authorities are as demanding as the examples above. We can only assume that some urban areas are less restrictive; likewise, some are more restrictive. In fact, it is difficult if not impossible to generalize the extent to which regulatory authorities control the use of compost toilets in public facilities.

It should not come as a surprise that public authorities are suspect of compost toilets. Despite the tragic flaws of conventional wastewater treatment systems, they are designed for safety first. Excessive use of water and loss of nutrients are secondary concerns – if concerns at all. The driving ambition of those promoting compost toilets, generally speaking, is closing the loop. Of course, safety is a concern, but it appears to be less of a concern to those designing (and manufacturing) composting toilet systems than it is to regulatory authorities. Proponents of compost toilets often refer to operation guidelines, which are merely recommendations; health authorities mandate standards, which are enforceable laws.

Looking towards the future, the prospective role of compost toilets in urban areas offers promise, albeit with cautious optimism. As long as society promulgates laws to protect public health, and regulatory authorities are empowered to enforce these laws, advocates of compost toilets must harness their unbridled enthusiasm with scientific evidence that such systems do not jeopardize public health. Saving water and recycling nutrients are noble concepts and practical concerns, but the public won’t close the loop until they feel safe.

4.4.2 Urine separating toilets

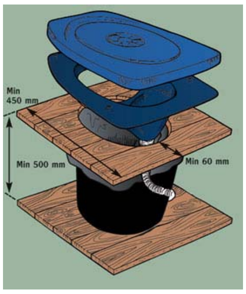
Urine is the most nutrient rich wastewater fraction

Urine is the most nutrient rich wastewater fraction (section 4.3). At the time when faecal matter was collected in buckets from households in many European cities, urine was often collected separately and poured into the drain to avoid smells and to prevent the latrine filling too quickly. But it was also known at least in the latter part of the 18th century that ”the proportion of value of the fertilizing components in urine to that contained in faeces is as six to one”.

Among the european countries Sweden has been pioneering the development of urine separating toilets as well as the use of urine in agriculture (JØNSSON et al. 1999). The revival of the urine separating idea started in the beginning of the 1970s, where urine-separating inserts were mounted in dry-toilets. In the beginning of the 1990´s several porcelain urine separating toilets were available on the Swedish market. Urine separating toilets differ from the normal flush toilet in that there is a division in the toilet bowl so that the urine is diverted from the faecal matter (Fig. 4.3). Urine separating toilets are available both in floor and wall mounted versions.


(a)


(b)



(c)


(d)

Fig. 4.3 The urine separation system is based on toilets where the bowl is divides into two parts, a front one collecting urine and a rear one collecting fecal material. Urine-separating toilets originating from Sweden. (a and b) two different double flush models; (c) urine separating insert to a bucket toilet, (d) and a single flush urine-separating toilet.

4.4.2.1 Single/dual flush urine separating toilets

Urine separating toilets come in two major types; single flush and double flush (Fig. 4.3). The single flush toilets only use water to flush the urine compartment and have a dry collection of the faecal matter. The flush volume is 0.1 – 0.2 liters per use. The dual flush toilets have a two button flush system and flush with 2 liters for urine and else 4 liters. Only a fraction of the flush water, 0.2 - 0.4 liters drains through the urine section. The total nominal collection volume per person per day and year is shown in Tab. 4.8.

Tab. 4.8 Volume of urine and flushwater per person per day and per year.

	Flushwater (l/d)	Urine (l/d)	Total (l/d)	Total (l/y)
Single flush	0,4 - 0,8	1,3	1,7 - 2,1	620 - 767
Dual flush	0,8 - 1,6	1,3	2,1 - 2,9	767 - 1060

It is assumed an average urine production of 1,3 liters per person per day (HELLSTRØM and KÄRRMAN 1996) and four flushes per day and 4 visits per day. The average nominal daily production is in the range 1,7 – 2,9 liters per person and day. The average actual daily collection volume depends upon the number of hours people are present; e.g. in a home people are normally leaving for school, work etc. In Sweden it is recommended to size the urine storage tank based on a collection volume of 1,5 – 2,5 liters per day.

Single flush urine separating toilets

The single flush toilet generates smaller waste volumes than dual flush urine separating toilets

The single flush toilet generates smaller waste volumes than dual flush urine separating toilets (Tab. 4.8). The fecal matter is collected in a bucket or container directly below the toilet (Fig. 4.4). Because of the need for a straight chute from the toilet to the collection container for fecal matter single flush urine separating toilets are not easily adapted to multistory buildings. Maintenance of the toilet is facilitated if there is access to the fecal collection chamber from the outside of the building. This eliminates handling of fecal matter inside the building and opens for professional collection and emptying of the toilet, thus reducing the overall risk of handling fecal matter.

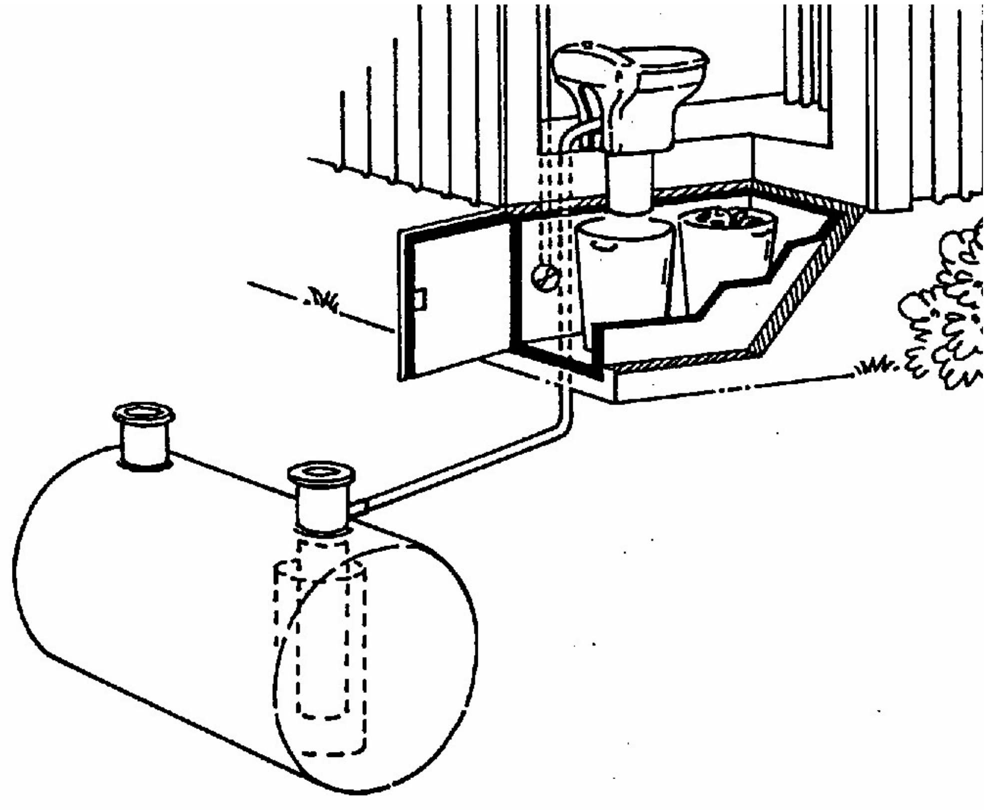


Fig. 4.4 Single flush urine separating toilet with direct access to the fecal collection chamber from the outside of the building (from Wost Man Ecology AB).

As with composting toilets the ventilation of the toilet room using a single flush urine separating toilet is important to avoid smell. The used air should pass down through the fecal collection chute. This can be obtained with a fan that generates a slightly lower pressure in the fecal collection chamber as compared to the ambient air pressure. The exhaust air from the fecal collection chamber should be expelled above the roof of the house.

Alternatively a small organic filter (soil/peat) can be used to filter the air (Fig. 4.5). This eliminates the need for a ventilation chimney above the roof.

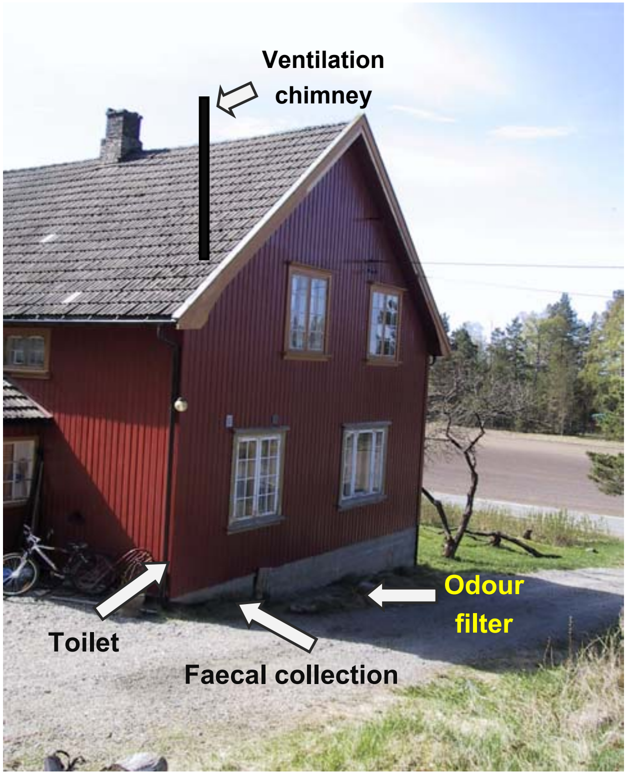


Fig. 4.5 Alternative venting of the faecal collection chamber; a ventilation chimney or an odour filter adjacent to the basement wall. This house actually has an odour filter.

It is worth to note that the odour from the fecal collection chamber of a urine separating toilet has very little odour compared to a composting toilet where both urine and fecal matter is collected.

The collected fecal matter of a single flush urine separating toilet is dry and will become drier if the collection chamber is properly ventilated. Composting and stabilization of the fecal matter does therefore not take place in the collection chamber. A proper stabilization and hygienization of the collected fecal matter is dependent upon proper composting after collection.

Dual flush urine separating toilets

Dual flush urine separating toilets look and function very much like an ordinary flush toilet (Fig. 4.6). Dual flush urine separating toilets are easily used in multistory apartment or office buildings buildings, thus they are well suited in an urban environment.

Dual flush urine separating toilets are easily used in multistory apartment or office buildings buildings, thus they are well suited in an urban environment

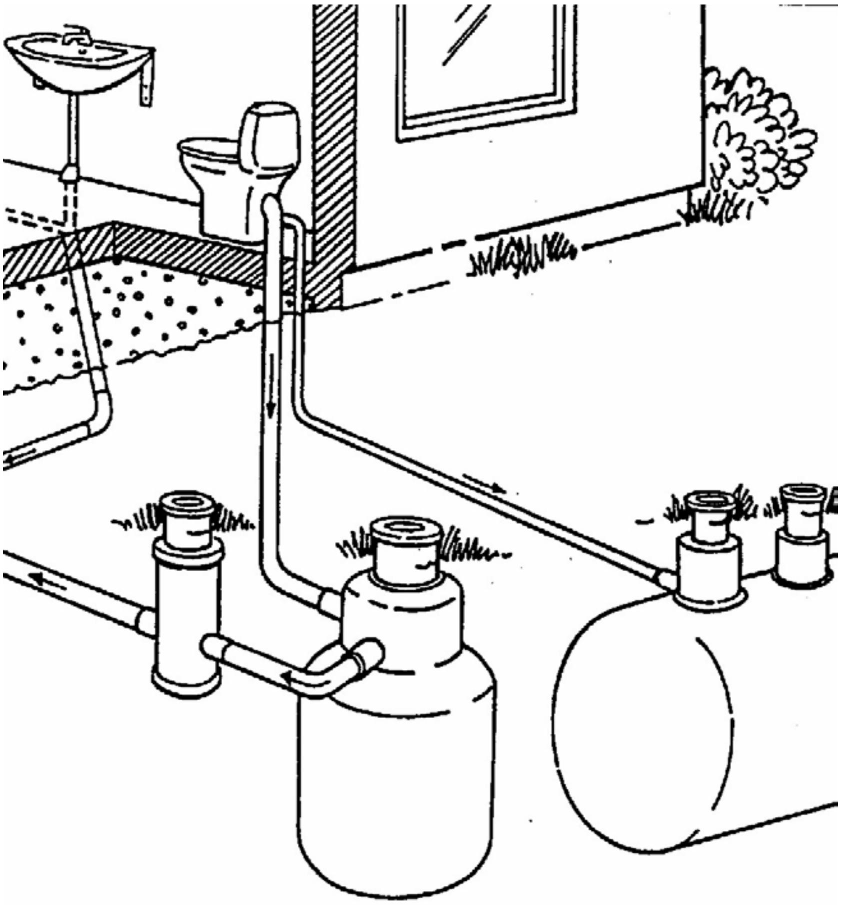


Fig. 4.6 Dual flush urine separating toilet (from Wost Man Ecology AB).

In Sweden dual flush urine separating toilets are used in Understenshöjden consisting of 44 two storey condominiums and Palsternackan consisting of 51 apartments in one building. At Understenshöjden the houses were constructed using urine separating toilets. The building Palsternackan was renovated in 1995 and dual flush urine separating toilets were installed as high priority was given to improving the environmental aspects of the building. One interesting feature with the dual flush toilets is that they are easily retrofitted to existing buildings. All that is needed is to fit an extra urine collection pipe and a urine collection tank.

4.4.2.2 Experience with urine separating toilets

Urine separating toilets are different from the traditional toilets and some adjustments of personal routines may be necessary. For instance, the amount of urine diverted nutrients recovered is dependent on the motivation of the users. Investigations referred to in VINNERÅS (2002) show that 55 – 90% of the urine diverted nutrients have been recovered. In addition to motivation higher recovery is found with the newer toilet types showing a potential for technical improvement. One of the main problems with the urine diverting toilets has been clogging of the urine pipe. The clogging mainly occurs in the first part of the small diameter pipe leaving the urine collection point in the toilet. The clogging may be due to hair and particles, but also to urine precipitation as urine stone or struvite. The difficulty in cleaning the urine pipe depends on toilet model. In some toilets the pipe is easily detached and cleaned in other models cleaning has to be done with the pipe fixed to the toilet. Particles or fibers are removed mechanically. To remove urine stone caustic soda is recommended.

4.4.3 Extremely low flush gravity and vacuum toilets

The toilet waste or blackwater (urine and fecal matter) contains the majority of the nutrients in wastewater (section 4.3). A century ago toilet waste was still collected in major European cities and used as fertilizer in near urban agriculture (TORSTENSON 1994). The toilet waste was often mixed with lime prior to agricultural application. In China the blackwater and fecal matter, ”night soil”, has been an important source of fertilizer up until our days (ETNIER and JENSSEN 1997). Ordinary flush toilets use much water and the blackwater becomes dilute and not economical to collect and treat separately. Modern toilet technology, vacuum and gravity, have flush volumes down to about 1 liter. With these toilets collection and separate treatment of blackwater is again made feasible.

4.4.3.1 Blackwater volumes

Assuming an average of 1,3 liter of urine per person and day and about 0,2 l of fecal matter the total net blackwater volume becomes approximately 1,5 liters per person and day or 550 liter per year. The dry matter (DM) content in blackwater is appoximately 9%. When blackwater is diluted with water the DM content rapidly decreases (Fig. 4.7)

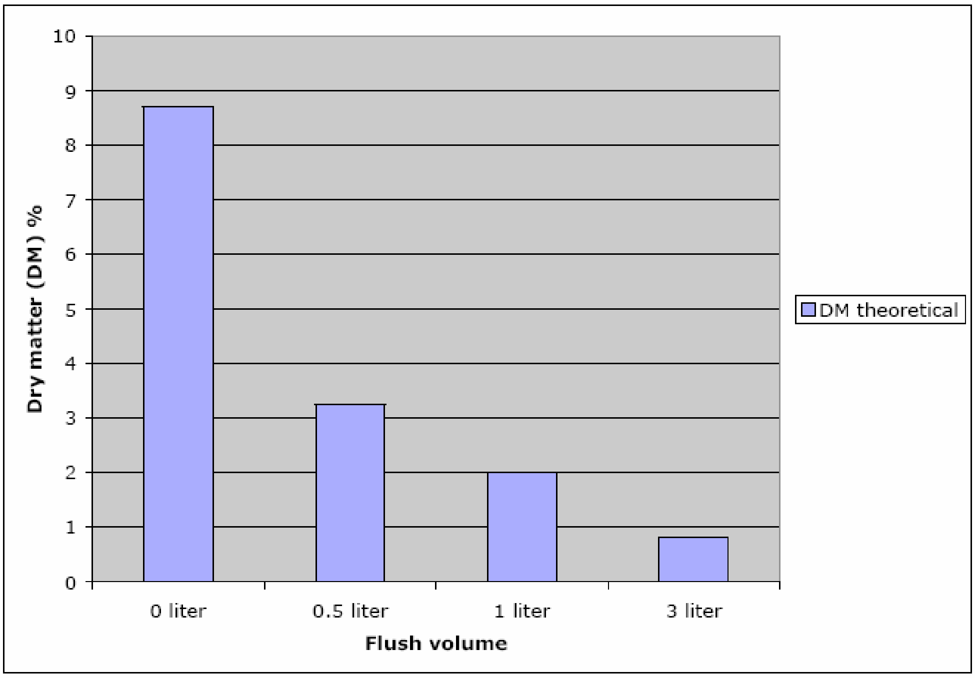


Fig. 4.7 Theoretical dry matter (DM) content in blackwater as a function of toilet flush volume.

In practice the dry matter content is lower than the theoretical because many users flush more than once after defecation. The measured DM content using 1 liter vacuum toilets in student dormitories in Norway is 0.8% at whereas the theoretical is 2%. A DM content of about 1% is the lower limit for treating the blackwater by liquid composting (JENSSEN and SKJELHAUGEN 1994).

The collection volume will depend on the flush volume (Fig. 4.8). As for the urine the collection volume will depend on the number of hours people are present in the actual building. Experience shows that toilets based on vacuum and gravity that use only 0.5-1.5 litres per flush these toilets produce 5-7 litres of blackwater per person per day (not compensated for presence), whereas conventional toilets normally produce 6-15 times more blackwater (JENSSEN et al. 2003). This means that an average family may will produce 6-9 m^3 blackwater per year, and 15 families may produce about 10 m^3 blackwater per month. Such volumes can be handled and treated locally.

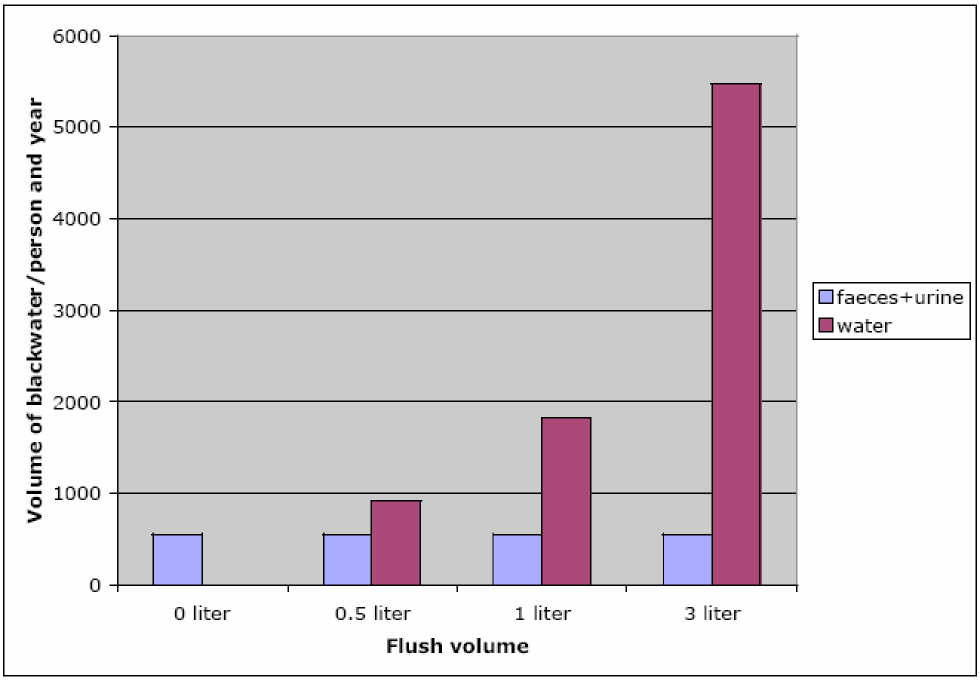


Fig. 4.8 Net volume of faeces and urine per person and year and additional flush water dependent on the flush volume and assuming 5 flush/person and day.

4.4.3.2 Extremely low flush gravity toilets

The reason why ordinary gravity toilets cannot flush with a lower volume than 2 – 4 liters is the need to be able to flush the fecal matter over the water lock in the toilet. In order to use less water the normal water lock mechanism cannot be used. There are several extremely low flush gravity toilets on the market today that all use around 1 liter or less per flush. As far as the authors know only one model is comparable to a normal flush toilet in terms of design and reliability. Extremely low flush toilets have a mechanism or valve that opens when the toilet is flushed (Fig. 4.9) Because of the low flush volume the horizontal transport distance for 1 liter gravity toilets is limited and give little flexibilty is these toilets are to be retrofitted to older buildings.

Fig. 4.9 The Miniflush toilet from GUSTAVSBERG has a spring loaded valve mechanism that opens when flushing

4.4.3.3 Vacuum toilet systems

Vacuum systems combine both the low flush volume and flexibility regarding transport

By using a vacuum toilet system the limitations of horizontal transport distance is overcome. Vacuum systems combine both the low flush volume and flexibility regarding transport. Vacuum toilets systems were originally developed by the Swedish engineer Joel Liljendahl around 1960 as an alternative to gravity transportation in buildings. The system was well suited for the maritime market and today vacuum systems are dominating offshore. The largest vacuum systems on cruise vessels have more than 1800 toilets and 2-3 km of vacuum piping. Vacuum toilets are a reliable option today. The price of a vacuum toilet is approaching the price of an ordinary flush toilet as the use of vacuum increases on-shore and the production series become larger.

Vacuum pipes are normally 50 or 63 mm. When rehabilitating or upgrading older buildings to a higher sanitary standard using a vacuum toilet system may be cheaper than a gravity system because of the flexibility of the vacuum piping and the lesser diameter piping.

Vacuum systems are dependent of a vacuum generation unit. In principle there are three different designs:

a. Vacuum collection tank with vacuum pump

b. Ejector with atmospheric collection tank

c. Vacuum generating and forwarding pumps (vacuumarator)

The vacuum collection tank with vacuum generator is the original design

The vacuum collection tank with vacuum generator is the original design. Because of the vacuum tank this system has a large vacuum reservoir and can operate a short while without power to the pump.

The vacuum generation by an ejector is produced by circulating sewage through an ejector

The vacuum generation by an ejector is produced by circulating sewage through an ejector. In order to avoid temperature rize in the recirculated sewage, relatively large volumes have to be pumped.

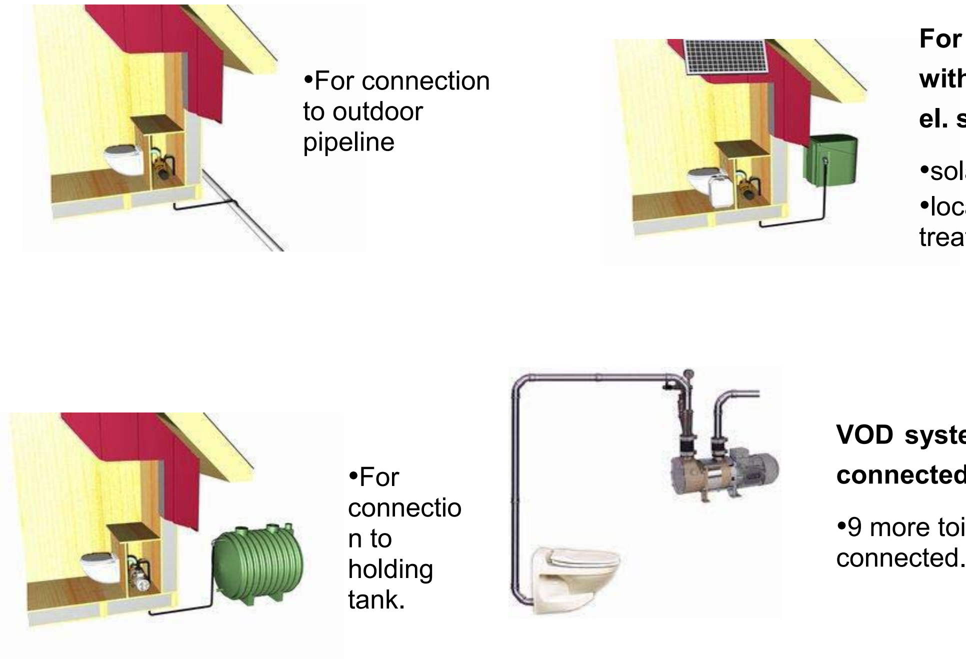
The vacuumarator is a unit which generates vacuum on the inlet side

The vacuumarator is a unit which generates vacuum on the inlet side which is connected to the vacuum piping and the toilet and discarges the wastewater under pressure in the other end. When the blackwater enters the arator it is mascerated, then it runs through the arator and is expelled on the pressure side. The arator is able to transport the blackwater to an atmospheric holding tank that is at a higher elevation than the arator.

On-shore the experience with vacuum systems is still limited. In Norway, 4 years experience from two housing developments, 48 and 120 persons respectively, have shown the viability of these systems in ordinary homes. There have been some technical problems, related to construction details in the vacuum transportation system for on-shore use in cold climate, but these have all been solved and have given valuable knowledge for implementation of new systems. In both housing developments all toilets are connected to one vacuum system under constant vacuum

The latest development is vacuum on demand (VOD)

The latest development is vacuum on demand (VOD), i.e., vacuum is generated only when flushing (Fig. 4.10). Small vacuum on demand systems using the technology mentioned under c. above, are now also available for buildings. Compared to VOD systems already known from train and airplanes, these new systems for buildings can operate with low vacuum, thus creating much lower noise during flushing than so far known from traditional vacuum toilets. These Softsound® toilets are also available with dual flushing buttons. Water consumption is adjustable individually for each of the buttons (i.e. from 1liter and down to 0,x l.).



- For connection to outdoor pipeline

For use in buildings with no water and/or el. supply:

- solar powered
- local sewage treatment,

- For connection to holding tank.

VOD system - with one toilet connected

- 9 more toilets can be connected.

Fig. 4.10 Vacuum on demand (VOD) system options (from Jets Standard AS).

VOD systems are available in a solar powered version and since the vacuum only is generated when needed the energy use is low; less than 10 kWh/person/year according to one manufacturer. The VOD is suitable for use in single houses or cabins, and for installations of up to 10-15 toilets connected to one vacuum generation unit. The VOD is very flexible and more robust than earlier vacuum systems. The robustness is due to the flexibility and ease of serviceability of the smaller units and increased tolerance of air leaks.

4.5 Logistics of sustainable systems in urban areas

It is unlikely that one single system can solve all future sewerage problems in our cities. Large investments have been made in conventional sewage systems which will be in operation for decades, but conventional systems will evolve as the principles sustainability and ecological engineering are communicated to engineers. Totally new systems as well as hybrid or combination systems will appear. A variety of systems are needed to meet the natural constraints of different regions, differing legislation, different sociological aspects, different budgets, personal needs, and preferences. Below are some key issues regarding the infrastructure of different systems

It is unlikely that one single system can solve all future sewerage problems in our cities discussed. The main focus is given to systems with decentralised collection and treatment (section 4.4.1).

Blackwater contains the majority of the resources in domestic wastewater. Of the blackwater components, it is the urine that contributes the greatest amount of nutrients (Section 4.3.1). The system mentioned in section 4.5.2.2, is a recycling system, but not based on source separation. Systems with source separation require the use of toilets that use little or no water. These systems open a variety of new possibilities for wastewater treatment that also may include treatment of organic waste.

4.5.1 Systems with decentralised collection and treatment

Source separation requires a change of sewage system infrastructure. The system logistics depends on toilet type (Fig. 4.11).

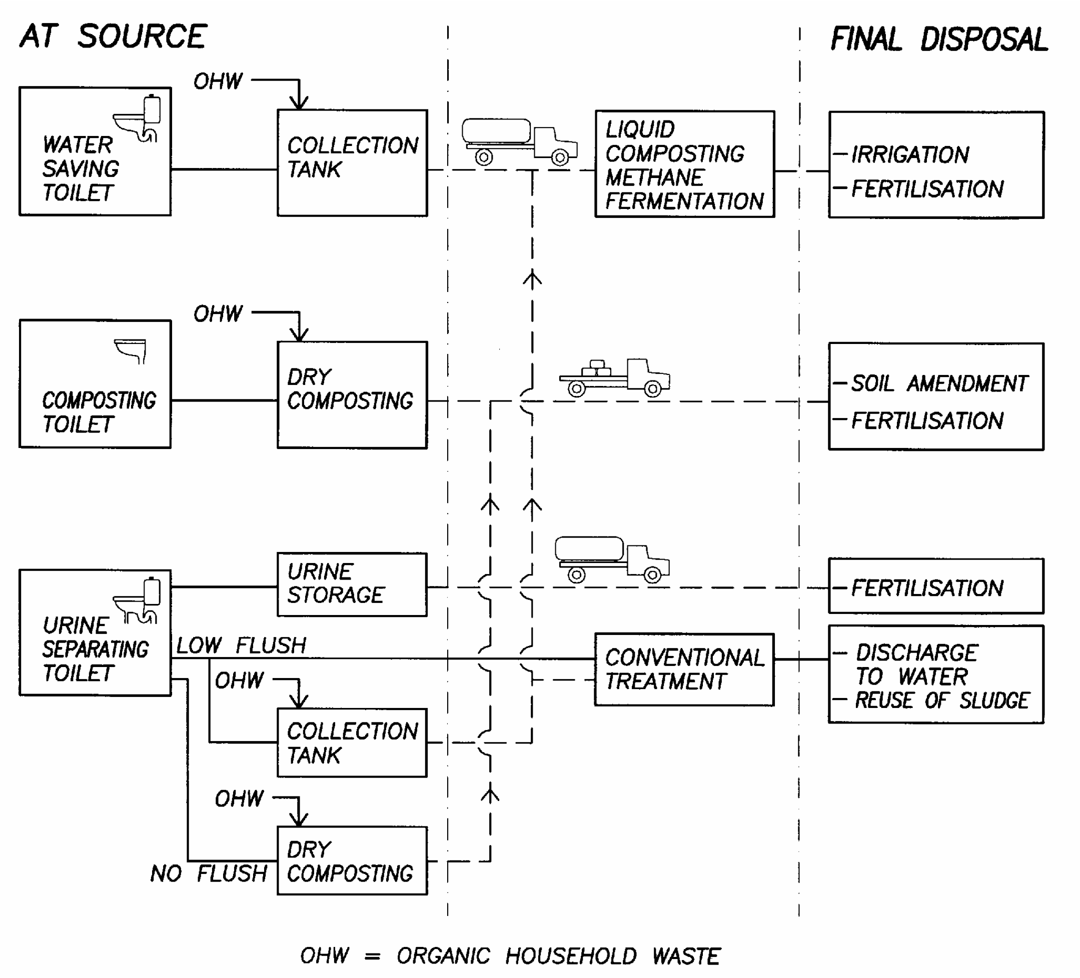


Fig. 4.11 Logistics of blackwater and organic waste handling dependent of toilet type. (Jenssen and Etnier 1997).

The use of a source separating system for wastewater treatment requires at least a dual plumbing system; one for blackwater and one for the greywater. If a urine separating toilet is used three handling lines may be needed one for urine, or yellowwater, one for the the faecal matter and one for the greywater. I Norway 110mm pipes are used for inhouse wastewater transport when using conventioanl systems. If a dual or triple system is used the diameter of the pipes can sometimes, but not always be reduced. If low flush gravity toilets are used normally 110mm pipes are used. For the faecal fraction of dual flush urine separating toilets normally 110mm pipes are used. The greywater pipes are normally from 50 – 75mm.

Fig. 4.11 shows that the blackwater, urine or composted faecal matter is collected and transported to agri- or silvicultural production. Transportation by truck is energy consuming and has to be taken into account in a sustainability analysis of a decentralized source separating wastewater treatment system in urban areas. One main question is how far it is feasible to truck the material. This is not an easy question to answer. The energy aspects of sewage treatment and fertilizer production are complex and a complete analysis is not available. One way to obtain data is to consider a truckload of blackwater, urine or compost toilet residue and look at the energy needed to produce an equivalent amount of mineral fertilizer. Then take this amount of energy and see how far the truck can run. JENSSEN and REFSGAARD (1997) have done this for different organic waste resources.

One way to obtain data is to consider a truckload of blackwater, urine or compost toilet residue and look at the energy needed to produce an equivalent amount of mineral fertilizer

Tab. 4.9 Transport distance for different organic fertilizers based on comparing energy content in an equivalent amount of mineral fertilizer to energy needed for transportation (from JENSSEN and REFSGAARD 1997).

Organic fertilizer resource	Transport distance (km)
Blackwater	25 - 30
Urine	40 - 50
Compost	500 - 1400

The table shows that it may be feasible to truck blackwater up to 30km, urine up to 50km and the compost material up to 1400km. 25 – 30 km is sufficient to reach agricultural areas from the center of many mid-size cities (100 000 – 500 000 inhabitants).

The reader should bear in mind that this calculation is based on several assumptions some of which have large inherent uncertainties. There are also many other aspects that need to be considered in a more complete system analysis.

The end product from the composting toilet is relatively dry and can tolerate a much longer transport distance

The large difference in transport distance is mainly due to how concentrated the material is. The blackwater is normally more dilute than in urine. The end product from the composting toilet is relatively dry and can tolerate a much longer transport distance before the energy used for transportation equals the energy used for production of an equivalent amount of mineral fertilizer. However, for composting toilets the transport distance is very much dependent upon how much nitrogen that is reclaimed in the compost.

4.5.1.1 Integrating organic household waste (OHW)

Adding organic household waste to a conventional sewer system is practiced in some areas in the United States. In other parts of the world this practice is limited. Adding the organic household waste to a conventional sewer system is not recommended in Norway (LINDHOLM et al. 2002). In the 2nd draft (EU) for Biological Treatment of Biowaste it is suggested to ban discharge of mascerated biowaste to sewer systems.

integrating the organic household waste

Adding OHW to a composting toilet will increase the C/N ratio

If a source separating sewer system is used integrating the organic household waste may be beneficial. The organic household waste increases the dry matter content in blackwater and this facilitates aerobic treatment and increases biogas production if anaerobic treatment is used. Adding OHW to a composting toilet will increase the C/N ratio. This is beneficial because if urine and faeces are composted together the C/N ration is to low due to the nitrogen content in the urine. The organic household waste (OHW) may be added to the blackwater collection tank or in case of a composting- or single flush urine separating toilet, directly to the composting chamber. Adding the organic household waste to the composting chamber involves no extra devices; you just simply put it in the toilet. Note, however, that only compostable material must be added.

In order to add OHW to the collection tanks for blackwater or, in case of a dual flush urine separating toilet, to the collection tank for faecal matter (Fig. 4.11) the waste must be collected and grinded. In principle three options exist: 1) use a grinder in the kitchen, 2) use one common grinder at the collection tank or 3) grind and add the OHW at the treatment facility.

Option 1 is probably the most convenient for the homeowner, but it requires that grinders using little water are available. At Volvo´s vacation and conference center near Udevalla in Sweden a grinder system is modified to accommodate adding of OHW to a blackwater collection system. Option 2 is well suited for apartment buildings and operation by a janitor. Option 3 is also suited for professional handling. In Norway this is practiced in several municipalities where farmers collect both blackwater and source separated OHW, mix the waste and treat the waste by liquid composting (SKJELHAUGEN 1999).

4.5.1.2 The logistics using low flush toilets and blackwater collection

dual plumbing system

Using a low flush toilet and separate collection of the blackwater requires a dual plumbing system for the wastewater. The blackwater is transported to a holding tank. For optimum cost efficiency the holding tank should be sized to correspond to the capacity of the pumper truck. Most pumper trucks or tractor mounted equipmet have capacities in the range 5 to 15m^3. If the truck has a capacity of 10m^3 the holding tank should be somewhat larger (11-12 m^3). This will allow for some flexibility regarding the need for emptying. For a given tank size the emptying interval will depend on the toilet flush volume and number of people connected (see section 4.4.3).

The holding tank may be fitted inside the basement of the building or buried adjacent to the building. In urban areas, especially, a basement tank may be convenient because of space and conflict with other infrastructure outside the building. In existing buildings where water saving toilet system is retrofitted a flexible tank may be used. A flexible tank of reinforced plastic fabric can be folded and carried into the building without having to modify doors or other building structures. What is needed is to prepare a corner or other suitable space by constructing watertight walls as support for the tank. The watertight space should also be connected to a drain in case of leaks or for cleaning and maintenance. The flexible tank must be custom made to the available space. The tank should be vented through the normal ventilation of the plumbing system. The tank should be equipped with a suction pipe that emerges at street level at a convenient site for the pumper truck to connect.

4.5.1.3 The logistics using composting toilets

The use of composting toilets in highrize buildings is limited because a straight chute is needed from the toilet to the composting/collection chamber (see section 4.4.1). However, it is also possible to design buildings where the composting/collection chambers are fitted on the floor below. The latter case will demand collection at different floors in the building and transporting through the building. For these reasons composting toilets are not much used in multi storey buildings. However, with technical and architectural adaptations composting toilets may be an interesting option in apartment buildings. Since most composting toilets use no or very little water the volumes to be collected is much smaller than for urine separating or extremely low flush toilets (section 4.4). This simplifies collection and transport, because less capacity is needed.

health risks

Handling of faecal matter is something that is not popular among the general public. It may also be connected with increased health risks. It is therefore important to develop systems that are convenient for the user and at the same time reduces the risk of handling. Using removable composting/collection compartments and professional collection may be one option. It is possible to organize collection of compost containers along with collection of other source separated household waste. If the professionals have access to the building or the building is constructed with a separate access for collection of compost toilet waste, handling of toilet waste by the public is eliminated. A reactor for sanitizing partially composted waste from biological toilets is being tested in Norway (WARNER and PARUCH 2003). The reactor is suited for professionals, farmers or others, who wants to collect and treat organic household waste and waste from composting toilets. The logistics of the system is also being tested at farm level.

professional collection

4.5.1.4 The logistics of urine separation

If a dual flush urine separating toilet is used the faecal fraction may either be collected or discharged with the greywater

Urine separating toilets come in two editions- single flush or dual flush (section 4.4.2). If a dual flush urine separating toilet is used the faecal fraction may either be collected or discharged with the greywater. The combined greywater and faecal matter may either be discharged to a secondary collecting sewer or treated on site. However, if the faecal fraction is added to the greywater the treatment requirements increase due to larger loads of nutrients, organic matter and pathogens especially. For nature based systems (wetlands, sandfilters etc.) the area requirements increase and the possibility of finding available space for the use of such systems in urban settings decrease.

Collection of the faecal part with a dual flush urine separating toilet is possible, but yield large amounts of dilute blackwater. Because a dual flush urine separating toilets flush the faecal matter with 2-4 liters of water the dry matter (DM) content will be <<1% . This will render this option relatively expensive due to collection of large amounts of dilute water and the subsequent problem of treatment using liquid composting or anaerobic digestion (section 4.6).

When using a single flush urine separating toilet the faecal fraction is collected dry

When using a single flush urine separating toilet the faecal fraction is collected dry. This is normally accomodated by a small removable chamber or bucket or in some models a larger collection chamber. Since the urine is not present the collected faecal matter has much less odour than the combined urine/faecal mixture in e.g. a composting toilet. The experience with the present single flush urine diverting toilet systems is that the faecal fraction is to dry or dessicate when stored under the toilet so that a composting process does not start. In order to achieve composting the faecal matter should be removed from the collection point under the toilet and then composted.

In Norway secondary composting of toilet waste from composting and single flush urine separating toilets is being tried out on a pilot scale (WARNER and PARUCH 2003). The aim is to develop a system based on a dry composting reactor where the collection and treatment of the toilet waste can be done professionally and with a minimal nuisance for the user.

One option to capture some of the faecal nutrients when using a dual flush urine separating toilet is to use the Aquatron. This is a centrifugal separator attaced below the toilet. The Aquatron separates the solids form the liquid. In this way additional P and N can be separated from the waste stream and recycled (VINNERÅS 2002). The separated faecal matter must be hygienized. This can be done in a liquid composting reactor or by thermofilic anaerobic digestion (section 4.6). Other options are dry composting or chemical treatment. For more details the reader is referred to (VINNERÅS 2002).

4.5.2 Centralized systems.

There are numerous ways where end-of-the-pipe solutions can be optimized for a larger degree of sustainability

There are numerous ways where end-of-the-pipe solutions can be optimized for a larger degree of sustainability (e.g. higher degree of recycling, lower energy cost, water saving). Phosphorus is easily precipitated chemically, but in the traditional biological-chemical treatment systems most of the nitrogen and potassium and all the water is lost. There are systems where the nitrogen can be precipitated (JENSSEN et al. 2001) but still potassium and water is lost.

Blackwater contains the majority of the resources in domestic wastewater. Of the blackwater components, it is the urine that contributes the greatest amount of nutrients (Section 4.3). Except for the system mentioned in section 4.4.2.2, systems with source separation require the use of toilets that use little or no water. These systems open a variety of new possibilities for wastewater and organic waste treatment. The systems briefly described in section 4.4.2 are less suited for utilization of the energy resources in wastewater and organic waste than the systems described in section 4.4.1.

4.5.2.1 Collection in ponds for agricultural reuse

In order to recycle the water and the nutrients, biological treatment with collecting ponds or reservoirs can be used

irrigation and fertilization

In order to recycle the water and the nutrients, biological treatment with collecting ponds or reservoirs can be used. Biological treatment will remove odours, improve the hygienic quality of the water and mineralize the main plant nutrients. The water, containing the nutrients and some organic matter, can be pumped from the reservoirs to agricultural areas and be used for irrigation and fertilization (GOTLANDS kommun 1986, MALMQUIST and SAMUELSSON 1993). The reservoirs can also be used for recharge of groundwater if they are located in suitable geological settings.

The greatest advantage with such a system is that it requires no changes in the plumbing fixtures in buildings, as the systems described in section 4.5.1 do. Irrigation with sewage effluents requires no innovation in agricultural methods, since the equipment and competence already exist. Individual farms or regions will require varying amounts of infrastructure investment, however.

Agricultural water consumption in many areas dwarfs domestic and industrial use (ASANO and TCHOBANOGLOUS 1990, SHELEF 1991). The system described can achieve significant water conservation on the farm. Where agriculture competes directly with urban areas for the water supply, cities help themselves by helping farmers.

Irrigation with sewage water is not always feasible, or even desirable. In climates with a short growing season, this end-of-the-pipe system requires large storage reservoirs. Energy costs of pumping sewage water up to agricultural land from the present collection network can be high in some areas. Continued use of the present undifferentiated sewage network makes source separation of heavy metals and toxic organic compounds more difficult and offer smaller possibilities to save water in the household than the systems described in section 4.5.1.

In order to avoid disease transmission, certain requirements regarding hygiene must be met prior to application of sewage water in agriculture.

These requirements limit the number of treatment methods as well as crops that can receive the wastewater.

4.5.2.2 Urine separation with timed release

If urine-separating toilets are used, the urine can be collected in tanks. These tanks can be equipped with a pump and a device controlling the urine discharge. The urine can then be released to the sewage system during hours when the flow is minimal (e.g. midnight). The relatively concentrated urine can be collected at the treatment plant for further treatment and reuse. This interesting system was proposed in GUJER (1996).

The urine can then be released to the sewage system during hours when the flow is minimal (e.g. midnight)

The system offers the possibility of reclaiming 90% of the nitrogen since that is the fraction nitrogen in the urine. The percentage of the phosphorus in the urine is lower. If high P-removal and recycling are to be obtained, a phosphorus removal step for the faeces and the graywater is necessary. A high quality separate (stormwater and sewage in separate systems) collection system with only minor leakage is also a requirement for this option to be viable. If collection system has leaks urine will be lost during times of low precipitation and diluted from infiltration water during times of precipitation.

4.6 Treatment and use of blackwater fractions and organic waste

Since wastewater and organic household waste are rich in plant nutrients, their use as amendments in agriculture has long been accepted in many places. However, since these wastes are associated with hygienic risks and malodour, the use of treatment processes to eliminate pathogen and odour problems is essential. An additional aim of processing is to mineralise organically bound nutrients in the waste, thereby making them more plant available.

treatment processes to eliminate pathogen and odour problems is essential

One of the most common practices for treating domestic sewage from urban areas is the use of anaerobic digestion in centralised treatment plants. Examples of decentralised systems for treating blackwater are still a rarity, particularly in industrialised countries. In the case of organic household waste the prevailing practice is combined collection with other domestic refuse, and disposal by either land filling or incineration.

The utilisation of source separation for blackwater and organic waste offers a number of benefits, e.g., facilitation of nutrient recycling to agriculture with minimal risk of contamination of the recycled materials by toxic elements, and reduced dilution of blackwater by greywater. However, even if water saving or vacuum toilets are used to reduce the amount of flush water to only 1 litre/flush, the amount of dry matter in blackwater is still less than 1% (section 4.4). In order to raise the dry matter to levels which are more appropriate for biological treatment, it is advantageous to mix blackwater with other organic wastes (JENSSEN and SKJELHAUGEN, 1994). Milled organic household waste, animal manure or residues from food processing are all additives that have been used successfully in this connection (JENSSEN and SKJELHAUGEN, 1994).

4.6.1 Aerobic treatment of blackwater and organic waste

Currently, in Norway a system exists where a local farmer collects blackwater and organic household waste by truck from the surrounding community in return for payment corresponding to the municipal sewage fee (SKJELHAUGEN, 1999). The farmer then takes responsibility for treating the waste in an aerobic bioreactor and applies the finished product to his own land. During collection, samples are taken and sent for chemical analysis to reveal the presence of any contaminants. In cases where contamination is detected, which exceeds accepted limit values, it is possible to trace the source of contamination and additional fees charged to the households responsible.

The Fig. 4.12 below depicts the main features of the farmer operated bioreactor. The wastes are handled as liquids (dry matter content between 2 and 10 %) and stabilised in the reactor at thermophilic temperatures between 55 and 60°C with a hydraulic retention time of 7 days (SKJELHAUGEN, 1999). This temperature range is effective at destroying pathogens in the waste and meets the hygienic standards set by the NORWEGIAN MINISTRY OF ENVIRONMENT (1996). The process is run semi-continuously and is characterised by high oxygen utilisation, low ammonia loss and no odour release (SKJELHAUGEN, 1999). Since considerable amounts of heat are generated during the aerobic bacteria which breakdown the organic matter, no additional heat input is required to achieve thermophilic temperatures.

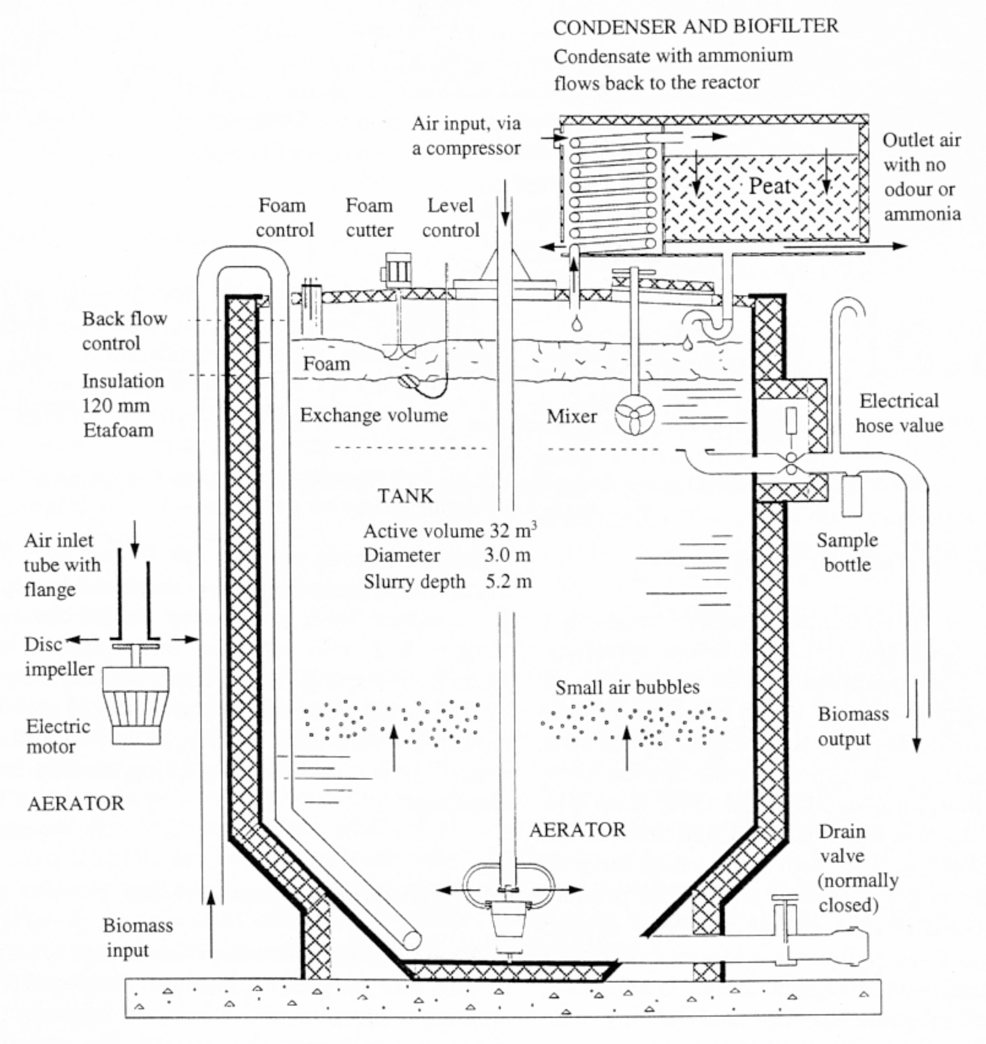


Fig. 4.12 Thermophilic aerobic reactor for processing organic liquid wastes, or a mixture of liquid and solid wastes (SKJELHAUGEN, 1999)

In processing trials with cattle slurry, the stability of the product proved to be sufficient to give odour free storage for a period of 10 months (SKJELHAUGEN, 1999).

The reactor is capable of treating blackwater and organic household waste from about 700 homes. The amount of finished product produced which can be spread onto the farmer's own land will be determined by national regulations. The NORWEGIAN MINISTRY OF ENVIRONMENT (1996) will permit up to 4 tonnes of dry matter per hectare, provided the product is hygienic and heavy metal concentrations are very low and in accordance with prescribed limit values. Under Norwegian conditions the amount of product which can typically be spread to agricultural land will require an area of 18 to 23 hectares per 1000 people (SKJELHAUGEN, 1999). This assumes that the land does not already receive applications of other organic wastes or manure.

SKJELHAUGEN (1999) has undertaken an economic analysis of the farmer operated system. In Norway, the profit for the farmer for operating a processing plant serving 1700 people, and spreading the finished product on his own land, is around NOK 200 000 (EURO 25 000) per year. In addition, a small financial return can be generated from transporting sludge and organic household waste from homes to the processing plant.

From the customer's perspective, the cost of participating in the farmer operated system is around NOK 840 (EURO 105) per year (SKJELHAUGEN, 1999). This is based on the assumptions set out in Tab. 4.10.

Tab. 4.10 Costs to be charged to householders for handling blackwater and Organic Household Waste (OHW) in a farmer operated recycling system (SKJELHAUGEN, 1999).

Operation	Waste type	Gate fee, NOK/t	Amount, t/home/yr	Cost, NOK/home/yr
Transport	Blackwater and OHW			400
Processing and spreading	Blackwater	200	1.8	360
Processing and spreading	OHW	400	0.2	80
Total cost				840

In 1996, the average cost for centralised treatment of domestic wastewater in Norway was NOK 2813 (EURO 352) per home (REFSGAARD and ETNIER, 1998). This rises to NOK 3152 (EURO 394) per home if the cost of handling organic household waste is included.

It should be remembered that the farmer operated system does not include treatment of greywater. According to Refsgaard et al. (1998) the cost for onsite treatment of greywater from 40 homes connected to a single facility is around NOK 583 (EURO 73) per home. Participation in the farmer operated system, together with onsite greywater treatment, therefore gives a theoretical saving to the householder of 1729 NOK (EURO 216) per year.

4.6.2 Anaerobic treatment of blackwater and organic waste

Organic wastes are broken to elementary nutrients and soil humus by a variety of bacteria and fungi. The biological processes involved can take place in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic). Under aerobic conditions, organic carbon in waste materials is oxidised to carbon dioxide by decomposer organisms. Under anaerobic conditions, organic carbon is more likely to be reduced to methane gas, although the generation of a small quantity of carbon dioxide is possible. This gaseous mixture of methane and carbon dioxide, which can be burned as an energy source, is commonly called biogas. The controlled decomposition of organic wastes to produce biogas fuel is therefore an attractive feature of anaerobic treatment processes. In addition, nutrients such as soluble nitrogen compounds remain available in anaerobically treated sludge, providing a valuable source of fertiliser.

The controlled decomposition of organic wastes to produce biogas fuel is therefore an attractive feature of anaerobic treatment processes

Anaerobic treatment, or digestion as it is often termed, is suitable for a wide variety of organic wastes, with the main criterion being that a dry matter content in the waste of around 10% is achievable. This explains why the mixing of a low dry matter substrate, such as blackwater, with a higher dry matter substrate, such as organic household waste, yields an optimal raw material for the digestion process. However, the benefits of this have only relatively recently been realised, and examples of properly working digesters for decentralised treatment of blackwater are few.

EULER et al. (2001) describe several examples of decentralised anaerobic treatment systems:

Model project “Living and working”

Here, anaerobic digestion of source separated blackwater and organic household waste is incorporated into a comprehensive urban project for sustainable living in Freiburg, Germany. The waste substrates are mixed and preconditioned by grinding before digestion. The digestion treatment takes place in an airtight reactor vessel with mixing to ensure good contact between microorganisms and substrate. The digested substrate is lead from the reactor to a post-digestion tank, which incorporates a gas sack for collection and storage of the biogas. Finally, the finished sludge is held in a storage tank to ensure compliance with national hygiene standards for organic wastes prior to application to agricultural land. The biogas produced has several functions including mixing of the reactor contents, electricity generation and burning as a fuel for cooking.

The plant has been designed with low maintenance requirements in mind, but its decentralised character requires greater participation by householders than would be the case with a centralised treatment plant. Currently it is unclear as to how well this "self-management" approach will work in other social settings where the residents are less ecologically motivated than is the case in this particular model project.

Biogas latrines

These are more advanced versions of the septic tank. The septic tank is a simple, closed tank, which facilitates sedimentation and retention of the settleable solids in wastewater. The sediment, or sludge, degrades anaerobically in the bottom of the tank. This degradation is important for reducing the volume of the sludge. Septic tanks are widely used for onsite wastewater treatment and may be found connected to private households, business premises, and public buildings such as schools and hospitals.

raise the dry matter and increase the yield of biogas

Biogas latrines differ from the septic tank in that they allow collection of the biogas produced from the anaerobic degradation of the settled sludge. Blackwater is conveyed to a biogas reactor where organic household waste, agricultural and garden wastes are often added to raise the dry matter and increase the yield of biogas for cooking purposes. The use of additives also increases the amount of sludge produced for use as a fertiliser. The biogas latrine concept is versatile and may be applied to urban or rural settings and has great potential in developing regions.

4.6.3 Storage and handling of urine

Storage is an effective means of hygienising-diverted urine

Storage is an effective means of hygienising-diverted urine. This can be explained by the fact that nitrogen in fresh urine is present in the form of urea. In concentrated urine, the concentration of urea-N is typically 6 to 11 g/l and has a pH of 7. During transport in pipelines, urea breaks down to ammonia and carbon dioxide which results in a pH increase to between 8.9 and 9.2 (VINNERÅS et al., 1999). Ammonia is toxic to microorganisms and the amount of NH_3 evolved increases with temperature, pH and the concentration of NH_4^+ in solution. The combination of increased pH and evolution of ammonia effectively hygienises urine.

VINNERÅS et al. (1999) have studied the inactivation of a range of indicator organisms in urine during storage. These include, enterococci, thermotolerant coliform bacteria, clostridia, protozoa (Cryptosporidium), rotavirus and a salmonella phage (a virus which attacks the bacterium salmonella). It was found that the coliforms were rapidly inactivated during a period of days to weeks, whilst the enterococci were inactivated more slowly over a period of weeks to months. The spore forming clostridia were not affected by storage. Protozoa were slowly inactivated with a decimal reduction time of 29 days at 4°C. The two viruses were most stabile with the phage showing twice as much resistance as the rotavirus. At 5°C the inactivation of the viruses was slight whilst at 20°C, 90 % of the phage was inactivated after 71 days and 90 % of the rotavirus after half that time. Since hygienisation is dependent on temperature and time, a list of recommendations have been drawn up (see Tab. 4.11) showing storage conditions for urine and the type of crops which the stored urine may be used to fertilise (HÖGLUND, 2001). It is also important that the ammonium concentration in the urine is at least 1g/l and the pH should exceed 8.8 in order to ensure hygienisation at the recommended storage temperature and time.

It is also important that the ammonium concentration in the urine is at least 1g/l and the pH should exceed 8.8

Tab. 4.11 Relationship between storage, pathogen content and recommended area of use for larger urine diverting systems, after HÖGLUND (2001).

Storage temperature	Storage time	Possible pathogens in Urine	Recommended area of use
4 °C	≥1 month	Viruses, protozoa	Food and fodder crops for further processing
4 °C	≥6 months	Viruses	Food crops for further processing and fodder crops
20 °C	≥1 month	Viruses	Food crops for further processing and fodder crops
20 °C	≥6 months	Presumably none	All crops

Note that for smaller systems (e.g., in the case of a family which fertilises its own vegetable produce) there is no need to store urine, on the condition that the urine is spread at least one month before harvesting.

4.6.4 Agricultural application and use of waste derived fertilizer products

If agriculture is to be truly sustainable, it is essential that the resources, which are present in toilet wastewater, are recycled back into plant production as fertiliser. For centuries, animal manure has been returned to the soil for agricultural purposes, but the re-use of human excreta meets significantly more prejudice from society, which does not appreciate the resources it contains. Human urine is in fact well suited to use as a fertiliser and more rich in nitrogen and phosphorous than the urine of many farm animals (Tab. 4.12).

Tab. 4.12 Physical and chemical properties of human urine, swine urin and cattle urine after storage (STINTZING and RODHE, 2000).

	Dry matter %	N-total kg/t	NH_4-N kg/t	P kg/t	K kg/t
Human urine	0.6	2.60	2.10	0.23	0.85
Swine urine	0.6	1.03	0.98	0.11	1.40
Cattle urine	1.2	1.70	1.4	0.04	3.00

The proper re-use of human urine can yield significant benefits for the environment in terms of reduced nutrient losses with their related pollution effects. Another motivation for re-using human urine as a fertiliser in agriculture is as a replacement for mineral fertiliser. Tab. 4.13 indicates that in Norway, approximately 15 % of the nitrogen which is applied to agricultural land as mineral fertiliser could be replaced by the nitrogen in urine.

Tab. 4.13 The percentage of mineral fertiliser nitrogen in Norway which could be replaced by urine nitrogen.

		kg N	Source
Mass of mineral fertiliser N sold 1999/2000		107 410 000	NORSK LANDBRUKS-SAMVIRKE (2002)
N in urine per person per yr.		4.00	NATURVÅRDSVERKET (1995)
No. of adult PEs in Norway	4 000 000		
Totalt produced		16 000 000	
% of mineral fertiliser N	14.9		

This assumes that each adult excretes 4 kg of nitrogen in the urine each year. In addition it is assumed that not all of Norway's population (ca. 4.5

million) is adult and that the adult population can be equated to 4 million PE (Person Equivalents).

Although the figure of 14.9 % is not enormous, it is worth considering that most of the cereal production in Norway takes place on farms without livestock but close to the most populated urban districts of the country. Therefore, there is great potential for recycling human urine to arable land.

4.6.4.1 Agronomic effects of human urine

COTTIS (2000) has studied the effect of human urine used as a fertiliser on cereal crops in Norway. Experiments were carried out on conventionally and organically cultivated crops with levels of nitrogen application ranging between 0 and 120 kg/ha. Urine was applied undiluted during times in the growth season when it would be normal to apply mineral fertiliser. The urine was incorporated into the soil by harrowing within 5 minutes of application. Control plots were also prepared using mineral fertiliser (ammonium nitrate). Fig. 4.13 shows that an organically cultivated oat crop gives improved yields after fertilising with urine than an unfertilised crop.

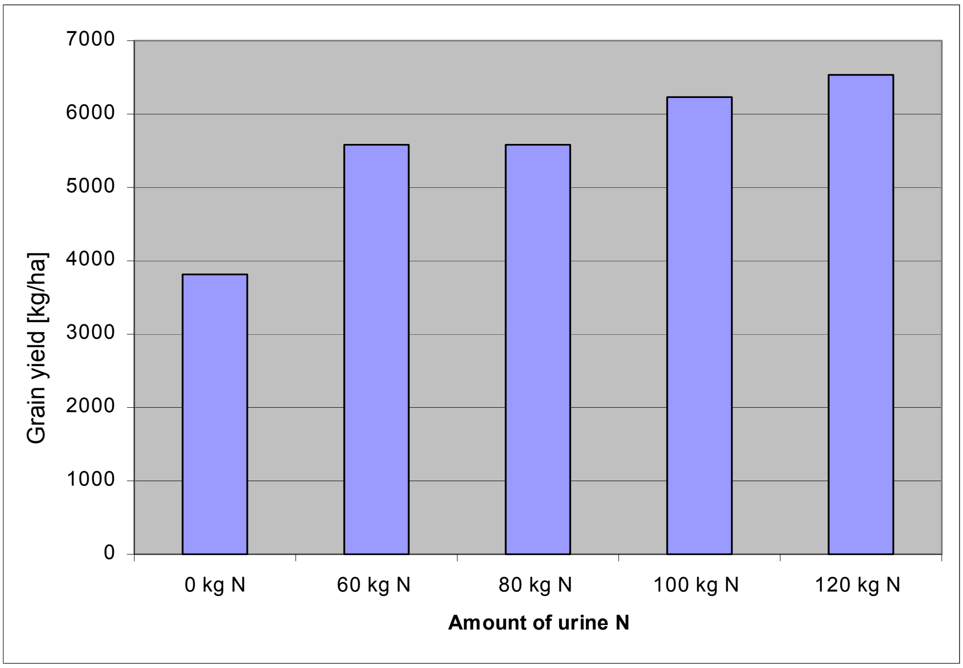


Fig. 4.13 Grain yield of an organically cultivated oat crop at different levels of human urine nitrogen application (after COTTIS, 2000).

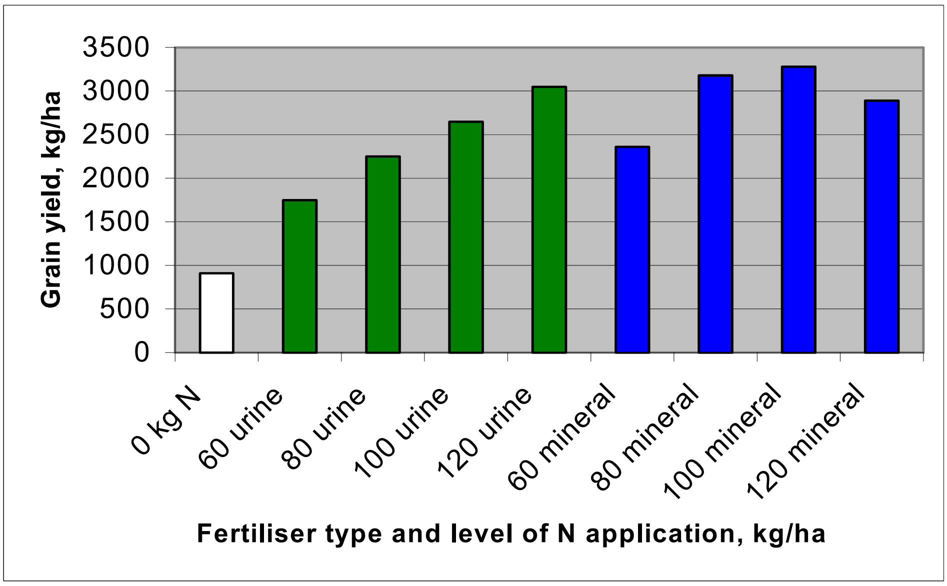


Fig. 4.14 Comparison of grain yields in conventionally cultivated barley fertilised with different levels of human urine nitrogen and mineral fertiliser nitrogen (after COTTIS, 2000).

Comparing the data Fig. 4.3 reveals that barley fertilised with urine gives a similar grain yield to barley fertilised with mineral fertiliser (ammonium nitrate). STINTZING and RODHE (2000) in a similar study found 100 kg of human urine nitrogen, after losses due to ammonia volatilisation, gave a crop yield corresponding to ca. 85-90 % of that which 100 kg of mineral fertiliser nitrogen gave. JOHANSSON et al. (1998) have also found that human urine gives almost as good a fertilising effect as equivalent amounts of nutrients in mineral fertiliser.

However, one should also consider that a greater volume of urine needs to be applied to achieve the same fertilising effect as mineral fertiliser. In the case of mineral fertiliser with nitrogen comprising 22% of the dry matter, approximately 22 times more undiluted human urine must be applied to give the same fertilising effect. This amount will be further increased if the urine is diluted.

4.6.4.2 Agronomic effects of blackwater

There is a lack of information in the literature about the agronomic effects of blackwater. However, blackwater should be suitable as a fertiliser since most of the nutrients it contains originate from urine and these should be just as plant available as the nutrients which are found in uncontaminated, diverted urine.

With regard to the faecal fraction, in Asia human faeces have been used as a fertiliser for many centuries. In Japan, for example, faeces were much used in agriculture especially near towns and urban areas from as early as the 12th century to as late as the 1960's (TERAKAWA and KITAWAKI, 1994).

Because of the nutrients present in blackwater, this resource should be considered more often as an organic fertiliser resource for modern agriculture where there is an increasing need to improve soil structure and quality. It is, of course, essential that blackwater or faeces are properly hygienised before they are returned to food crop production so as to avoid any negative health consequences. In addition, recycling of blackwater to agriculture is an important sustainability issue in closing the loop between agriculture and urban populations.

4.7 Greywater treatment and reuse

In a recycling system based on source separation of wastewater fractions, water saving or dry toilets are used, hence, the greywater volume constitutes >90% of the total wastewater flow. The toilet waste contains the majority of the nutrients and only 10% of the nitrogen, 26% of the phosphorus and 21% of the potassium is found in the greywater (VINNERÅS 2002). In Norway where phosphate free detergents are used the phosphorus content in greywater is less than 20%. Nutrient removal then becomes a minor issue. However, greywater may contain more than 50% of the organic matter in wastewater (RASMUSSEN et al. 1996) and a substantial amount of bacteria and viruses (OTTOSEN and STENSTRÖM 2002). Systems that can remove organic matter and pathogens are therefore needed in order to facilitate discharge or reuse of the greywater.

The selection of greywater treatment method will depend on the final discharge and use of the water

A large variety of greywater treatment methods exist

The selection of greywater treatment method will depend on the final discharge and use of the water. If discharged to the sea, no treatment or maybe only a primary treatment step is required. However, if the discharge is close to areas where people swim a more advanced treatment may be necessary. If discharged to lakes or rivers a secondary treatment step is often needed. Before discharged to streams or use in irrigation or groundwater recharge, the hygienic parameters must be reduced. For in-house reuse and drinking water, sophisticated tertiary treatment may be necessary. A large variety of greywater treatment methods exist; natural, conventional and combinations thereof (RASMUSSEN et al. 1996, JENSSEN and VRÅLE 2003, OTTOSON 2003), thus finding methods that meet the limited area requirement in urban settings is possible.

4.7.1 Greywater composition and volume

There is a limited number of studies characterizing greywater composition. There are also differences observed between different homes in the same country and between countries. More data are needed to thoroughly characterize greywater composition and specific per person production at least on the country level. Some data that can elucidate the general greywater composition is given below (Tab. 4.14).

Tab. 4.14 Mass (g/person and year) and concentrations (mg/l) in greywater (from JENSSEN and VRÅLE 2003).

Source	**Phosphorus**		**Nitrogen**	
	g/p and year	mg/l	g/p and year	mg/l
TORVETUA*	58	1,07	406	7,1
KAJA*	56	0,97	470	8,2
VINNERÅS 2002	190	5,0	500	13,2

*Measured in septic tank effluent (STE)

JENSSEN and VRÅLE (2003) found the average total nitrogen concentration in Norwegian greywater septic tank effluent to be around 8 mg/l. VINNERÅS (2002) who studied Swedish greywater found a higher value - 13.7 mg/l. The WHO drinking water requirements for nitrogen are 10mg/l. This shows that greywater, almost without treatment may meet the WHO standards for nitrogen. Specific per person production of nitrogen to greywater varied from 400 – 500 g/person and year, the highest value in the Swedish studies.

The phosphorus concentrations in Norwegian greywater average around 1mg/l and the specific per person production is 55-50g per year. In Sweden the comparable values are 5mg/l and 190 g/year. The explanation for the large difference is that phosphate free detergents are used in Norway. The need for phosphorus removal in Norwegian greywater is therefore very limited and only needed when discharging to small sensitive freshwater bodies (streams, small lakes).

In the proposed new Swedish design values the total per person yearly production of organic matter to greywater is 9.5kg for BOD and 19000kg for COD (VINNERÅS 2002). With an annual per person greywater production of 36.5m^3 the expected concentrations become 260 and 520 mg/l for COD and BOD respectively. In Norwegian studies the content of organic matter measured as BOD or COD on the average is somewhat lower than the

Swedish design values, but some individual households show higher values. This is due to differences in individual routines and food habits.

Some household chemicals still contain substances that are considered harmful in the environment

Some household chemicals still contain substances that are considered harmful in the environment. In household wastewater these are mainly found in the greywater (ERIKSSON et al. 2002). The majority of the heavy metals in household wastewater is also found in the greywater fraction. According to VINNERÅS (2002) heavy metals in Swedish greywater have decreased over the last years and suggest that the design values for all metals except copper is reduced. If this trend is correct it may reflect that more environmentally friendly building materials and household chemicals are introduced and chosen by the consumers. The only sustainable way to reduce the impact of heavy metals and toxic chemicals in domestic wastewater is to phase out the products from which the unwanted substances originate.

Greywater has been perceived as relatively free of pathogens yet the number of indicator bacteria (mainly Coliforms and Enterococci) in many studies have been high (RASMUSSEN et al. 1996). Indicator bacteria may multiply in greywater systems and OTTOSON (2003) investigated the faecal load by using sterols and found that assessments based on the indicator bacteria overestimated the faecal load and associated risks to greywater. However, the OTTOSON (2003) found that viral contamination posed a potential risk. He concluded that more studies on virus occurrence in greywater as well as validation of the faecal load are needed to improve the basis for future qualitative microbial risk assessments. In order to reduce the risk to below acceptable levels a log reduction of 0.7 – 3.7 of rotavirus was needed dependent on type of greywater discharge (OTTOSON 2003).

Tab. 4.15 shows that the per capita greywater production varies from 81 to 133 liters. The lowest greywater production displayed in Tab. 4.2 is from a Norwegian ecovillage project and shows what is possible to achieve if the people are focused on water conservation. VINNERÅS (2002) reports that in a Swedish Ecohousing development the greywater production is only 66 liter per person and day. At the student dormitories (Kaja) the greywater production is higher despite water saving showerheads. Without water saving showerheads the greywater production was 156 liters per student per day. This shows that the showers account for a major part of the greywater production in the student dormitories. In Norway young people (15 – 25 years) generally take more frequent and longer showers than the rest of the population and thus it can be expected that the average greywater production for the population as a whole is lower than at Kaja. In the proposed new Swedish guidelines a greywater production of 100 liters/person and day is suggested (VINNERÅS 2002).

Tab. 4.15 Wastewater production in households - liters/person and day (from JENSSEN 2001).

	Norway[1]	USA[2]	Ecovillage Norway[3]	Kaja[4]
Blackwater	40	57	0	7
Greywater	120	133	81	112
Total	160	180	81	117

[1] VRÅLE 1987, [2] TCHOBANOGLOUS 1998, [3] KRISTIANSEN and SKAARER 1979, [4] SØYLAND 1998

4.7.2 Greywater treatment methods

Natural systems as soil infiltration, constructed wetlands and ponds have small energy cost and do no use of chemicals. These systems be integrated as part of a park or natural environment. When recycling of nutrients is not the main issue, as it is with treatment of greywater, natural systems are intuitively sustainable. However, most natural systems require larger areas than the conventional and more technical systems. In an urban setting area may be a limiting factor. Below some aspects of various treatment systems for greywater are briefly discussed. The natural systems are given most attention. The cost and sustainabiliity aspects of the different systems are not considered because good data for making such comparisons regarding greywater treatment are lacking.

4.7.2.1 Soil infiltration

Soil infiltration is the most common method for wastewater treatment in rural areas and decades of experience is available (SIEGRIST et al. 2000). The success of the method, however, is dependent on careful site investigations and corresponding design to suit the local conditons (JENSSEN and SIEGRIST 1991). The systems are technically simple (Fig. 4.15) but competence regarding soils, hydrogeology and wastewater infiltration is necessary to have a successful system. Infiltration systems are therefore normally cheap (often the cheapest) to build and maintain, but relatively expensive to plan.

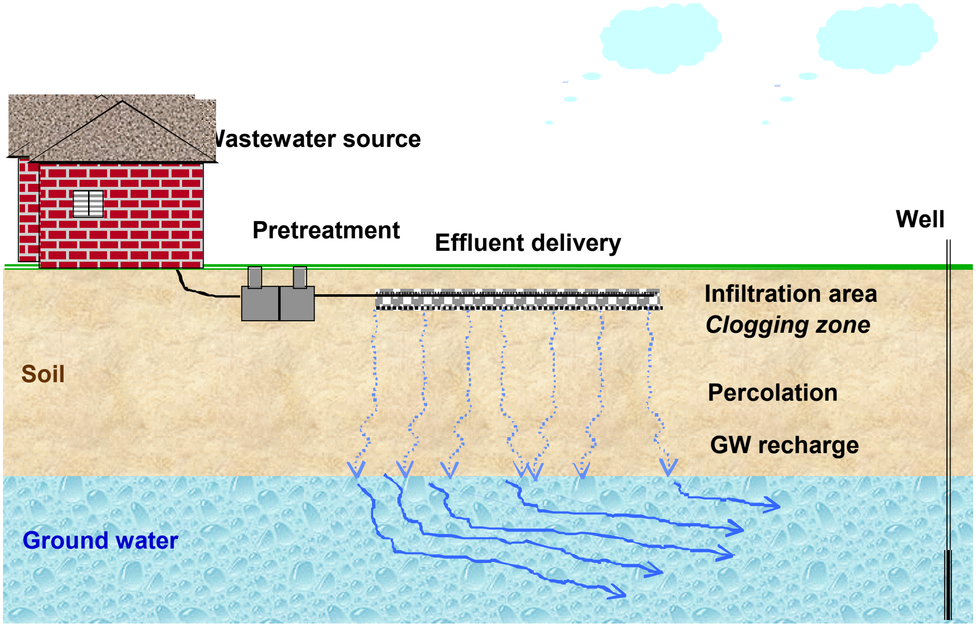


Fig. 4.15 A subsurface soil infiltration system (from SIEGRIST et al. 2000).

Small soil infiltration systems (< 100 persons) are normally constructed subsurface (Fig. 4.15). Such systems may be completely invisible and covered by a lawn, park or agricultural area. If the necessary area and natural conditions are available such systems can be integrated in urban areas. As infiltration systems grow larger it is more common to use open infiltration basins. In Scandinavia the largest currently operating open infiltration system is treating wastewater (including toilet waste) for 8000 persons. In the United States systems for more than 50 000 people are built. Large open infiltration systems are hard to imagine in an urban environment, but may be used if the greywater is collected and transported to a suitable location outside the city.

In Scandinavia the largest currently operating open infiltration system is treating wastewater (including toilet waste) for 8000 persons

Subsurface soil infiltration systems normally consist of a septic tank prior to a leachfield (Fig. 4.15). In order to optimize purification it is important to distribute the septic tank effluent (STE) evenly over the infiltration surface. Even though it is possible to construct infiltration systems without moving mechanical parts, a pump or other dosing device (siphon, tipping bucket) is recommended, especially for larger systems (more than one trench) and in soils coarser than fine sand.

Reduction of organic matter and bacteria are strong sides of wastewater infiltration. Virus removal is also good, but varying more than for bacteria. In suitable soils virus removal is excellent. A removal of 3 logs or more regarding bacteria and virus is normally achieved in soil infiltration systems. A high content of iron and aluminium oxides in the soil normally favours virus and bacteria removal (SCHIJVEN and HASSANIZADEH 2000). The depth of the unsaturated zone is also an important factor in reducing the risk of microbial contamination. The unsaturated zone is the zone between the infiltration system and the groundwater zone. In a properly designed infiltration system the flow is usaturated in this zone. This means that the soil media is not water saturated and that the water flows in the smaller pores and the larger pres are filled with air. This type of flow enhances retention and reduction of microbial components in wastewater.

Norwegian guidelines recommend loading rates of 1 – 5 cm/d

Norwegian guidelines recommend loading rates of 1 – 5 cm/d (10 – 50 liter/m^2 and day) depending on soil conditions for greywater septic tank effluent. Higher loading rates can be used if more sophisticated pretreatment (biofilter or sandfilter) is used (JENSSEN and SIEGRIST 1992, HEISTAD et al. 2001).

4.7.2.2 Sandfilters

A sandfilter (Fig. 4.16) is in principle the same as a soil infiltration system, except that the soil volume available for purification of the wastewater effluent is normally much smaller. Sandfilters have been used for over a century in wastewater treatment (CRITES and TCHOBANOGLOUS 1998) and their principal design has not changed much. According to Norwegian guidelines (MD 1993) loading rates of 2 or 4 cm/d are used for buried sandfilters depending on sand type (Fig. 4.16). Higher loading rates can be used especially for filters with accessible surface where the clogging can be controlled mechanically and for coarser sand types than given in the Norwegian guidelines. For coarser media, however, the removal of microbial organisms, especially, may become lower.

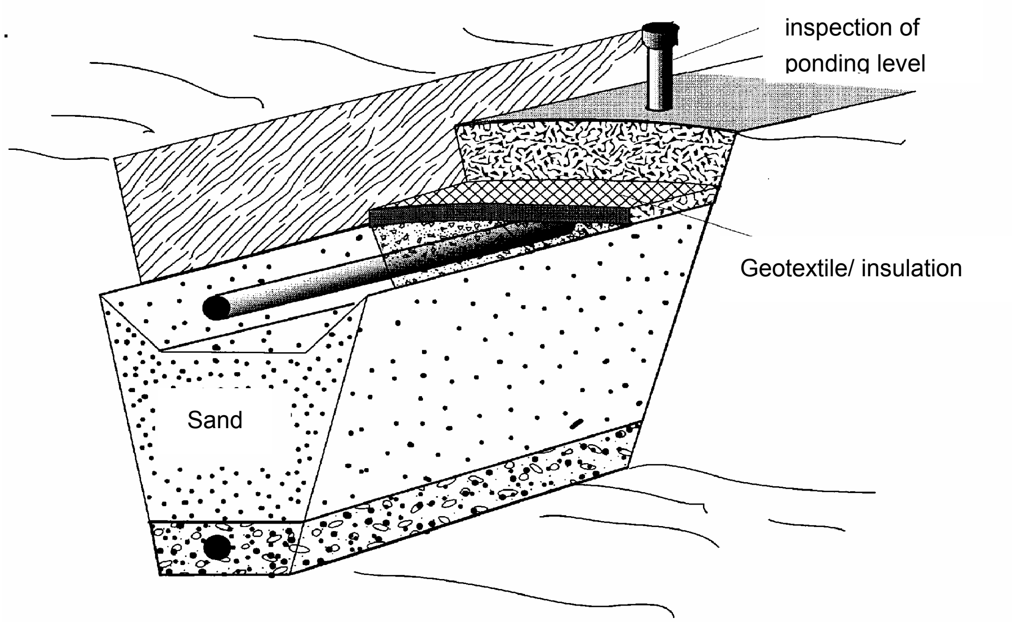


Fig. 4.16 Sandfilter (from JENSSEN and HEISTAD 2001)

It is recommended to build the sandfilter with sloping sand sides (Fig. 4.17). This reduces the potential for shortcircuiting through the backfill of the sandfilter if water is ponding on the filter surface. Sloping sand sidewalls also will enhance aeration of the filter (JENSSEN 1986).

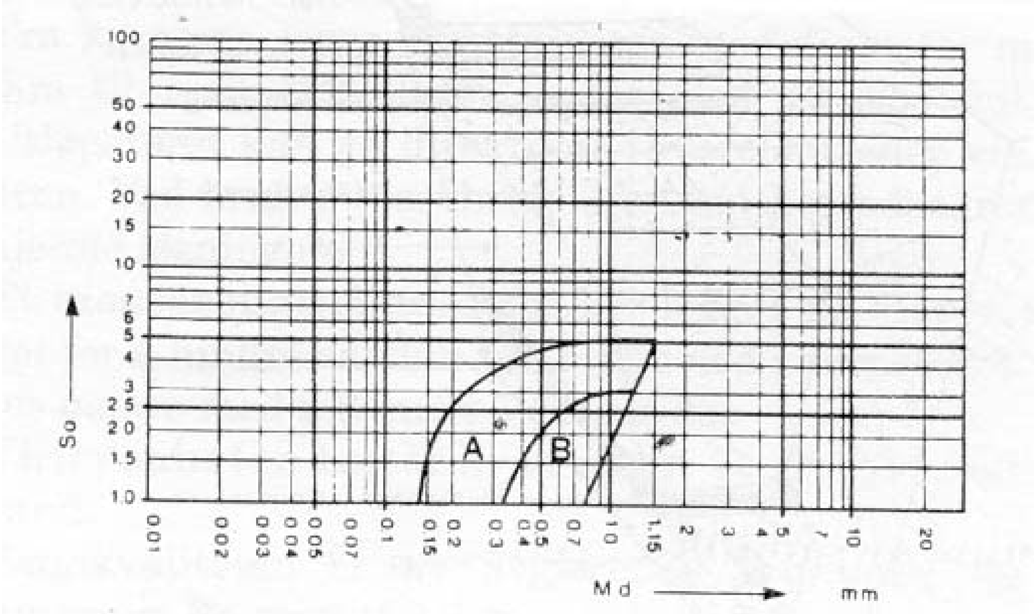


Fig. 4.17 Diagram for selection of sand and sizing of sandfilters (MD 1993). Sand in section A: loading rate 2cm/d and sand in section B: loading rate 2cm/d. Md is mean grain size (d_{50}) and So is sorting (d_{60}/d_{10}).

A properly constructed sandfilter has very good abilities to reduce organic matter. A sandfilter normally will reduce bacteria 3 logs or more. It also has potential to reduce the number of virus substantially (SCHIJVEN and HASSANIZADEH 2000).

4.7.2.3 Bio- and wetland filters

Bio- and wetland filters for greywater treatment has been pioneered in Norway (JENSSEN and VRÅLE 2003). The general concept (Fig. 4.1) consists of pre-treatment of the wastewater in a septic tank, pumping to a vertical down-flow single pass aerobic biofilter followed by a subsurface horizontal-flow porous media filter. The biofilter may be integrated (as in Fig. 4.18) or located separate from the horizontal flow section. The wetland section is usually vegetated with common reed (Phragmites), but systems are also built with a grass cover. Evaluation of the role of plants in these systems when treating wastewater (including toilet waste), both in field and mesocosm scale systems, showed that the root-zone had a positive effect on N-removal, but no significant effect on P and BOD removal (ZHU 1998, MÆHLUM and STÅLNACKE, 1999). It is also suggested that the plant roots may have a positive effect regarding removal of bacteria (REED 1993).

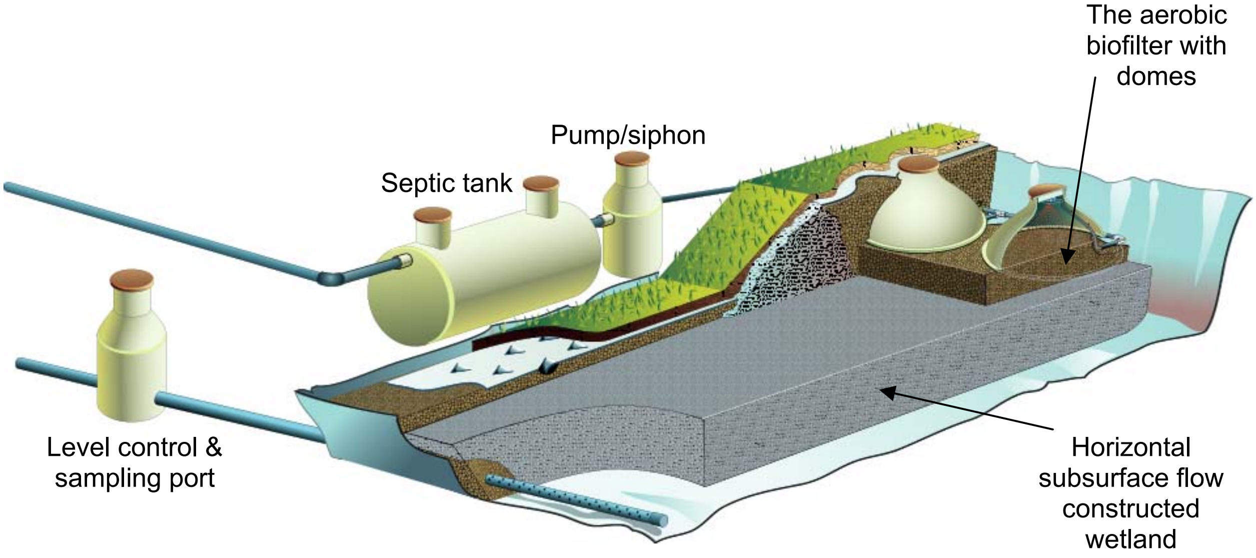


Fig. 4.18 The latest generation of constructed wetlands for cold climate with integrated aerobic biofilter in Norway.

The aerobic biofilter

The biofilter (Fig. 4.18) is covered by a compartment (e.g. a hemispherical dome) which facilitates spraying of the STE over the biofilter surface. The biofilter has a standard depth of 60 cm and a grain size within the range 2 – 10 mm is recommended. In Norway light weight aggregate (LWA) in the range 2 - 4 mm is the most common filter media, but gravel or other type media in the above size range may be used.

The single pass biofilter aerates the wastewater and reduces BOD and bacteria. Using such biofilters for treating greywater more than 70% BOD reduction and 2-5 log reduction of indicator bacteria has been obtained at a loading rate for greywater up to 115 cm/d. Assuming a greywater production of 100 liters/person/day a biofilter of 1 m^2 surface area can treat greywater from about 10 persons, hence, very compact biofilters can be made. Clogging has not been observed even at loading rates exceeding 100cm/d, however, earthworms are observed living in the biofilter. Their grazing of the biofilm probably reduces clogging and enhances the hydraulic capacity of the filter. The key to successful operation of the biofilter is uniform distribution of the liquid over the filter media and intermittent dosing (HEISTAD et al. 2001). A biofilter alone may be sufficient for treatment of greywater. In Norway several small compact greywater biofilters are commercially available for use in cottages or single dwellings. In order to further improve the quality of the effluent, the biofilter can be followed by a subsequent sandfilter (section 4.7.2) or a constructed wetland (Fig. 4.18). This is needed if the receiving water body is sensitive.

The horizontal subsurface flow constructed wetland

According to the Norwegian guidelines (Gaut and Mæhlum 2001) the recommended depth of the horizontal subsurface flow constructed wetland is minimum 1 m. This is more than suggested in other guidelines (Vymazal et al. 1998, Kadlec et al. 2000). The reason is the cold climate. In Norway the systems are sized so that the upper 30cm of the system can freeze while still leaving sufficient hydraulic capacity to transport the water below the frozen zone. The final geometry (length, width) of a system is based on hydraulic considerations, but for systems treating combined grey- and blackwater, sizing also depends on the phosphorus sorption capacity of the media. For commercial systems treating greywater the resulting surface area is 2-3 m^2/person. For systems treating combined grey- and blackwater the recommended surface area is normally in the range 7-9 m^2/person under Norwegian conditions. In experimental systems treating combined black- and greywater and for greywater systems only, more compact designs are being examined.

In Norway the systems are sized so that the upper 30cm of the system can freeze

Combined aerobic biofilter/constructed wetland systems

Three large combined biofilter/constructed wetland systems are in operation in Norway (Tab. 4.16)

Tab. 4.16 Average outlet concentrations and treatment performance (%) for 3 combined biofilter/constructed wetland systems. Average over total service time (from Jenssen and Vråle 2003).

System	Persons connected	Built year	TP		TN		COD		BOD$_7$ [a]		TCB[b]
			%	Cout	%	Cout	%	Cout	%	Cout	
Kaja	48	1997	94	0,05	70	2,6	94	15,8	94	5,6	sw
Torvetua	140	1998	79	0.21	60	2.2	88	41,0	97	5,5	sw
Klosterenga	100	2000		0,03		2.5		19,0			0

a) 7-day BOD is standard in Norway, b) Termotolerant coliform bacteria

sw = swimming water quality < 1000 TCB/100ml

At Klosterenga, in the city of Oslo, the greywater is treated in the courtyard of the building. The space required for this demonstration system is about 1 m^2/person, and the treatment area is partly used as a playground, partly as an aesthetic component of the landscaping. The compact design is due to making the horizontal flow section 1,8m deep instead of the standard 1m, thus saving area and still having sufficient porous media volume in the horizontal flow section. Additional aeration, in the summer season, is provided by a flow-form system (WILKES1980). No inlet samples are presently available at Klosterenga. The outlet samples show better performance with respect to phosphorus and bacteria than the systems at Kaja and Torvetua (Tab. 4.16). This is due to a new LWA, FiltraliteP®, which has very high phosphorus sorption and bacteria reduction capabilities. It is estimated, assuming similar inlet phosphorus concentrations as for Kaja and Torvetua that saturating the wetland media with phosphorus will take more than 40 years at Klosterenga.

The systems (Tab. 4.3) more than fulfil the 3 log reduction suggested by OTTOSON (2002) with respect to bacteria. Preliminary investigations in a system with similar design receiving wastewater including toilet waste indicate that systems with FiltraliteP has potential for excellent virus reduction. With such high qualities of the effluent water, as shown in Tab. 4.16, the need for a secondary sewer collection system is reduced because local streams or water bodies can be used for receiving treated water even in urban areas.

The effluent quality (Tab. 4.16) should meet most requirements for irrigation and groundwater recharge. Except for high pH in the initial phase (1-2 years) it may be possible to use the effluent water (Tab. 4.16) for flushing toilets and car wash without further treatment.

4.7.2.4 Ponds

Ponds are one of the most common treatment methods for conventional wastewater world wide and may also be used successfully in cold climate (BROWNE and JENSSEN 2001). The experience with ponds for greywater treatment is limited. OTTOSEN (2002) refers to an investigation by GUNTHER (2000) where a pond system in Sweden with a retention time of one year reduced *E.coli* and somatic coliphages by 1.2 and 3 logs respectively. However, the size required by 1 year retention time as well as potential direct contact with contaminated water will limit the use of ponds as the main treatment component for greywater systems in urban areas. As a polishing step of effluent from biofilters, sandfilters or constructed wetlands ponds may have a function in an urban environment both as a purification step and a landscape element.

4.7.2.5 Conventional biological treatment

Conventional biological treatment, means active sludge or enhanced active sludge systems and fixed film systems as trickling filters or rotating biological contactors (RBC). A RBC especially designed for greywater treatment was available in Germany (NOLDE 1996). The advantage of these systems is that they are compact and that they efficiently reduce organic matter. In order to meet the bacteria and virus requirements suggested by OTTOSON (2002) these biological methods must be succeeded by other methods as a sand filter, subsurface flow constructed wetland with a fine grained substrate or disinfection. Combination with chemical treatment will also be possible.

4.7.2.6 Chemical treatment

Chemical treatment is primarily used to reduce phosphorus, but also reduce organic matter by up to 80% (ØDEGAARD 1992). According to STENSTRÖM (1986) chemical precipitation also reduces virus and bacteria. Chemical treatment systems are compact, and may be an option in urban areas especially in combination with post treatment in a sandfilter or wetland.

4.7.2.7 Membrane filtration

Membrane filtration systems are compact and energy efficient (EPA 2001). If reverse osmosis is included in the filtration sequence drinking water quality is possible to produce. One major problem is blocking of flow through the membranes due to material buildup on the mambranes. Pretreatment therefore becomes important in order to make this method viable. Membrane filtration of greywater treated by sandfiltes or combined biofilters/constructed wetlands (Fig. 4.18) opens interesting possibilities of inhouse reuse, even as drinking water, but the latter may require additional carbon filtration or disinfection.

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