Evaluating Ecological Sanitation Systems (EvaSan) for handling Human Waste

By
Ketil Haarstad (Editor), Henrik Lystad & William Warner

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Jordforsk

Preface

At least half of the population of the world has no access to proper sanitation, and the trend is that the number of unserved people is increasing (Gøransson, 1997). Most cities are short of water and many are subject to critical environmental degradation, with peri-urban areas among the worst polluted and disease ridden habitats of the world.

This report examines these problems from the perspective of ecological sound sanitation systems, with a focus upon Southeast Asia. This work is still in its infancy.

Authors:
Ketil Haarstad (Project leader)
Henrik Lystad
William Warner

Jordforsk,
Norwegian Center for Soil and Environmental Research,
November 1, 1999
N-1432, Ås, Norway

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1. Introduction

Humans have known for a long time that fecal material and wastewater can fertilize crops but transmit diseases. The difference today is that we make sound risk assessments. There remains, however, widespread ignorance on these matters, which perpetrates the maxim: Poor health leads to poverty as poverty leads to poor health.

Although the values of improving sanitation facilities have been realized for decades all aspects of sanitation must be given a higher profile and more attention. Improved facilities reduce contamination of drinking water and reduce diarrhoeal disease transmission. Nevertheless, the World Bank and WHO statistics show that as many as three million children still die from intestinal infections every year, and a third of the world's population is infected with excreta-related parasites. The main reason for this tragedy is that too little has been invested in technological improvement of facilities, and that facilities are often inappropriate, unaffordable, or unacceptable to the intended users (Almedom et al. 1997). The result: no use, limited use, or inappropriate use of sanitation facilities.

A key sanitation element is the safe disposal and treatment of human excrement. Feces are the principal carrier of pathogens and contain few nutrients, urine is relatively free of pathogens in healthy people and contains most of excremental nutrients. All sanitation can be said to be environmental in the sense that it protects the environment against emissions. There are basically three ways to deal with excrements (Figure 1).

Flush and discharge; conventional for developed countries

Drop and store; Tradition for low income countries

Sanitize and reuse; Ecological sanitation

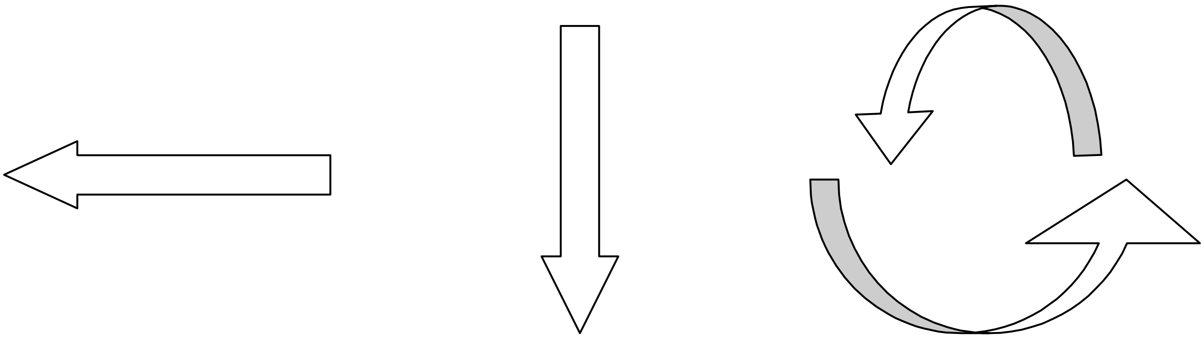

Figure 1. Three ways to manage human excreta (after Winblad, 1997)

The conventional method:
Flush and discharge rapidly moves the fecal material off site and downstream together with large volumes of water, and is usually mixed with surface water and industry effluents

containing toxic compounds. There may or may not be an operating treatment plant - which probably produces toxic sludge in large volumes - before reaching a recipient. Many of these sanitation systems were not designed to recycle nutrients; therefore, the design of treatment plants might be the root of the problem for such systems. Sewage discharges from centralized water-borne collection systems pollute surface waters, and seepage from sewers, septic tanks and cesspools pollutes groundwater.

The traditional method in developing countries:
Drop and store systems traditionally consist of the pit latrine, of various designs. Generally these systems are not designed to use excrements and deprives the soils of nutrients and frequently pollutes groundwater. Moreover, pit latrines have traditionally meant containment, which does not guarantee the isolation of fecal contamination. Various routes such as fingers, flies, soil and water transmit excreta-related diseases.

The ecological method:
The *sanitize and reuse* system is designed to collect and treat human excreta with or without urine diversion in order to hygienize the material and prepare the nutrients for reuse. These methods typically use little or no water.

How does one compare the conventional method with the ecological method? How are the numerous ecological systems evaluated? Is it a series of performance tests, similar to comparing automobiles, or is the entire system examined over time in situ, akin to evaluating dietary impact on human health? These questions are answered, in part, by the sanitary system's priorities.

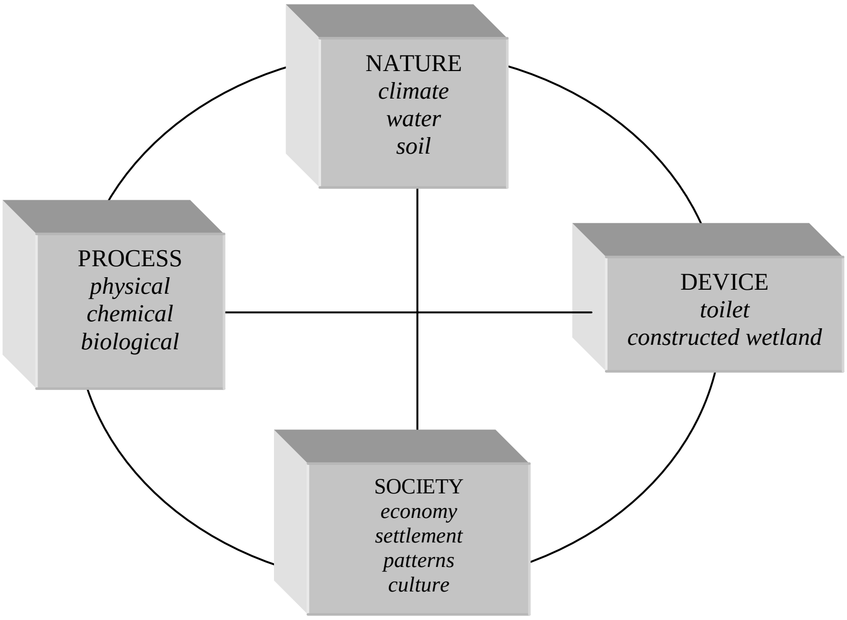

Figure 2. Sanitation is a system where the main components (device, process, nature and society) are considered together (from Winblad, 1998)

Sanitation is generally designed to meet one or more of the following priorities:

- protect the health of people
- recycle resources (energy and nutrients)
- protect the environment
- aesthetic values

The success of any sanitation system meeting its goals, even if it is just one of the above, depends on all the system components working together: device, process, nature, and society (Figure 2). The multitude of sanitation devices and processes, combined with various ecosystems and cultures, intuitively suggests that every treatment alternative has its own potential, depending on where it is adapted. We know, for example, that attitudes and behavior can vary so widely worldwide that it should not be assumed that wastewater practices can be readily transferred from one area to another (Cross, 1985). It should be noted, however, that these things are not static, and that new practices are constantly evolving in most societies (Winblad ed., 1998). It is a daunting task to evaluate the success of different sanitation systems under a variety of circumstances. For economy of thougt, however, one must categorize and, as a result, generalize. Although this report generalizes, evaluations are based inductively upon solutions in specific environments.

The heart of this study is to identify ecological sanitation solutions that are potentially suitable for low income countries. The focus is primarily, but not exclusively, upon rural conditions. And particular attention is devoted to Southeast Asia.

It is difficult to give any region of the world a meaning in a sanitation context, except in the broadest sense (i.e., nature, device, process, or culture). An example illustrates the point: compare the sanitation cultures of Southeast Asia with Sub-Sahara Africa. The former has a pre-disposition towards using human excreta as fertilizer; the latter does not. Asia’s intensive cultivation practices evolved to feed large populations in areas of limited land availability, which necessitated the careful use of all resources available to the community, including excreta. In contrast, Africa’s history of land abundance, shifting cultivation and lack of population pressure have led to the development of agricultural practices in which nutrient re-usage is rarely maximized (Cross and Strauss 1986).

Despite these gross regional generalizations, it is not useful to group the countries and seek characteristics concerning human waste management and technology, because the socio-political context of Viet Nam, the Philippines, and Indonesia, for example, are so different as to obviate the usefulness of a regional discussion. In addition, basic geographic characteristics, for example population density and rainfall (Figure 3), have no relationship to the definition of Southeast Asia. Generally speaking, the same holds true for most regions of the world. In fact, many countries of the world are varied enough to require evaluation at the sub-national level, at the level of cultural groups or sub-groups. Thus, although this report sometimes refers to sanitation within a regional framework, we emphasize that a thorough assessment of the local context is always necessary.

It is also important to remember that sanitation may take a long time to improve. It took more than one century to sanitize urban industrialized cities like Stockholm (Drangert, 1996). Typically organizations that initiate any improvement scheme, whether it be sanitation or agricultural development, fail to realize that nature-dependent initiatives often take decades to assimilate in a culture before reaching fruitful maturity.

This report summarizes the most important aspects of the current state of ecological sanitation, and proposes a method to evaluate alternative systems *in situ*. The report is divided into three sections. The first part examines the fundamental processes, the second part adresses the devices, health impacts, cultural considerations and economy associated with ecological sanitation. There is also a summary of examples of existing projects and experiences. The third part briefly addresses the evaluation process, followed by conclusions and recommendations, including forms giving examples on how decisions can be achieved, and system evaluation. For those not familiar with technical aspects of the subject matter a glossary is given at the end of the report.

The following criteria, though important in sanitation, are not discussed in this report due to lack of expertise in the project group: transport and handling of processed waste products, the effect of scaling up the technology to larger sanitation networks, the organizational and legal aspects, and sanitation education. Sanitation based on water transport as sewerage is also not considered. The separation between the use of excreta and nightsoil, and not wastewater is, however, in some respect artificial, because the range of pathogens and the health risks associated with their use are of a similar nature (Cross & Strauss, 1986).

The appendices gives an overview of other alternative sanitation methods not prioritized in this project, e.g. greywater issues and treatment of waste in anaerobic digestion producing biogas.

Information in this report is mainly from peer reviewed journals and published books, not from field data collected by the authors.

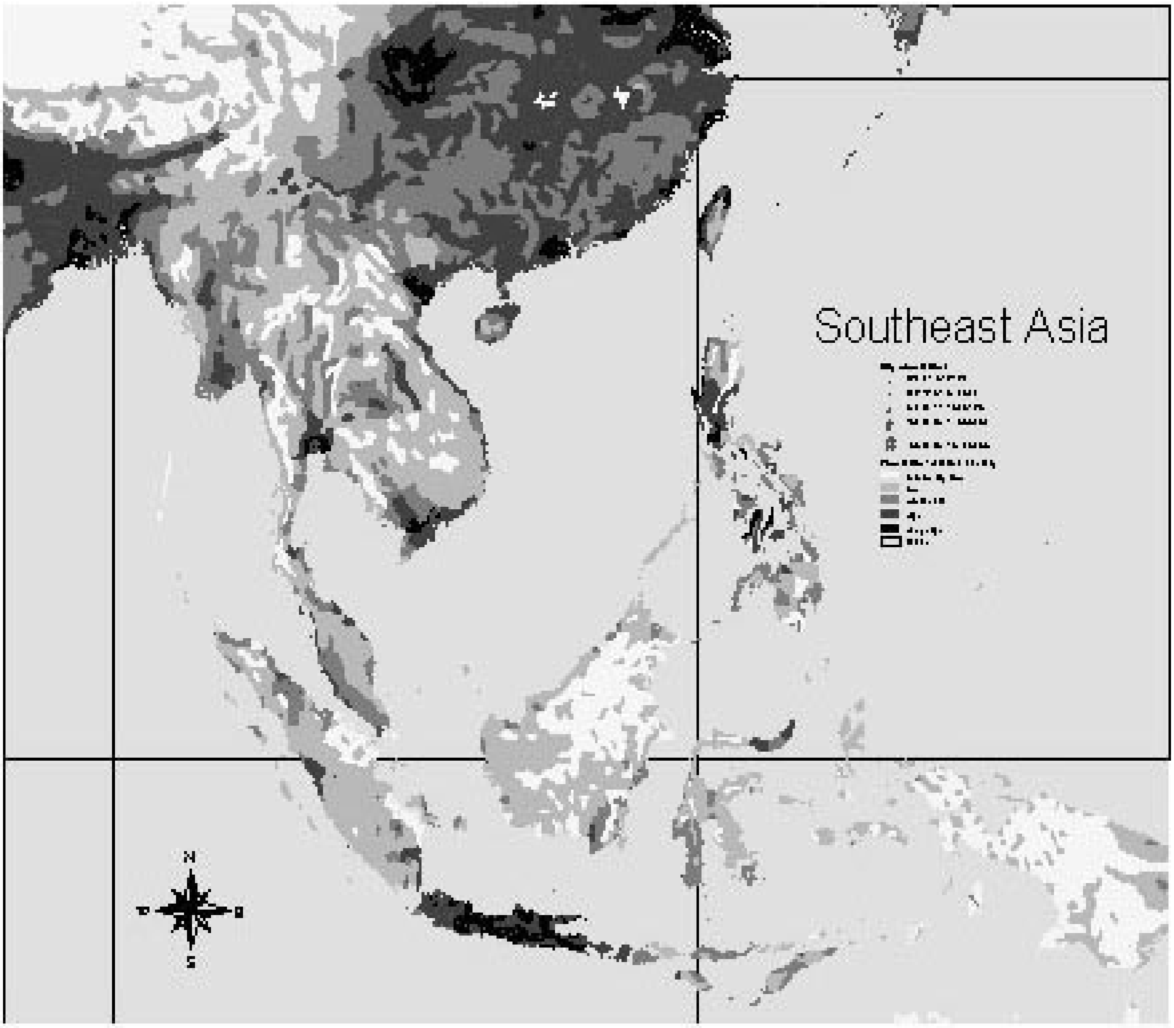

Figure 3. The distribution of precipitation and population density in South East Asia

2. Objectives

The main objective of this report is two-fold: (1) to explain the prospective role of ecological sanitation in low income or developing countries, with emphasis upon Southeast Asia, and (2) outline an evaluation procedure for ecological sanitation systems that strives for zero emissions and optimal recycling of energy and nutrients.

The objective is not to evaluate the actual systems themselves. Rather, it is to formulate an evaluation process, which integrates technology, health and environment, culture, and economy. Hence field tests are not included. We envisage, however, that the evaluation procedures outlined – along with the interdisciplinary evaluation forms – would be put into practice, by a team of skilled evaluators. Ideally, the evaluators will have demonstrated four essential qualities: (1) technical competence in ecological engineering, (2) sensitivity to cultural impacts, (3) an acute awareness of economic considerations, and (4) field experience in sanitation and health programs. Unlike the plethora of generic evaluation literature, which either describes toilet systems or outlines “how to” evaluate hygienic standards, the proposed procedures and forms aim to truly evaluate the *sustainability* of ecological sanitation solutions.

3. Problems with existing sanitation

The juxtaposition of conventional systems with ecological alternatives focuses on the key issues: health, technology, environment, and economics. A fundamental concern is the destruction of pathogens and recycling nutrients, which leads to a review of aerobic composting, urine diversion, dehydration, filtration, etc.

The worst sanitation scenario is water piped into densely populated areas, with no wastewater treatment (local or offsite), plus unfavorable disease control. Generally, piped water increases the polluted volume from 0.2 L per day (with urine diversion) to 40-400 L per day. In a conventional piped sanitation system annual effluent for each person is 400-500 L of urine and 50 liters of feces flushed with 15000 L of water, often purified. Water from the bathroom, kitchen and other household applications, often called greywater or sullage, is added in the order of 15 000 to 30000 L for each person annually. Along the pipeline, drainage water, surface run-off and stormwater are added with wastewater from industry. In many cases, there is no treatment at the end of the pipe and polluted water is discharged into watercourses. In developing countries 90- 98% of the wastewater is emitted untreated.

Even when worst case situations are mitigated, for example with traditional local treatment (septic tanks), problems frequently arise:

- Improper installation, use, operation and maintenance of flush toilets and treatment systems
- Poor siting of septic tanks in high density areas, impermeable ground conditions or on highly permeable soils, in areas with high water tables such as tidal flats with regular flooding conditions
- Leaching tanks and pipes
- Lack of fields for safe disposal of partially treated effluents
- Lack of sludge removal service at affordable costs
- Lack of sludge treatment facilities or failure of operation of such facilities

- High consumption of valuable water

In a study from the Kau-Ping river in Taiwan, 7 out of 8 samples of raw water, and 40% of the samples from treated water contained *Giardia* and *Cryptosporidium* parasites (Hsu et al., 1999). Even for larger river systems pathogenic bacteria like *P. aeruginosa* can survive nearly one month after applied as sewage discharge (De Vincente et al., 1988). Table 1 shows that Asia and Latin America have rivers with fecal coliforms > 100,000, but even in Europe there are 18 rivers with fecal coliforms between 1000-100,000, due to extensive sewerage and lack of adequate treatment.

Table 1. Fecal coliforms in rivers (Strauss, 1996)

	No. of rivers per category and region			
Fecal coliforms	Asia & Pacific	North America	Latin America	Europe
< 10	1	8	0	1
10-100	2	4	1	3
100-1000	14	8	10	9
1000-100,000	12	3	11	18
> 100,000	3	0	2	0

Fang (1998) made an evaluation of the sanitation component in previous World Bank projects. The experiences from this and other evaluations and projects can be summarized as follows:

Application of technology

Some toilet designs have proved effective for low-cost local sanitation. Care must be taken to address their limitations when selected for a specific project. Innovative technology is needed for low-cost sanitation in low-income urban areas with high population density. For example there are still no fully satisfactory solutions for emptying and disposing pit latrine contents. It is also difficult to determine and measure groundwater contamination by pit latrines, especially in saturated zones below the groundwater table. Although many Bank projects monitor groundwater bacteria, little effort has related contaminant problems with the location of pit latrines. This is either because water supply and sanitation components of a project are not coordinated, or because the beneficiaries and the project implementators organizations do not understand the link between water source contamination and inappropriately positioned pit latrines.

Toilet design - community involvement

The importance of selecting an appropriate toilet design for a specific project area can not be overemphasized. Getting communities involved in the selecting process is a key to finding an economically and culturally acceptable design. However, most of the projects reviewed did not seem apply this concept. Frequently, the most popular technology was chosen by the government and there was no evidence showing that any modifications were made to accommodate special economical and cultural backgrounds.

Low priority of sanitation programs

It is commonly true that project beneficiaries, sometimes even project managers, do not understand the importance of the health benefits that sanitation programs are intended to bring. Limited political support and low public awareness that sanitation programs often receive result in many of the difficulties encountered. Rarely does a Bank report give the reasons for the failure or success of the sanitation portion of a project. Other information related to sanitation, such as toilet design, cost sharing and recovery, and facility operation and maintenance, are usually absent in World Bank reports as well.

Users' perceptions of on-site sanitation

Most toilet users considered toilets to be some kind of a status symbol. The motivating factors for many households to build a toilet are not hygienic but rather primarily social: comfort, convenience and privacy. It is true even for households that have been exposed to health education. Project implementers should focus on the social benefits that a toilet can bring as well as the hygiene benefits.

Sustainability

Many of the projects reviewed had trouble sustaining the sanitation facilities and the improvements they bring. This is often the result of a low sense of ownership by the facility users, or the users' unawareness of the operation and maintenance procedures.

Based on the problems described above it is obvious that sanitation systems should receive more attention and thorough evaluation before and after implementation. Many local variables will influence the choice of an appropriate sanitation system (Winblad et al., 1998):

- Climate – temperature, humidity and precipitation
- Topography and soil type – important for construction and water movement
- Abundance of water – the relative importance of water conservation
- Energy – the availability of local energy inputs, such as solar radiation
- Social/cultural – customs, beliefs, values and practices
- Economic – the financial resources of both individuals and the community
- Technical capacity – the level of technology that can be supported locally
- Infrastructure – the level of both physical infrastructure and existing services that might help support a sanitation system (i.e. extent of water supply, roads, transport, public health network, educational system etc.)

4. Fundamentals of ecological sanitation

This chapter describes the contents of human excreta and fundamental processes of ecological sanitation. [1]

4.1. Characteristics of human excreta

Industrialized countries produce daily about 1.5 L of toilet waste per person, of which 0.25 L are feces, 1.2-1.3 L are urine and 10-20 g are toilet paper (Øberg & Molland, 1982). These amounts and the composition of the waste can vary depending on nutrition, climate, health, age and lifestyle. If the water is evaporated or removed, and the solids are composted, the total daily volume can be reduced to 0.1-0.2 L per person and day.
Ecological sanitation can recycle nutrients as outlined in Figure 4. This chapter describes the content of human excreta and basic processes that are relevant for local ecological sanitation.

4.1.1. Chemical composition

Measurements of the constituents in human waste are given in Table 2 and

Table 3. Human excreta is wet and nitrogen (N) rich. Urine contains the major part of the excretion of nitrogen. This comes in the form of urea, or $CO(NH_2)_2$, about 30 g per person/day, which in contact with water quickly is transformed into ammonia.

Urine contains about 95% water and feces about 80% water. Most of the nitrogen, phosphorus and potassium is contained in the urine, whereas the organic matter (mostly carbon) is contained in the feces.

Table 2. Estimated mean content in human excreta (SEPA, 1995; Hellstrøm & Karrman, 1996; Rohrer, 1996)

	Urine		Feces		Total
	g/pe*d[a]	% of dry weight	g/pe*d	% of dry weight	G/pe*d
Wet weight	900-1200		70-140		1000-1400
Dry matter	60		35		95
Nitrogen (N)	11-13	18	1.5	4.3	12.5
Phosphorous (P)	1.0-1.1	1.7	0.5	1.4	1.5
Potassium (K)	2.5	4.2	1.0	2.9	3.5
C/N	0.8		< 10		

[a] g/pe*d = grams per person and day

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[1] Though not treated intensively in this report ecological sanitation with wastewater production can also be considered as an option. A short description of these systems is given in appendices.

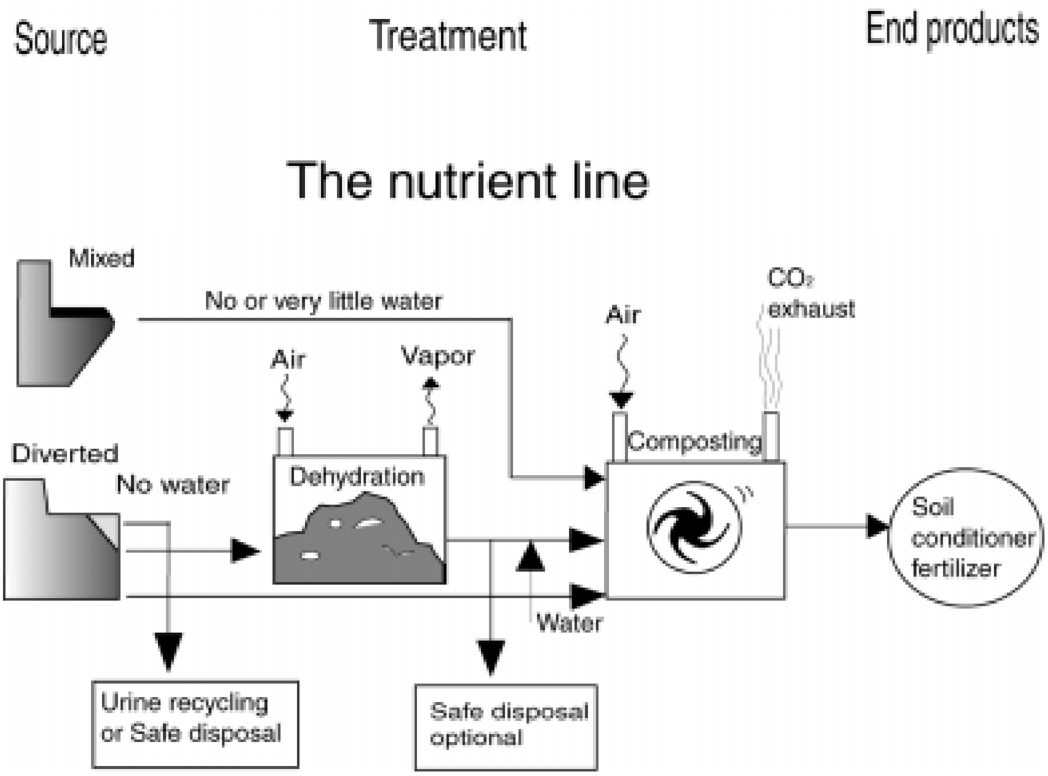


Figure 4. Nutrient recycling

Table 3. Estimated mean content in human excreta and nightsoil (Cross & Strauss, 1986; Rohrer, 1996) [a]

	Urine		feces		Nightsoil	
	g/pe*d [b]	% [c]	g/pe*d	% [c]	g/pe*d	% [c]
Wet weight	1200		250		1450	
Dry matter	60		50		110	
water %	95		80		94	
Carbon (C)	8	13	24	48	32	29
organic matter	45	75	46	92	91	83
Nitrogen (N)	10	17	3	6	13	12
Phosphorous (P)	0.5	0.8	0.4	0.9	0.9	0.8
Potassium (K)	0.9	1.5	0.3	0.7	1.6	1.1
C/N	0.8		8		2-25	

a representative for low income countries b g/pe*d = grams per person and day, c % of dry weight Nightsoil is feces and urine often mixed with dry soil or other additives.

The tables above show that the excreta volumes measured in high and low income countries basically is the same, though variations in the content can be found. e.g. in phosphorous and potassium. Also, vegetarians generally produce higher quantities of feces with a higher water content than people who eat meat.

4.1.2. Pathogens

Table 4 through Table 7 list the important excreted viruses, bacteria, protozoa and helminths and their associated diseases. All of these diseases are endemic in many areas of tropical countries, but prevalence varies depending on region, continent, type of settlement (rural, urban), climate and other factors such as agricultural practice, eating habits, culture and society.

Table 4. Important Viruses excreted in feces (Cross and Strauss, 1986)

Agent	Disease or major symptom
- Enteroviruses	
polio-	Poliomelitis, paralysis, meningitis, fever
Echo-	Diarrhea, fever, meningitis and others
Coxsackie A and B	Meningitis, respiratory disease, fever and others
New eneteroviruses	Encephalitis, meningitis, conjunctivitis, and others
-Hepatitis A virus	Infectious hepatitis
-Rotaviruses, Norwalk agent and other viruses	Gastroenteritis (diarrhea, vomiting etc.)

Viruses are immediately infective upon release into the environment, they have no latent period. The minimal infective dose is usually low, it is believed that even a single virus may infect. Enteric infections are predominantly transmitted through person-to-person contact (fecal-oral or oral-oral). Other routes such as water or food have been found to play a lesser role with hepatitis A, poliomyelitis and gastroenteritis transmission.

Table 5. Important Bacteria excreted in feces (Cross and Strauss, 1986)

Agent	Disease or major symptom
- *Campylobacter* *Fetus ssp. Jejuni*	Diarrhea, vomiting
- Pathogenic *Escheria Coli*	Gastroenteritis (diarrhea)
- *Salmonella* *S. Typhi* *S. paratyphi* other *Salmonella*e	Typhoid fever Paratyphoid fever (including diarrhea) Food poisoning and other salmonelloses
- Shigela species	Shigellosis (bacillary dysentery) including diarrhea
- Vibrio *V. cholerae* other vibriosis	Cholera (diarrhea) Diarrhea
- *Yersinia enterocolitica, Y. psedotuberculosis*	Diarrhea, miscellaneous diseases

The bacterial pathogens of major epidemiological importance are listed in Table 5. *Salmonella*e may be transported by many routes and are of prime importance in association with excreta use on fields. *Campylobacter jejuni* and pathogenic *E. Coli* has recently been found to be a major cause of diarrhea, mainly among children in poor communities. *Salmonella*e routes in low income countries are more man-specific than in areas where meat production is dominant. Persons with reduced resistance to disease e.g. due to malnutrition or other diseases, may become infected with small *Salmonella* doses. For them person-to-person contact can play an important role if hygiene is poor.

The minimal infective dose and persistence of *Shigella* is lower than most other bacterial pathogens.

Cholera is known mainly as an epidemic disease with a high fatality rate. In many parts of the world, however, cholera is endemic and constitutes one of many variety of diarrhoeal diseases.

Table 6. Important Protozoa excreted in feces (Cross and Strauss, 1986)

Agent	Disease or major symptom
- *Balantidium coli*	Diarrhea, dysentery, colonic ulceration
- *Entamoeba histolytica*	Colonic ulceration, amebic dysentery, liver abcess
- *Giardia lablia*	Diarrhea, malabsorption
- *Cryptosporidium* p. oocyst	Diarrhea, malabsorption

Entamoeba histolytica, *Giardia* and *Cryptosporidium* are excreted protozoal pathogens of major public health importance, transmitted through fecally-contaminated hands or via contaminated food or water. The endemic prevalence can reach 30% or more. Load of excreted cysts from infected persons can reach 10^5-10^8 per gram feces, while the median infective dose is 10-100.

Cryptosporidium pavrum and *Giardia* lamblia have been recognized as major causes of waterborne diseases in the past decade (Schaffer, 1997; Gallaher et al., 1989; Smith, 1990; Moore et al., 1993, MacKenzie et al., 1994). These gastrointestinal protozoan parasites are transmitted by environmentally resistant cysts and oocyst (Current, 1986; Robertson et al., 1992). Because they can use a number of mammalian reservoir hosts besides humans there is an amplification of cysts and oocysts which are potential challengers to water pollution.

Table 7. Important Helminths excreted in feces (Cross and Strauss, 1986)

Agent	Disease or major symptom
Nematodes (Roundworms)	
- *Ancylostoma duodenale*, *Necator americanus* (hookworm)	Hookworm (anemia)
- *Ascaris lumbricoides* (roundworm)	Ascariasis (respiratory, digestive or abdominal disturbances, bowel obstruction)
- *Enterobius vermicularis* (pinworm)	Enterobiasis (anal itching)
- *Strongyloides stercoralis* (threadworm)	Strongyloidiasis (often asymptomatic: skin inflammation; lung or abdominal disturbances)
- *Trichuris trichuria* (whipworm)	Trichuriasis (often asymptomatic: bloody stool, diarrhea)
Cestodes (Tapeworms)	
- *Diphyllobothrium latum* (fish tapeworm)	Diphyllobothriasis (often asymptomatic: anemia, diarrhea, obstruction)
- *Humnolepsis nana* (dwarf tapeworm)	Hymenolepiasis
- *Taenia saginata* (beef tapeworm)	Taeniasis (often asymptomatic: digestive disturbances)
- *Taenia solium* (pork tapeworm)	
Trematodes (Flukes)	Chlonorchiasis, Opisthorchiasis (often asymptomatic: diarrhea, abdominal and liver disturbances)
- *Chlonorchis sinensis* (chinese liver fluke)	
- *Opisthorchis*	Schistosomiasis, bilharziasis (obstruction, blood urination, bladder tumors)
- Schistosoma	
S. haematobium	
S. japonicum	
S. mansoni	Paragonimiasis (blood coughing, cerebral disturbances)
- *Paragonimu westermani* (lung fluke)	

Worm infestation is a worldwide phenomenon, both in low and high income countries, particularly where communities use wastewater and sludge in agriculture. Viral, bacterial and protozoal pathogens reproduce asexually. Among the helminth pathogens, Cestodes (tapeworms) and trematodes (flukes, with the exception of schistosomes) follow the same pattern. Nematodes and schistosomes have separate sexes, so only those persons infected with both male and female worms have internal production of eggs. The infection cycles of helminths are long compared to those of viruses, bacteria and protozoa, with latency varying from days (hookworms, *Ascaris*) to weeks (*Taenia, Trichuris, Clonorchis*). *Ascaris* eggs have been shown to survive up to 7 years after applied to soil (Cross & Strauss, 1986).

Table 8. Epidemiological classification of excreted pathogens (Cross and Strauss, 1986)

Category I and II=activity decay with time, III=latency period, IV&V=with intermediate host

Pathogen	Excreted load[a]	Latency[b]	Prevalence[c]	Infective dose[d]	Intermediate host
Category I					
Enteroviruses	10^7	0	3 months	Low	None
Hepatitis A	10^6 ?	0	?	Low ?	None
Rotavirus	10^7 ?	0	?	Low ?	None
Balantidium coli	?	0	?	Low?	None
Category II					
Campylobact. fetus	10^8	0	7 days	High ?	None
E. Coli	10^8	0	3 months	High	None
Salmonella Typhi	10^8	0	2 months	High	None
Other *Salmonella*e	10^8	0	3 months	High	None
Shigella ssp.	10^7	0	1 month	Moderate	None
V. Cholerae	10^7	0	1 month ?	High	None
Yersina enterocolitica	10^5	0	3 months	High ?	None
Category III					
Ascaris lumbricoides	10^4	10 days	1 year	Low	None
Hookworms	10^2	7 days	3 months	Low	None
Strongyloides stercoralis	10	3 days	3 weeks	Low	None
Trichuris trichura	10^3	20 days	9 months	Low	None
Category IV					
Taenia s. *Taenia* solium	10^4	2 months	9 months	Low	Cow or pig
Category V					
Schistosoma haematobium	4/ml urine	5 weeks	2 days	Low	Snail
S. japonicum	40	7 weeks	2 days	Low	Snail
S. mansoni	40	4 weeks	2 days	Low	Snail
Leptospira spp.		0	7 days	Low	None
Clonorchis s.	10^2	6 weeks	life of fish	Low	Snail and fish

[a] Typical average number of organisms per g of feces [b] Typical minimum time from excretion to infectivity [c] Estimated maximum life of infective stage at 20-30 C [d] Low=<10^2, Medium=10^4, High=>10^6

4.1. Pathogen Removal

The health risk of excrement is generally reduced when the waste is kept in a as small volume as possible. This means that mixing of human waste with water contributes to a spreading of the pathogens. The concept of ecological sanitation is far more than to store and treat the waste at or close to the source and thereby reduce potential spreading of the health risk. The main goal of local sanitation is to remove pathogens thus reducing health risks. The time it takes for all organisms of the same species to die is referred to as the die-off rate. This time varies with the type of microorganism. Exceptions from the simple reduction scheme are *Salmonella* and some other bacteria, which may temporarily increase in number outside the body. The prevalence of eggs from parasitic worms are long compared to those of viruses, bacteria and protezoa because they are adapted to the envrionment.

A number of environmental conditions influence the survival time of the pathogens. The major conditions considered being important for die-off are: temperature, moisture, nutrients, other organisms, sunlight and pH.

Table 9. Environmental factors and how they are involved in pathogen destruction in ecological sanitation (adapted from Winblad et al., 1998)

Environmental factor	How pathogens are destroyed
Temperature	High temperature
Moisture	Low moisture
Nutrients	Few or no nutrients
Microorganisms	Large amount and diversion of microorganisms lead to competition (antagonism)
pH	High pH
Sunlight	Ultraviolet radiation

Temperature-time relationship

The most effective mode of disinfecting wastes is based on temperature-time relationships. Raising the temperature to 60°C (high temperature composting) will result in a near instant kill for most pathogens in feces (Figure 5). But increased temperatures at levels < 60°C will lead to pathogen destruction over time. Temperature-time relationship is also important in the destruction of infectious insects and other vectors. The US EPA “Processes to Further Reduce Pathogens” (40CFR Part 503) states that 14-days treatment with an average of 45°C, and no measurement below 40°C, destroys vectors in biosolids (US EPA 1993).

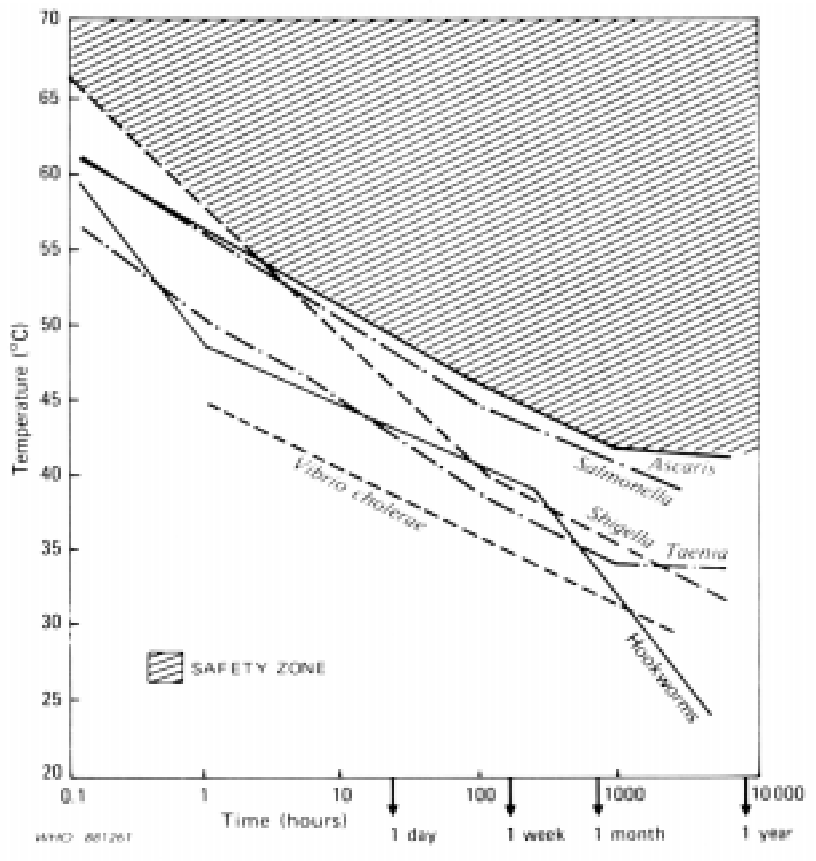


Figure 5. Influence of time and temperature on selected bacterial and helminthic pathogens in excreta and sludge (From Mara and Cairncross 1989)

With two or more factors unfavorable for pathogens (e.g. high temperature and low moisture) the die-off time of pathogens is further shortened. The right combination of the environmental factors is often the key to understanding the mechanism of pathogen destruction in ecological sanitation systems. Composting has been shown to be more effective in destroying the tobacco viruse than the temperatures alone would be (Nilsson & Åhman 1991).

As soon as human waste is deposited it starts to decompose, eventually becoming a stable material with no unpleasant smell and containing valuable plant nutrients. During the decomposition pathogens are destroyed because they are unable to survive in the environment of the decomposing material.

In order for a fecal product to be “safe” for unrestricted use as a fertilizer, it is crucial that those pathogens with low infective dose are reduced to insignificant numbers. *Ascaris* eggs are particularly persistent. The performance of treatment systems, including storage, should therefore be measured primarily by their potential for attaining a product which is free of, or which contains a very low count of *Ascaris* eggs. Such a product would then be free of other pathogens (Cross & Strauss, 1986).

4.2. Aerobic biological sanitation – Composting

The composting process – decomposition of organic matter

Composting is aerobic decomposition done by microorganisms (bacteria, fungi, actinomycetes and protozoa). Aerobic bacteria combine some of the carbon in organic matter with oxygen in the air to produce carbon dioxide while releasing energy. Some energy is used by the bacteria for reproduction. The rest of the energy is converted to heat, raising the temperature to more than 70°C under optimal condition. The heat evaporates moisture from the waste, which again is important for an odorless operation. Composting works better with large volumes than small, as for all biological processes, indicating that problems will be more frequent when operating on small (household) scales.

Composting is a controlled and accelerated process that occurs naturally in topsoil when dead organic matter such as leaves and other plant residues is decomposed. The end product, compost, is similar to the humus produced in the topsoil layer. Farmers and gardeners throughout the world have practiced composting for millennia. In China, the practice of composting human wastes with crop residues has enabled the soil to support high population densities without loss of fertility for more than 4000 years (McGarry & Stainforth, 1978).

Removal of pathogens

The removal of pathogens by heat starts at temperatures above 38°C but is complete at temperatures above 45 °C. Fecal pathogens have different resistance to heat exposure. All fecal microorganisms, including enteric viruses and roundworm eggs, will die if the temperature exceeds 46°C for one week. Fly eggs, larvae and pupae are killed at lower temperatures. Investigations have shown that fecal microorganisms are killed even at temperatures lower than 46°C, due to drying, antagonism and air supply.

Environmental and health impact during processing

The intensive composting process does not produce any majoor environmental impacts. CO_2 is produced from the microorganisms when digesting organic material. If the process is poorly operated, malodorous and greenhouse gases like volatile organic acids, nitrous oxide, methane, ammonia and other nitrogen- and sulfurous compounds can be produced. The emitted gases from a compost toilet or larger composting piles do not give cause to health risk. Flies, present in the toilet if temperature/moisture is unfavorable, may however serve as hosts for disease agents.

Different techniques, from simple covering too artificial bio-filters, are available to remove gases, but they are costly and have to be maintained. An effective step against flies, which also helps the decomposition process, is additional adding of dry structure material.

Leakage from the composting process may occur if the material is too wet. Leakage from the compost container may contain human pathogens and nutrients that may pollute rivers and ground water. Controlled infiltration can be an option if the compost toilet is likely to produce leakage.

End products

The composting process is finished when the microbial activity has fallen to a minimum and all pathogens are destroyed. This is normally the case after 4-12 months. The end product is a stable, fertilizer and soil conditioner that easily can be spread on the field as a dry material. The compost normally will have lost about half the organic matter due to gas emissions and even more of the total weight due to evaporation. The nitrogen losses are smaller and the nutrition value of the compost (nitrogen, phosphor, potassium and others) as well as the humus-like structure makes the compost a valuable soil conditioner, especially in regions where organic matter represents a limiting factor in the agriculture. The main effect of compost in soil is hence the improved physical behavior of soil, such as water and temperature household and cation exchange capacity {SHIRALIPOUR, et al. 1992 #1020}) and {SHIRALIPOUR, et al. 1992 #170}). Recent studies have revealed that compost from organic waste may contribute to disease suppression in the crop {Marull, Pinochet, et al. 1997 #1070}). It is also accepted that compost has a positive effect on soil biology, improves diversity of the microorganisms and soil enzymatic processes like nitrogen mineralisation {SERRAWITTLING, et al. 1995 #30}).

Criteria for a successful composting

Successful composting depends on a basic understanding of the process. Human waste is wet, rich in N and has little structure for composting (Table 2). It needs to be amended with structure material like dry earth, bark, straw, cones, wood ash or other material rich in dry matter, structure or carbon (C). The most important aim of adding structure is to rise the dry matter content and enable air supply to the microorganisms. Human excreta is about 90% water if both feces and urine is treated and about 80 % if only the feces is treated. The maximum permissible moisture content of human waste for biological decomposition is about 55-65% (see Table 10, where excreta is comparable to manure). If the structural stability is low, the material stick together, and even mechanical turning will only result in a short-term increase of oxygen supply until the material collapses again. Materials with low structural stability (such as human feces) must be mixed with materials with high structural stability (Rohre, 1996).

As Table 10 suggests, the maximum moisture content can be increased by adding fibrous or woody material. Adding dry material without structural capacity, like wood ash, means the moisture content should not exceed 65%. When urine is composted together with feces, and no steps are taken to remove the liquids (either by evaporating or drainage), the water content of the input material is higher than the optimum range of the composting process.

Excess water can be treated in two ways. Firstly the surplus water can be leached out of the container. The leakage must then be infiltrated safely or stored to prevent pathogen distribution and unwanted pollution to the groundwater. Secondly the water content can be reduced by adding dry material. This can be dry soil or ash but also wood chips, cones, paper and other organic material.

Table 10. Maximum permissible moisture content (Golueke, 1994)

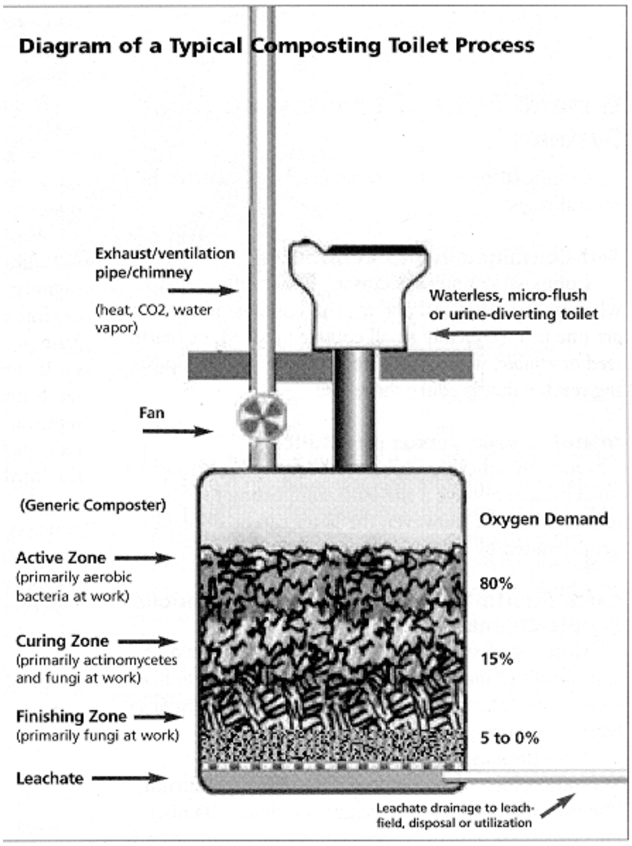
Type of waste (main fraction)	Moisture content (%)
Straw	75-85
Wood (sawdust, small chips)	75-90
Paper	55-65
Wet Wastes (vegetable trimmings, lawn chippings, garbage, etc.)	50-55
Municipal Refuse	55-65
Manure (without bedding)	55-65

In addition to moisture content and structure, the human waste has a need for carbon material for an optimized composting process. In the decomposition of organic matter CO_2 is released. If the removed CO_2 results in a surplus of nitrogen, malodorous compounds can be produced. It is therefore recommended to add carbon rich material as amendment. For optimal composting the C/N-ratio must be between 20-30 (Rohrer, 1996). For a mixture of kitchen waste (C/N = 12-20/1) and garden waste (C/N about 50/1) it is usually recommended to add from one to four volume parts of food waste to each part of garden waste. For human excreta similar recommendations can be made and therefore considerable amounts of C are needed. The adding of one cup (2-3 handfuls) of dry bark, woodchips or straw, or other material, after every toilet visit is recommended. But also easy available carbon sources like vegetable waste normally have a positive effect on the composting process. A summary of the characteristics from different additives is given in Table 11.

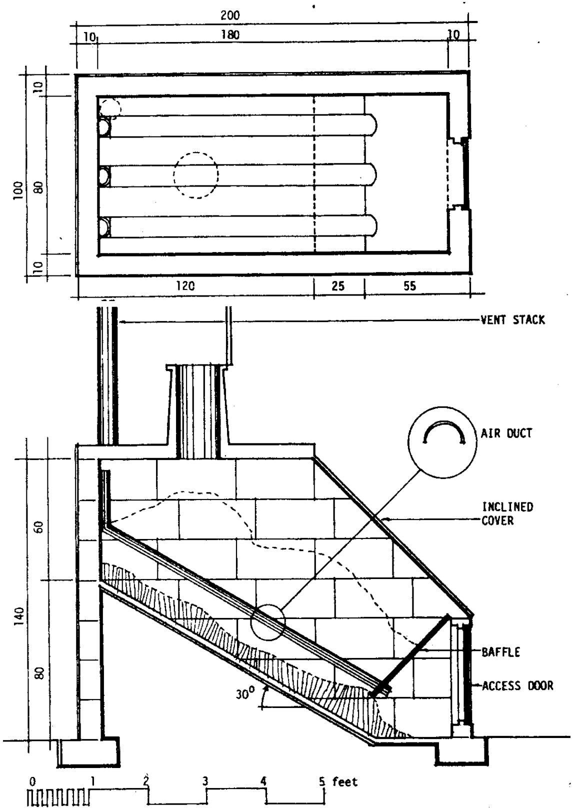
Table 11. Technical description of processing chamber additives (Rohrer, 1996)

Additive	Humidity	C/N	Structural stability
Lawn cut (fresh)	Humid	12-25	low
Kitchen waste	Humid to medium	12-20	low-medium
Straw	Dry	100	high
Garden waste	Medium	20-60	medium
Bark	Rather dry	100-130	high
Ash	Dry	No C	low
Woodchips	Dry	100-150	high

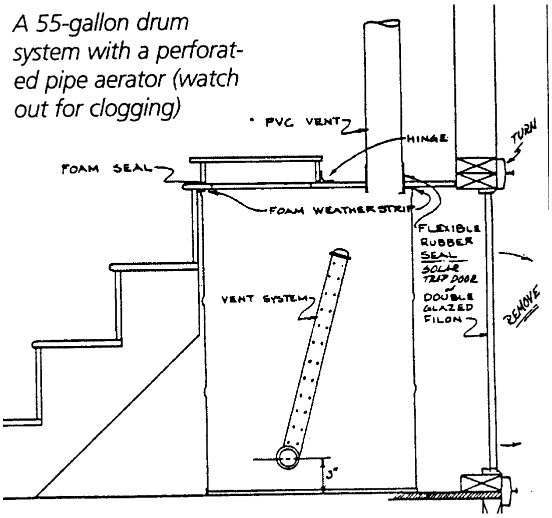
The characteristics of a malfunctioning composting toilet is very much the same as for a traditional pit latrine with malodor, flies and a deficient pathogen destruction.



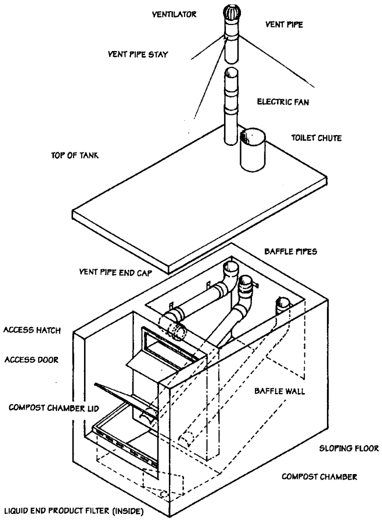
Key design considerations are processing zones and oxygen demand.



Sloped-bottom single-chamber compost toilet. Note air ducts for aeration.



Design plans for 55-gallon drum system with perforated pipe aerator and urine diverter



Recycle All Waste (RAW) single-chamber composting toilet system

Figure 6. Theoretical processes of compost appied to single-chamber toilet design (Illustrations: Del Porto & Steinfeld, 1999)

The task of composting human excreta is easier in dry and hot climates due to higher evaporation rates. This does however not imply that composting human excreta is not possible in humid climates. Special inventions like the CCD composting toilet has proved to be able to solve the humidity problem (Figure 13, Winblad, ed. 1998).

The emptying and disposal of the finished compost must be planned and managed in a way that ensures that the compost is stabilized (pathogens destroyed). This can be achieved by using several compost containers, so that a minimum retention time is ensured before a filled container is used again. If only one container is used this must be constructed in a way that makes it possible to remove only the finished and stabilized part of the compost

4.3. Dehydration

In a dehydrating toilet the content of the processing container is dried with the help of heat, ventilation, biological activity and the addition of drying material. The moisture content should be reduced as quickly as possible to below 25%, to destroy pathogens and avoid smell and fly breeding (Winblad et al., 1998). Dehydration differs from composting in that the former is based on drying instead of biological processes. Whereas composting toilets aim at optimal conditions for biological activity for removal of pathogens by increasing the temperature, the dehydration toilet rely on both the temperature, adding of dry materials and pH increase.

The concept of sanitation through dehydration is therefore effective when:

- urine is kept away from the feces and treated separately
- climate enables a rapid heating and drying of the material
- dry material like ash and dry soil are available
- pH is increased to above 8-9

If these conditions are met, the dehydration toilet may be a cost effective alternative to composting toilets.

If the dehydration process functions well, the shape of the dry material should build up to a conical heap. If the shape of the heap becomes flat this indicates that the water content is too high. Another sign of a high moisture content is egg or larvae in the material.

Removal of pathogens

The removal of pathogens by dehydration follows similar principles as the composting process where temperature is the main factor (Table 9). In dehydrating toilets temperatures are normally not so high as in composting toilets. Also there is no antagonism (competition from other microorganisms). This is compensated by the drying effect and the rising of pH, when lime or ash is added. For pathogen destruction it is also important that the pH is increased as much as possible, probably much due to ammonification of nitrogen (Cross & Strauss, 1986). A concern may be that pathogens become endospores, which can survive for decades until rehydrated. There has been little reports on the hygienic quality of the end products from dehydrating toilets, but those available indicate that a sufficient hygienization takes place (see Chapter 10).

Environmental and health impact during processing

A functioning dehydration toilet should not produce any health risks or pollution during processing. It is critical that the moisture content is quickly reduced as much as possible and remain low. Otherwise odors, leakage and fly breeding can take place. Ammonia may be evaporated during drying, but only in small concentrations. The impacts of a malfunctioning dehydration toilet are very much the same as for composting toilets.

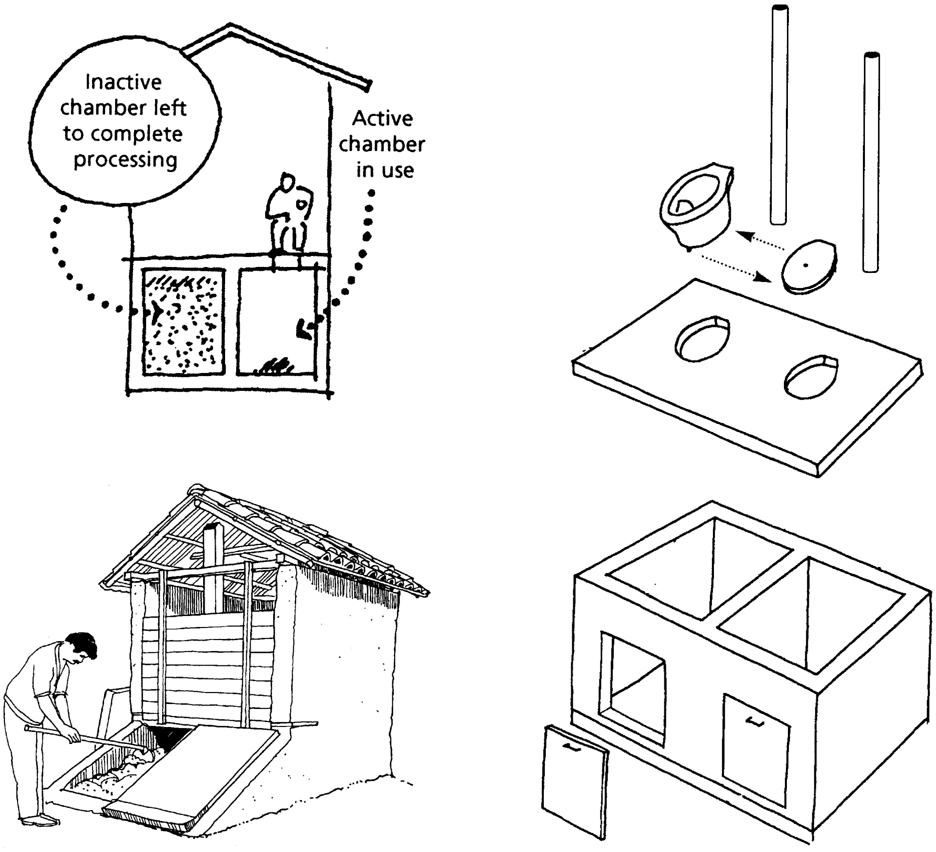
End product

The end product differs from the compost in its composition. Since the human waste has not been decomposed to a stable material the end product may look unesthetical containing toilet paper and other undecomposted constituents. Furthermore it cannot be regarded as a good fertilizer as long as the dried organic matter will require biological decomposition before the nutrients are available for the plants. This unfinished decomposition may even harm the plants and especially the ungerminated seeds and seedlings either by the production of harmful acids or by the lack of essential oxygen in the root system that is needed for decomposition. This effect, however, may be used advantageously in controlling weeds.

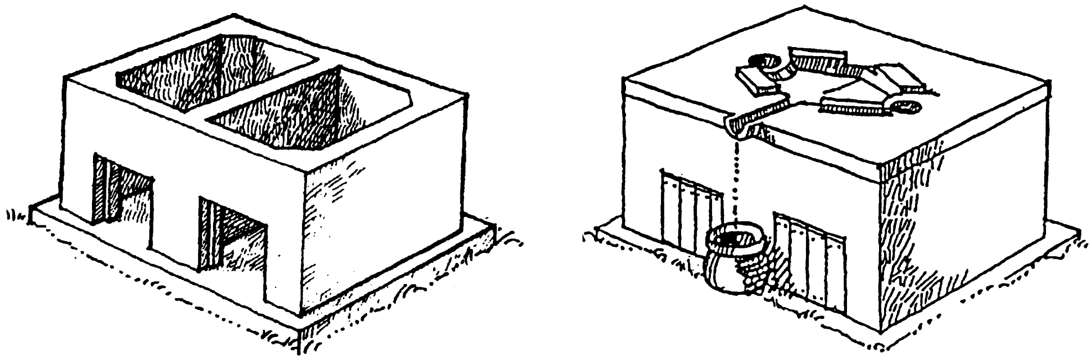
Criteria for a successful dehydration

Essential criteria for successful dehydration are the removal of urine, a relatively high temperature in the process chamber, and additives working as dry and pH-increasing material. If one of these criteria cannot be met then dehydration may fail, pathogen reduction will not be complete and odors and flies may become a problem.

Table 12 shows additives suitable for dehydration toilets.



The double-vault (or twin-bin) system. When one side is full, move the toilet stool.



(left) Chamber of Vietnamese double-vault toilet, with 30 x 30 cm openings for removal of dehydrated material. (right) Squating slab for urine diversion, a pot for collecting urine.

Figure 7. Double-vault or twin-bin toilet systems (Illustrations from Windblad ed. 1998)

Table 12. Technical description of processing chamber additives (primarily for dehydration toilets)

Additive	Expected pH in ash	Expected pH in process chamber	Added volume (ml/day)*	Reference
plant ash	11.3	9.5-10.3	1000-3000	Nga, 99
plant ash	11	9-10		Wang, 99
rice-husks	10.6	8.4-9.0	> 3000	Nga, 99
coal ash	8	7		Wang, 99
sawdust/husk	7-8	7-8		Wang, 99
loess	6-8	6-8		Wang, 99
shell sand	7-8	7-8		Jordforsk,99
crushed concrete (demolition waste)	11-12	10-11		Haarstad & Mæhlum, 99

- assumes 5 pe*2 = total of 10 visits/day

4.4. Urine diversion

The idea of dehydrating toilets is based on two principles. Firstly, urine contains the most nutrients and is basically sterile (see Table 2 and

Table 3). Secondly, a major factor in the biological decomposition of the solid waste (composting) is the moisture content. Feces contains approximately 80 % moisture. When mixed with urine, excrement is usually more than 90 % water; however, the optimal range for decomposition is between 45-70%. If the urine is kept apart from the feces, the moisture content is closer to the optimum range of biological decomposition.

Table 13. Nutrition value of human urine (Winblad and others 1998), (Øberg and Molland 1982)

Nutrient	Concentration with source diverting (g/l)	Concentration with filtering/drainage (g/l)	Annual adult load (g)
Nitrogen	11	2,7-5,9	4000
Phosphorus	1,0	1,5-3,1	400
Potassium	2,5	1,2-3,3	900

Urine can, however, be toxic to seeds and plants. According to Adamsson & Dave (1996), the environmental effect EC_{50} of fresh morning urine for *D. magna* was 5.4 +/- 2.9 volume-%. When stored in 30 days the toxicity increased 5 times due to ammonia transformation, which can be controlled by adding pH regulators (e.g. organic acids).

If a normal water closet is used, the diluting effect reduces the nutritional value of the urine and increases the costs for storage and handling of the wastewater. The concept of urine diversion is therefore recommended only in combination with low or no water consumption for flushing, or alternatively of diversion also of the flushing water.

Urine separating toilets may use a source-separating toilet seat. For cultures using squatting slabs similar diversion devices are available. The urine is collected in the front part of the toilet whereas the excreta falls into a collecting hole at the back of the toilet.

Urine can also be separated by letting it soak through the solids and collected at the bottom, although the liquid then becomes contaminated. Care must be taken to ensure the hygienic quality of the liquid fraction if stored and reused. Other more sophisticated technologies separate the urine in the toilet with hydro cyclones. The solid feces may either be treated with air supply (composting or dehydration) or without air supply (anaerobic digestion).

Removal of pathogens

Urine from healthy humans is normally sterile. In addition the urine itself has a sterilizing effect on pathogens. But diseases may introduce pathogens into the urine, or dilution with water may reduce the hygienic effect of urine and also favor breeding conditions for eggs and flies. To ensure that the urine is hygienic it can be stored in a tank more than six months, treated with ultra-violet radiation or filtered. The solid fraction can be treated in the same way as mixed human waste, using composting technology, dehydration toilets or pit latrines (see above).

End products

Urine is a valuable fertilizer with high concentrations of nitrogen, phosphorous, potassium and essential trace elements needed for plant production (Table 13). Undiluted it may even be too nutritious for the plants, and care has to be taken to either dilute the urine (one part urine with 2-5 parts of water) or spread it on the fields before sowing.

End product - feces

Although compost from urine diverting toilets contains fewer nutrients than from mixed human waste, the organic matter for soil conditioning is the same as the compost from mixed human waste. Since the content of organic matter often is considered to be the major contributor to the soil (Chapter 4.2) the compost from urine separating toilets is a valuable soil conditioner.

Environmental and health impact

The nitrogen in urine, originally in the form of urea, quickly converts to ammonia that can evaporate to the ambient air. Ammonia is toxic. However, storing urine in a sealed container can minimize ammonia loss to the air. Loss of nitrogen (through evaporation) may occur when spreading urine on soil.

Criteria for successful urine diversion

A successful urine diversion depends on the correct use of the toilet. For squatting slabs this is not a problem, but for toilet stools men always needs to sit on the toilet (if a urinal is not available). For small children a special toilet seat may be helpful. It is important, though, that the sanitation system tolerates a limited amount of improper use, which can never be avoided. In addition the urine pipes must be made of materials that tolerates the corrosive urine.

4.5. Storing and sanitation – Pit latrines

Pit latrines are considered to be the easiest method of local sanitation. Different from composting and dehydration toilet systems, pit latrines are based on long time storage instead of processing.

Pit latrines consists of a slab over a pit with various depth. The systems are cheap, usually waterless and relatively easy to construct. They attracts flies if not covered when not in use (and mosquitoes if the pit is wet) and are often malodorous.

The concept of pit latrines is based on leaching the water from urine and feces. If they are badly constructed precipitation and surface water will enter the pit. The infiltration depends on the soil material below the pit. The infiltration rate can be improved by using proper material.

There are a number of improved pit latrine models. Basically these improved systems utilizes the same principles as the composting and the dehydration toilets. Some toilet systems also divert the urine.

It has been established that the risk of contaminating groundwater from traditional pit latrines is much greater than generally assumed. The distances microorganisms can travel in the subsurface depend on many factors: the depth of the unsaturated zone, the length of the saturated zone, type of organism, the filter factor of the soil, the flow velocity, the soil grain and pore size, the ionic strength of the water (Matthess et al., 1991, Borrego et al., 1987). Experiments using biotracers have shown that pathogenic organisms may spread up to 100 m, considerably more than the “safe” distance of 30 m between pit latrines and wells as generally recommended (Lane et al., 1996). Virus seeding studies in coarse-grained aquifers have observed viruses travelling over 900 m (Noonan & McNabb, 1979). Multiple virus seeding experiments including enterovirus, polio virus and 3 bacteriophages at field scale have shown rapid transport up to over 40 m in an floodplain aquifer (Deborde et al., 1999).

Experiments in laboratory columns with glass beads, coarse sand and shale aggregate showed very little retardation of both parasites and phages, with higher removal in sand (Brush et al., 1999). Once in a watershed both fecal coliforms and enteric phages such as *Salmonella typhimurium* and *Bacteriodes fragilis* persists, especially during summer months (Brenner et al., 1999).

Pathogen removal

The underground transport of pathogenic microorganism will depend on the filtering capacity of the soil. The filtering of microorganism will depend among other factors on the size of these organisms. Typical sizes are 0.02-0.25 µm for viruses, 0.2-5 µm for bacteria and 10-100 µm for protozoa and fungi. Based on static filtering processes in soils saturated with water, Table 14 shows the critical pore size in different soils, that equals the minimum size of particles that can be removed in each soil type. For viruses and the smallest bacteria, the soil needs to be very fine grained to be an effective filter when water saturated, thus reducing the flow capacity.

Table 14. Soil grain size and critical pore size (Matthess & Pekdeger, 1985).

Soil	Critical pore size, µm
Fine silt	0.72
Silt	2.4
Fine Sand	24
Sand	72
Gravel	2400

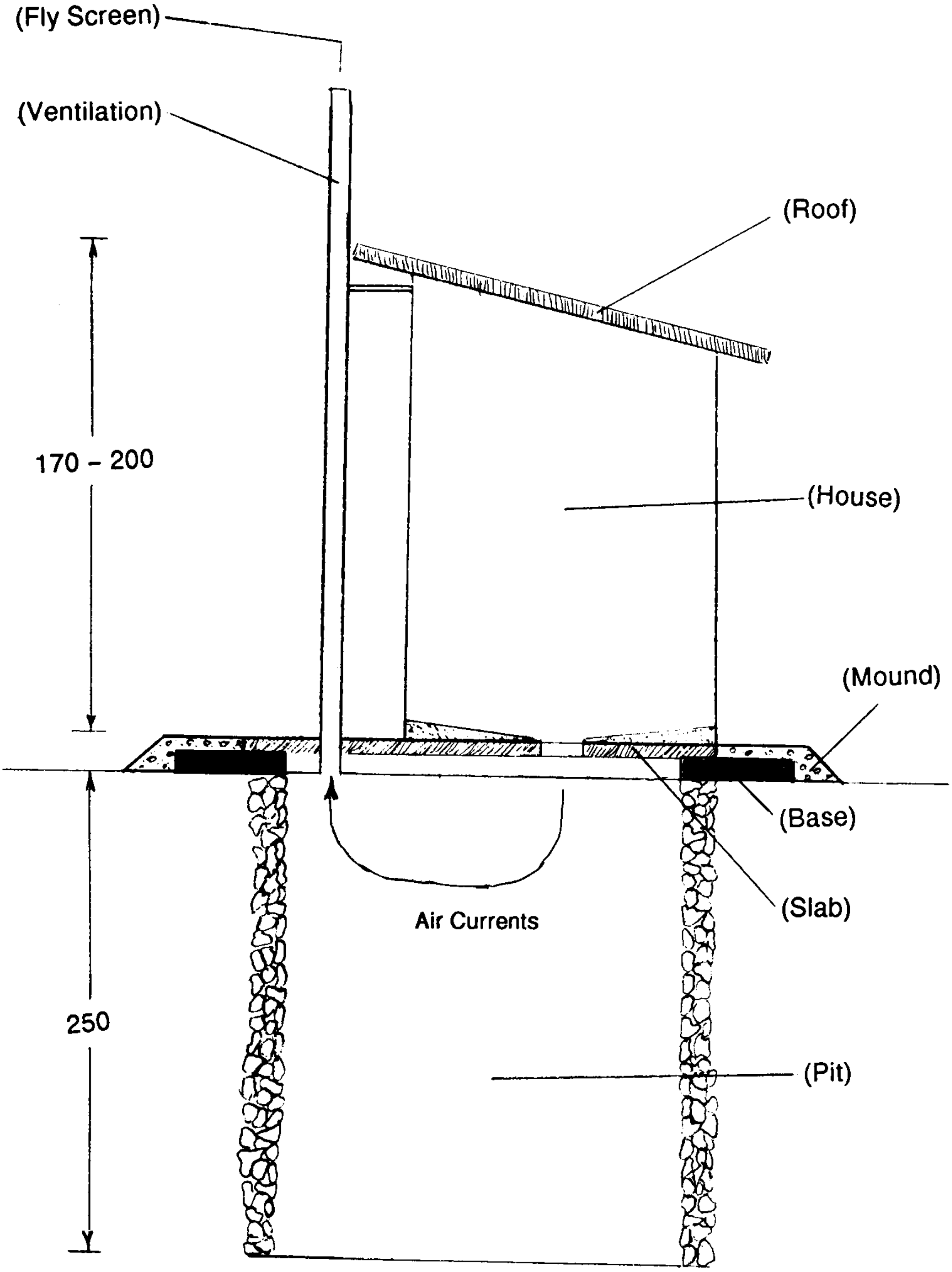


Figure 8. Cross-section of a pit latrine

Table 15 shows typical intervals for a 99.9% elimination of different organisms in saturated soil.

Table 15. Elimination time required for 99.9% of some relevant bacteria and viruses in groundwater (Pekdeger & Mathess, 1983)

Organisms	Time period (days)
Coliform bacteria	7
E. Coli	10-50, typically 25
Shigella sp.	10-35
S. *Typhi*	8-25
S. paratyphi	70
S. typhimurium	150
Viruses	20-300

It has been shown that filter media are more efficient in removing pathogens when not saturated with water, because biological processes become more important. A load of 25 mm wastewater per day (250 L per m^2 surface) efficiently removed *E. Coli* during intermittent loading in porous filters of light weight aggregates (LECA) and activated carbon (Stevik et al., 1999).

End product

Some pit latrines are designed to be emptied so the end product can be used as a soil conditioner and a fertilizer. Depending on the processes that occur in the pit, the human waste is either dried up or decomposed. The dry product is stable only as long as the moisture content remains low (<25%**.** Adding water to the end product (as it will happen on the field after disposal) will lead to biological activity and possibly odors. Decomposition leads to a biological more stable product.

For pit latrines the reduction of pathogens in the end product becomes important. Pathogen removal in pit latrines basically follows the temperature-time relationship showed in Table 7. With low temperatures in the pit the removal of pathogens need time before the end product is safe for transport and use. Sanitation requires a storage time of about one-year before the waste can be considered to be free of any pathogens and applied to soil (WHO - Regional Office for Europe 1982), but this will depend on the environmental factors (Figure 5). The time needed depends on dehydration (through infiltration, adding of dry matter like wood ash and evaporation) and temperature. The adding of wood ash additionally provides a high pH for stabilization and sorption capacity to reduce odor. Although the end product may be safe after a considerable storage time, the risks of spreading pathogens through the soil generally remains high.

Environmental and health impact

Pit latrines provide a lower level of health and environmental protection than composting and dehydration toilets do. This is mainly due to fly and odor nuisance and the risks connected to groundwater pollution.

The fly and odor problem is mainly a result of high water content and appears when the surrounding material has insufficient infiltration or the toilet is overloaded or water enter the pit. The effect of clogging from the waste can reduce the infiltration rate of the material during operation.

Water pollution occurs when the groundwater level rises into the pit. Areas periodically flooded may additionally experience excess water in the pit.

4.6. Summary of fundamentals and process factors

The most important process factors and criteria are listed in Table 16 and Table 17.

Table 16. Optimal process factors*

Factor	Compost toilet	Dehydration toilet	Pit latrine
Water content	25-70%	<25%	<70% ?
Temperature	>0ºC: biological activity >40 ºC: pathogen removal by heat	> 0 ºC	> 0 ºC
C/N-ratio	20-30	No limits	No limits
Storage time **	>6 months, or when hygienic	>6 months, or when hygienic	> 1 year
Additives needed	Yes (Table 11)	Yes (Table 12)	No

- Factors in process chamber ** Measured from when the tank is full

Table 17. Additional criteria for toilet systems

	Compost toilet	Dehydration toilet	Pit latrine	Urine diversion
Volumes	Large-small	Medium-small	Small	Large-small
Climate*	No demands, but special design may be needed if very humid or very cold	Warm and possibly arid	Above 0ºC	Above 0ºC
Odor nuisance	Low-high	Low-high	High	Positive effect on odors
Pathogen control	High if working ok	High if working ok	Low	Positive effect on pathogen removal
complicated operation & maint.	High, training should be considered	Medium, training may be required	Low	Low
Ground water level	No demands, but secure against flood	No demands, but secure against flood	Continuously below pit level	

* ambient

5. Technology

The information in this chapter is mainly based on; The World Bank, 1998; Freaceys et al., 1992; Mara & Cairncross, 1989; WHO 1982, Winblad ed., 1998, Fulford, 1998, IEA Bioenergy, 1998; Karki, A. B., 1998, Davies-Colley et al., 1999, Øberg & Molland, 1982, Winblad et al., 1998.

Ecological sanitation technology is aimed at preventing disease transmission, and optimizing resource conservation and recycling. It is common, therefore, to evaluate systems on the control of microbiological contamination. Health hazards caused by chemical pollutants are of minor importance. Conventional recycling of sludge from wastewater treatment plants has a potential of reusing phosphorous, but low recycling capacity of other nutrients such as nitrogen and potassium (Hellstrøm et al., 1999). Diverting urine can be an easy way to recycle nutrients because 70 % of the phosphorous and 90% of the nitrogen in wastewater is contained in the urine, which is also low in heavy metals. The annual per capita nutrient capacity in urine is about 0.4 kg P and 9 kg N.

5.1. Toilet systems

For most parts of the world ecological sanitation can be covered by two techniques, dehydration- and composting toilets. Composting can be achieved both with and without urine diversion, but for dehydration toilets urine diversion is strongly recommended (Winblad, 1997, Winblad et al., 1998). Composting and dehydration differ in moisture content in the process chamber, composting preferably around 60%, and dehydration below 20%, although these are not absolute limits. Under special circumstances, such as complete absence of high groundwater levels, adequate soil characteristics, dry climate and safe distance to recipients and water sources, pit latrines may also be used safely.

Table 18. Dehydration and composting toilets (Winblad, 1997)

Toilet system	Urine diversion	No urine diversion
Dehydration	Long-drop (Yemen) “WM Ekologen” (Sweden) Twin chamber (Vietnam) Twin chamber (Mexico) Solar heated (El Salvador)	Earth toilet, Ladakh (India)
Composting toilet	No-cost toilet (China) Solar heated (Mexico) Multi-unit (Sweden)	“Clivus Multrum” (Sweden) Solar heated (Ecuador) CCD (South Pacific)

A toilet system collects, treats and disposes of human excreta. The main system components are the structure supporting and surrounding the toilet, the seat-riser for sitting purposes, or the pan for standing purposes, distribution systems, treatment facilities and finally some kind of disposal system.

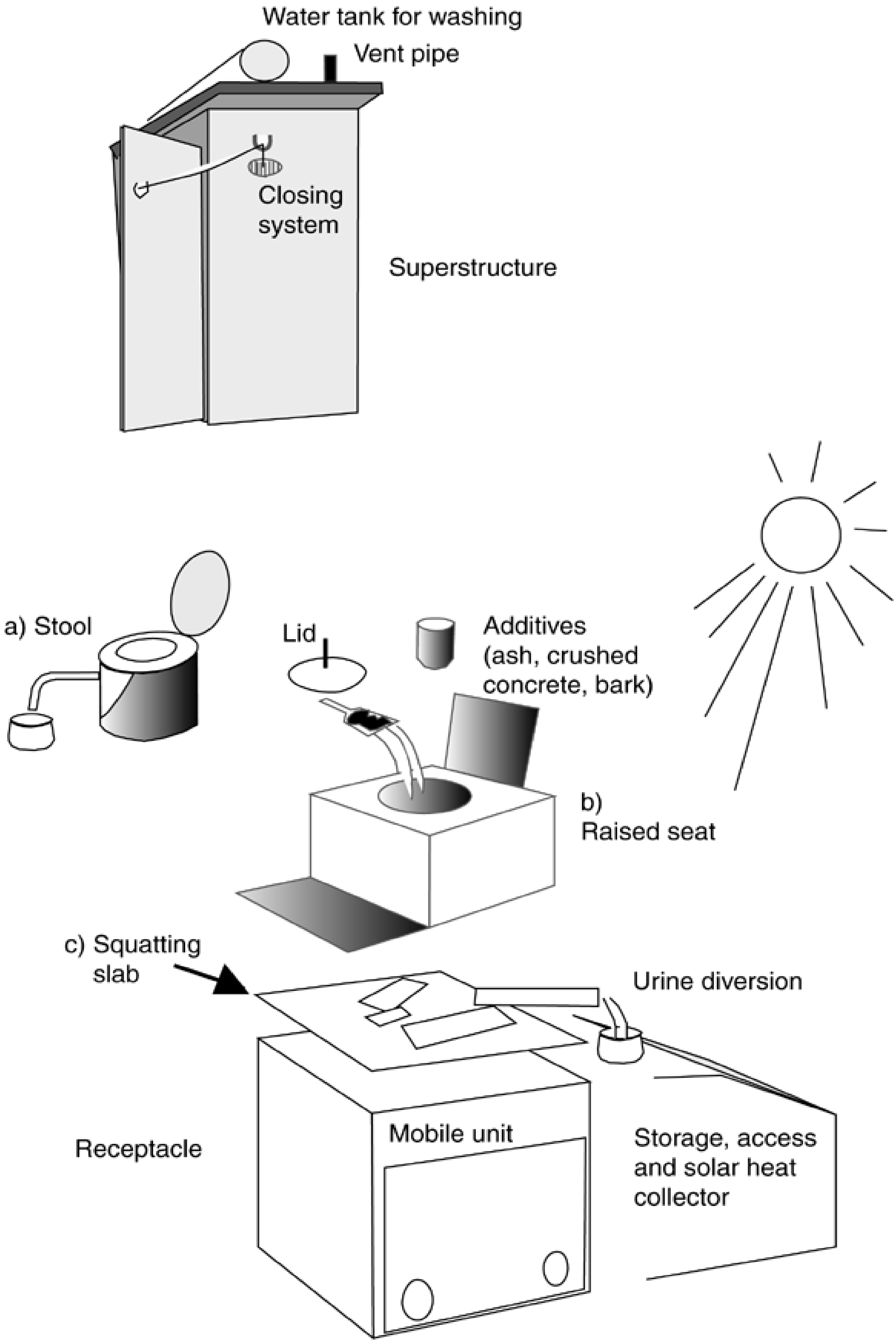


Figure 9. Toilet system components

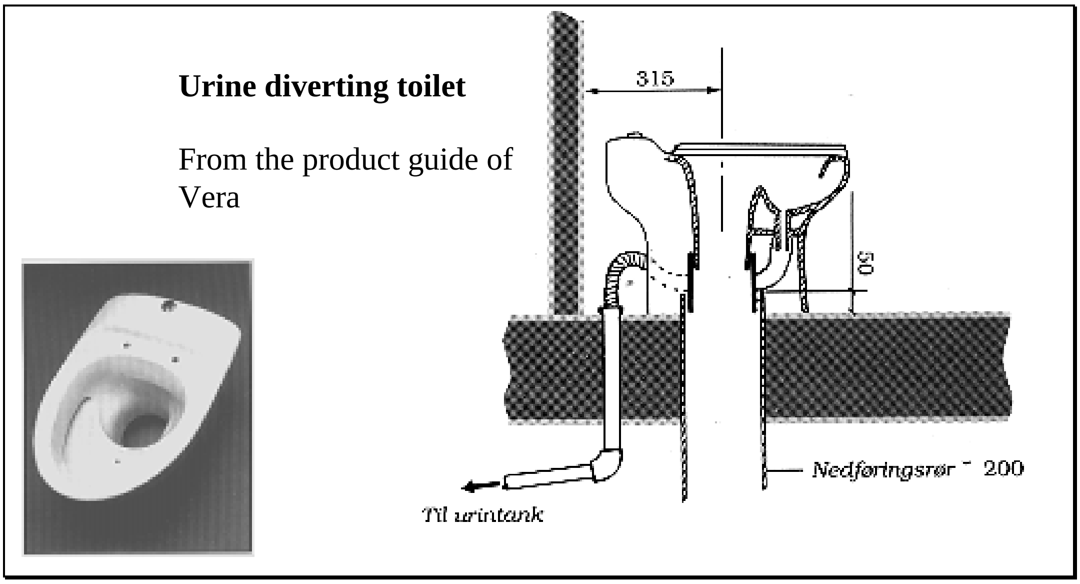
5.1.3. Urine diversion (Source separation systems)

Urine diverting toilets separate and collect urine and feces. The removal of feces may be dry or flushed.

In a dry toilet the feces drops to a collection tank without flushing. A fan in the collection chamber can be used to assure a lowered air pressure to avoid the release of unpleasant odors. In flushed systems the feces are collected in a cesspool and must be collected e.g. twice a year for further central processing (Jenssen, 1999).

Cost:
In China: USD 10
In Scandinavia,
1 seat = about USD 450

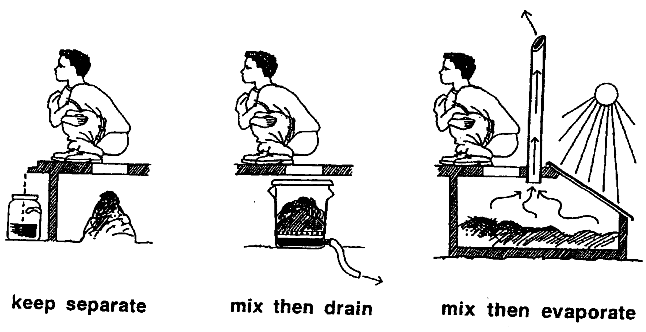
Recycling of nutrients by separating urine can be efficient for N and P. A potential problem can be N losses due to evaporation, but adding acids (up to 60 meq/L acetic or sulphuric acids) effectively prevents this for periods up to 100 days (Hellstrøm et al., 1999). If urine is applied on open soil it can be undiluted. If used on plants it must be diluted to prevent scorching, typically one part to 2-5 parts of water (Winblad et al., 1998).



Urine diverting toilet

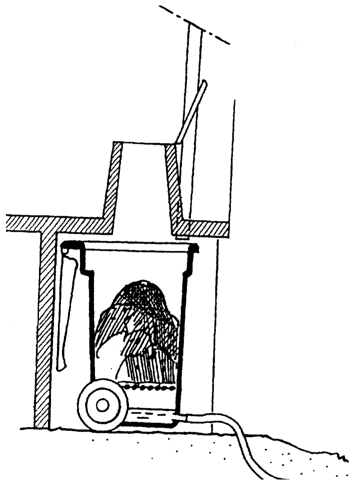
From the product guide of Vera

Figure 10. Urine diversion toilet stool

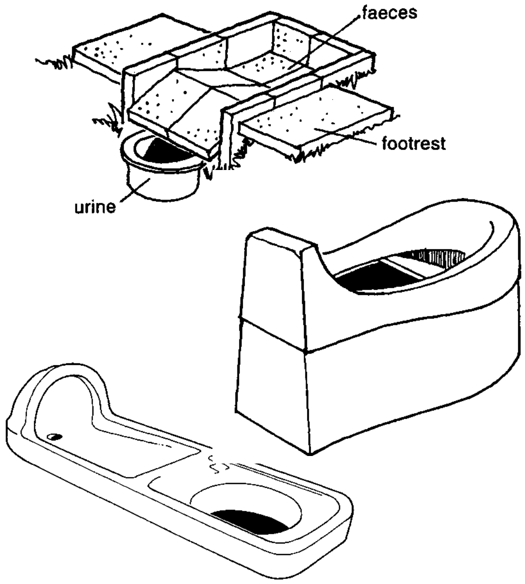

keep separate

mix then drain

mix then evaporate

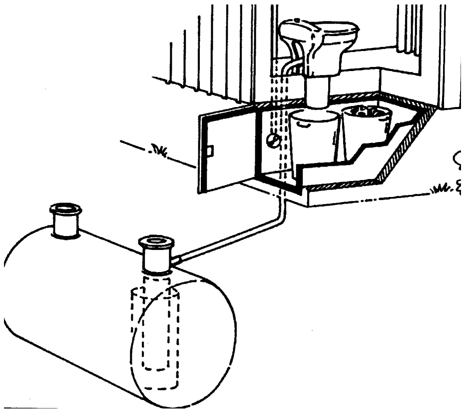


Composting toilet with liquid separation. Procesing chamber is standard wheeled plastic refuse bin modified to drain away liquid.

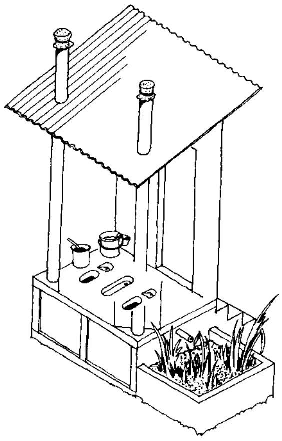


(clockwise): Traditional Chinese urine diversion squatting pan, 1994 Mexican fiberglass model, and 1997 Chinese porcelain pan ($10).

Urine diverted from squate plate to a soak pit. Senegal (photo: Del Porto & Steinfeld, 1999)



Urine diverted from a dehydration toilet to an underground storage tank.



Urine flows into an evapo-transpiration bed planted with vegetation. India

Figure 11. Alternative designs for handling urine (Illustrations from Winblad ed. 1998)

5.1.4. Composting toilets

In composting toilets, excreta falls into a watertight tank to which ash or organic matter is added. If the moisture content and chemical balance are controlled, the mixture will decompose to form a good soil conditioner in about four months. Pathogens are killed in the dry alkaline compost, which can be removed for application to the land as a fertilizer or soil conditioner. There are two types of composting toilets: in one, compost is produced continuously, and in the other, two or more containers are used to compost in batches. Types are also categorized after continuos or intermittent use.

In Scandinavia the development of compost toilets was aimed mainly for cottages and weekend houses with intermittent use. In the 1970s composting toilets were enjoying a relative heyday in the US and thousands of units were installed, mostly in homes with continuous use, but with a high frequency of problems.

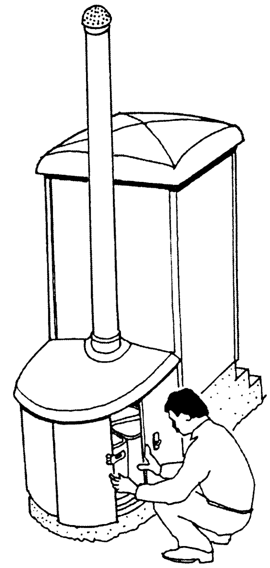
There are numerous systems commercially available over the world, and prices vary considerably, see e.g. Del Porto and Steinfeld, 1999. Costs range from USD 950-10,000 for large institutional prefabricated systems, and about USD 100 – 1,000 for site-built systems (Del Porto and Steinfeld, 1999). In Scandinavia prices are USD 2700-3300 for 1 household in continuous use, and USD 2100 for weekend house.

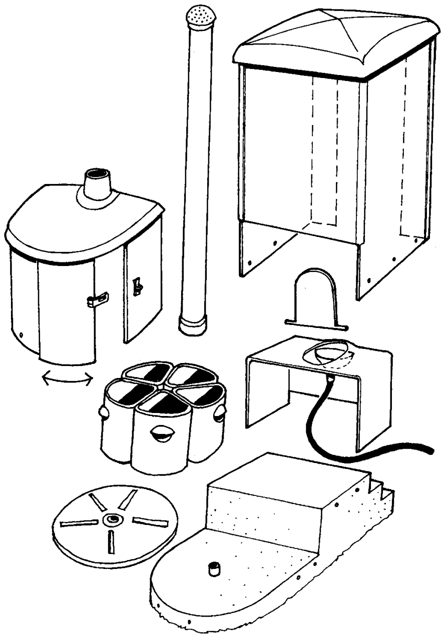
Technical consideration: Temperature should be above 10 °C, preferably between 40- 60°C. Water content should be above 40%, but not too high to avoid anaerobic conditions. The content of dry matter should preferably be between 35-60% (weight). The C/N-ratio should preferably be in the order of 20/1 to 30/1. A rule of thumb when composting kitchen- and garden waste is to add 1 volume of structure to 4 volumes of waste. Assuming the composition given in Table 2 and

Table 3, one volume of structure should be added to 3 volumes of feces. When full the material is stored, usually in the receiving tank, and should be completely stabilized and hygienized within 6 months, and can be used as a soil conditioner or fertilizer locally.

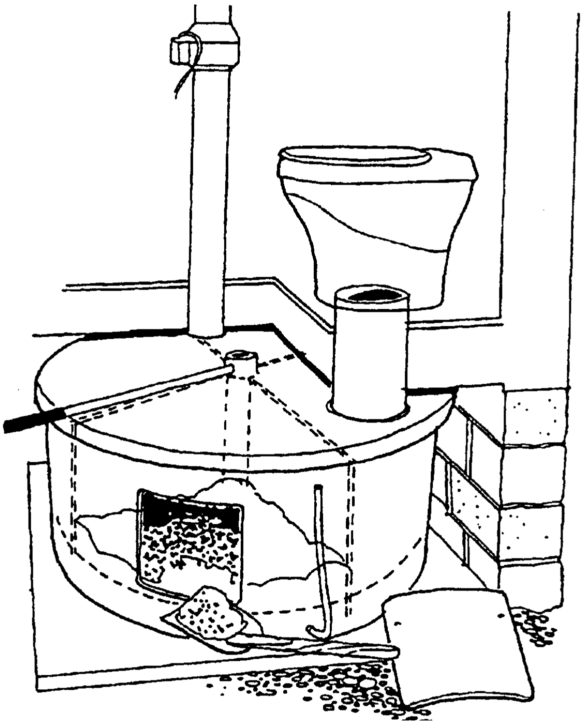
The compost should be homogenized, and the operation should consider:

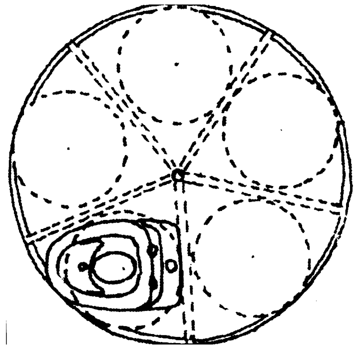
- that the toilet is both a sanitation instrument and a biological reactor
- for sanitation the toilet must adapt to the consumers preferences for comfort and hygiene
- the biological reactor must produce a good compost, and the capacity must be adequate and the operation hygienic
- for continuous use the operational safety and service is very important
- proper installation is essential for avoiding operational malfunction





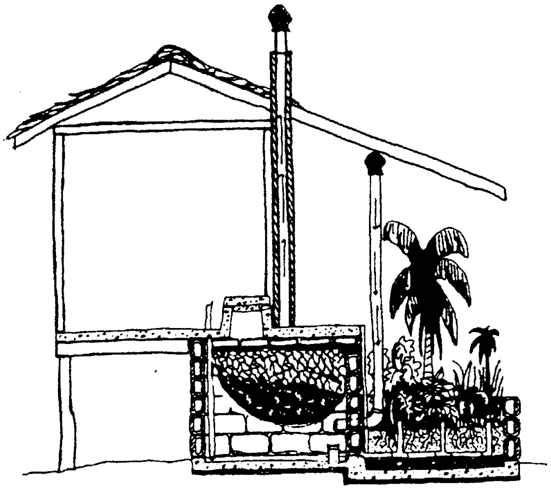
Eco-san toilets are built entirely above ground. Here solar heated processing and buckets on a rotating floor

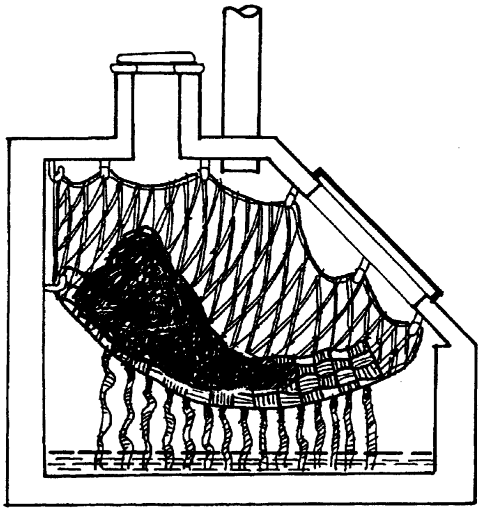


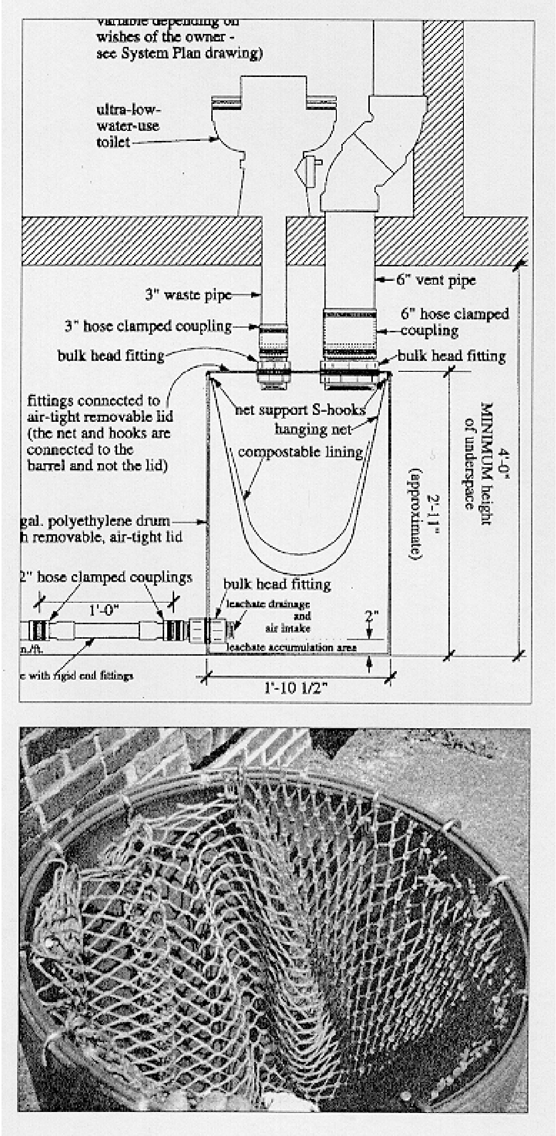


The ”Carousel” composting toilet from Norway. Unlike the design above, the contents must be shoveled from the compartments.

Figure 12. Composting toilet with batch chambers (Illustrations from Winblad ed., 1998)







CCD (Centre for Clean Development) toilet with an integrated planted leachate system (top). Rags tied to the net wick off moisture (bottom).

Following success of CCD double-vault system (left), Ecological Engineering developed this net composter for single chamber flush toilets in Fiji.

Figure 13. Net composting toilet systems developed for the Pacific Islands focusing on zero-discharge rather than urine diverson (Illustrations: Del Porto & Steinfeld, 1999)

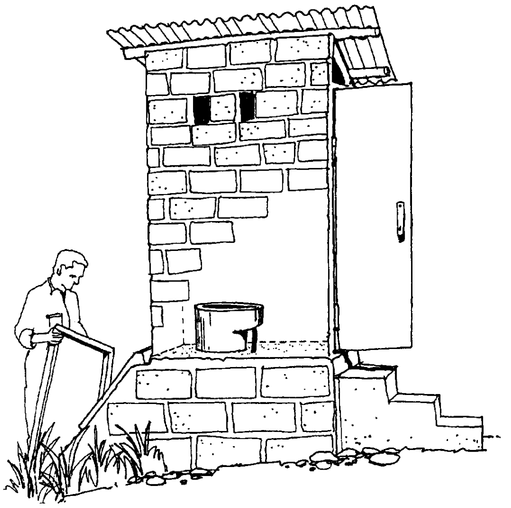
5.1.3. Dehydration toilets

Dehydration toilets reduce the water content in excreta by heat, ventilation and addition of dry material. The solid excreta enters a collection chamber where the water content should be reduced to below 25% as quickly as possible: at this level there is pathogen destruction, little smell and no fly breeding (Winblad ed., 1998). When full the material is completely hygienized within 6 months, and can be used as a soil conditioner in local gardens (Phi et al., 1999; Wang et al., 1999). Previous the so-called dry latrine was universally condemned, according to Pickford (1994), but that was the most primitive system for dehydration. The toilet has nevertheless been an affordable system for a great number of people.

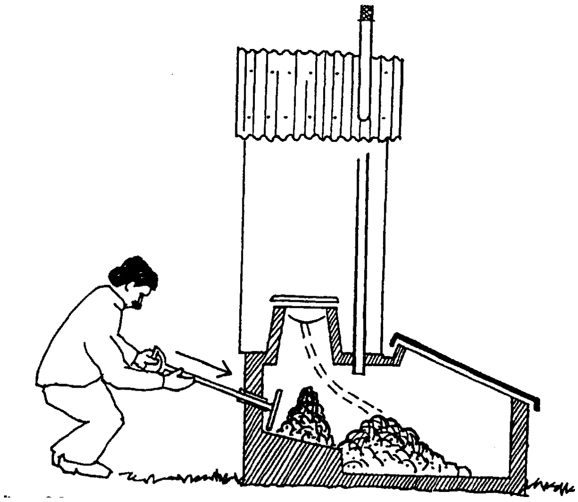
Dry methods of processing feces are more effective at destroying pathogens than wet methods with low levels of maintanance. The combination of low moisture, low amount of available organic matter and nutrients, and high pH, give an effective method removal of pathogen, according to Winblad ed. (1998). Methods for increasing the pH can be adding ash, lime- or carbonate additives e.g. as seashell residues, or crushed concrete. Experiments have shown that seashell residues can increase pH to about 9, crushed concrete to about 11-12 (Table 12).

Dehydration is an effective way of destroying pathogens, particularly helminth eggs, because it deprives them of the moisture they need to survive. At low humidity there is little odor and no fly-breeding. As there is little breakdown of organic material, toilet paper or other things placed in the processing chamber will not disintegrate regardless of storage time. Toilet paper must therefore either be handled separately or be composted in a secondary treatment process.

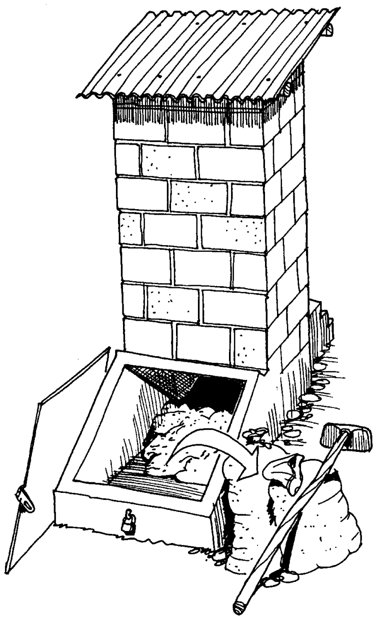
Solar heaters are fitted to the processing vaults of toilet to increase evaporation. This is more important in humid climates and where urine and water is mixed with feces. It is also more important in a system based on dehydration than in one based on composting. The simplest solar heaters consist of a black-painted metal sheet covering part of the processing chamber exposed to the sun. This metal sheet usually also acts as an acess lid to the processing chamber (Winblad ed., 1998).



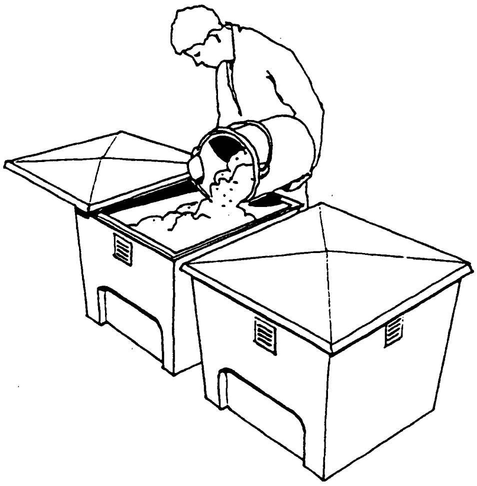
Solar-heat collector in this San Salvador dehydrating toilet increases evaporation in the processing chamber



Urine is diverted and faeces (with ash) are pushed into a solar heated processing chamber.



When chamber is full the material is removed and placed in bags for further storage until ready for use as fertilizer.



Dehydrated contents of the buckets are transferred to composting boxes for secondary treatment.

Figure 14. Dehydrating toilets that use heat, ventilation and addition of dry material to remove water from excrements (Illustrations from Winblad ed., 1998)

5.1.4. Pit latrine/toilet

Pit latrines consists of a slab over a pit usually 2 m deep or more. The slab should be firmly supported on all sides and raised to prevent surface water entry to the pit. Unstable sides in the pit should be lined. The systems are low cost, typically waterless and easy to construct. However, they attract flies (and mosquitoes if the pit is wet) and are malodorous.

Ventilated improved pit toilet (VIP)

Fly and odor nuisance may be substantially reduced if a pipe extending above the latrine roof, with fly-proof netting across the top ventilates the pit. The inside of the superstructure is kept dark to prevent fly breeding. Such latrines are known as ventilated improved pit (VIP) latrines.

Pour-flush pit latrines

A latrine may be fitted with a trap providing a water seal, which is cleared of feces by pouring in sufficient quantities of water to wash the solids into the pit and replenish the water seal. A water seal prevents flies, mosquitoes and odors reaching the latrine from the pit. The pit may be offset from the latrine by providing a short length of pipe or covered channel from the squatting pan to the pit. The pan of an offset pour-flush latrine is supported by the ground and the latrine may be within or attached to a house.

5.2. Summary - technology

A summary of the main benefits and problems with different factors for the described technologies is given in Table 19.

Table 19. Summary of expected characteristics for the described systems*

System	Pathogen Control	Costs	Technology (System complexity)**	Vector Attraction (flies+ mosquitoes)	Odor	Ground water contamin.	Potential fertilizer & soil cond.
Pit latrine	Low	Low	Simple	High	High	High	Low
Pit latrine with urine diversion	Medium	Low	Simple-Moderate	Moderate	Low-Med.	Moderate	Low
Pourflush pit latrine	Very Low	Low - Nominal	Simple – Moderate	Moderate - High	Low	High - Very high	Low
Composting toilet	Very High	Nominal - High	Moderate - Complex	Low	Low-Med.	Low – None	High
Composting toilet with urine diversion	Very High	Nominal - High	Moderate - Complex	Low	Low-Med.	Low – None	Very High
Dehydration toilet	High	Low-Nominal	Simple-medium	Low-moderate	low-Med.	Low	Medium
Dehydration toilet with urine diversion	High	Low-Nominal	Simple-Moderate	Low-moderate	low	Low	High

* a high or low probability or value for the factors (i.e. high probability for disease spreading for pit latrines, low costs for dehydration toilets)** Operation and maintanance complexity

6. Health

From (Mara & Cairncross, 1989; Esrey et al., 1991; Stenstrøm, 1997, Strauss & Blumenthal, 1990, Cross and Strauss, 1985; Cairns and Strauss, 1985; Strauss, 1996)

In many tropical areas, the majority of communicable diseases are excreta-related. Health protection measures should receive regular monitoring to ensure their continued effectiveness.

6.1. Measured improvements from sanitation

For water supply systems, public authorities in many countries prescribe double hygienic barriers between potential polluters and the consumer. The transmission route from feces to the face via fingers usually only has one hygienic barrier: personal hygiene. The route via food has two barriers; (1) the sanitation system and (2) adequate cooking (except if spread by vectors, then there is usually only one). The transmission route from water usually has two barriers: the toilet and water disinfection.

In a review article by Esrey et al., 1991, the health impact of sanitation was examined in 30 studies, of which 21 reported health improvements. Overall, a 21 % reduction in morbidity was calculated for 11 of the studies, but was 36 % if calculated only in rigorous studies. Of the studies that compared the relative importance of water and sanitation, most reported that sanitation had a greater impact on children than to adults, based on mortality, growth and morbidity indicators. Some mortality studies reported that the method of disposing of excreta determined the magnitude of the health impact. Mortality was reduced to a greater extent by flush toilets than by pit latrines. Sanitation has also been reported to produce a differential health impact depending on other risk factors. For example, sanitation was most effective in reducing mortality among non breast-feeding infants and infants of illiterate mothers than among breast-fed infants or literate mothers.

6.2. Excreta reuse

Excreta use in agriculture and aquaculture must be based on epidemiological evidence. Important aspects to remember are:

- Fertilization with untreated excreta causes significant excess nematode infection in crop consumers and field workers

- There is evidence that excreta treatment can reduce the transmission of nematode infection

- Excreta fertilization of rice paddies may lead to excess schistosomiasis infection (bilhariza) among rice farmers

- Cattle may become infected with tapeworm but are unlikely to contract salmonellosis

6.3. Urine reuse

In some parts of the world reuse of urine has a long tradition, e.g. Asia, but in other parts there is little tradition, e.g. in Latin America.

If urine is diluted with water there is a higher risk for mosquito breeding in the liquid thus increasing the risks for mosquito related diseases like malaria.

Urine is usually free of pathogens, although *Leptospira*, *Salmonella Typhi* and paratyphi, and *Schistosoma* heamatobium have been found in urine(Stenstrøm, 1997), most pathogens experience a rapid die-off in the urine. Some, however, like Leptospora and viruses, have not been investigated. When pathogens and/or indicator bacteria occurs are reduced it is probably related to the high pH and high salt concentrations (Høglund et al, 1998). A problem might be pollution of feces in the urine. The present rule in Sweden is that the urine should be stored for sixth months before use. Coprostanol (5-cholestan-3-ol) can be used as an indicator of cross contamination (Sundin et al., 1999).

Reports (FAO, 1997; Jonsson, 1997; Drangert, 1996) estimate 50-250 m^2 per person to completely utilize the urine as plant nutrients. For fertilizing intensive horticulture including three annual crops, 50-100 m^2 is needed. To merely dispose of the urine requires about 1.5 – 10 m^2 for a family of 5, depending on the soil type. This show that, in principle, it is theoretically possible to dispose of the urine locally, even in the most crowded parts of the world.

Urban areas can also sustain agriculture. In China some large cities produce more than 80% of the nutritional needs. There are also examples of special constructed walls that can produce the equivalence of Botswana pound P40 per 1 m^2 a year fertilized by urine (Winblad, 1992).

6.4. Polluted water reuse

Recent advances in epidemiology have shown that past standards of hygiene in waste reuse, which were based solely on potential pathogen survival, are stricter than necessary to avoid health risks. The use of wastewater as irrigation for crops poses significant health problems. Experiments have shown that bacteriophages like *Salmonella* typhimurium 28 B transport rapidly through soils, especially in clay soils (Carlander et al. 1999). This is probably due to preferential flow in fissured clay.

The health aspects of the reuse of wastewater is illustrated also in the context of dry sanitation, although the production of wastewater means combining human excreta and water, which is not a main part of this project. Wastewater use in agriculture can be based on epidemiological evidence such as:

- Crop irrigation with untreated wastewater causes significant excess intestinal nematode infection in crop consumers and field workers. Field workers, especially those who work barefoot, are likely to have more intense infections, particularly with hookworms, than those not working in wastewater-irrigated fields.

- Irrigation with adequately treated wastewater does not lead to excess intestinal nematode infection in field workers or crop consumers.

- Cholera, and probably typhoid, can be effectively transmitted by irrigation of vegetable crops with untreated wastewater.

- Cattle grazing on pasture irrigated with raw wastewater may become infected with beef tapeworm, but there is little evidence of actual risk to humans.

- In communities with high standards of personal hygiene any negative effects are generally restricted to an excess incidence of beginning, often viral, gastroenteritis, although there may also be an excess of bacterial infections.

- Sprinkler irrigation with treated wastewater may promote aerosol transmission of excreted viruses, but infections are likely to be rare in practice because most people have normally high level of immunity to endemic viral diseases.

The treatment of wastewater is a highly effective method of safeguarding public health. Guidelines recommend that treated wastewater for agricultural use should contain:

< 1 viable intestinal nematode egg per liter (on an arithmetic mean basis) for restricted irrigation to edible crops, sport fields and public parks, or unrestricted irrigation to trees, fodder and industrial crops, fruit trees and pasture

< 1000 fecal coliforms bacteria per 100 ml (on a median basis) for unrestricted irrigation

The fecal coliforms guideline value is less stringent than earlier recommendations, but is in accord with modern standards for bathing waters, and is probably more than adequate to protect the health of consumers.

Guidelines for the microbial quality of treated excreta and wastewater for aquacultural use are more stringent as these pathogens multiply very fast in their first intermediate aquatic host, recommend:

Zero viable trematode eggs per liter or kg.

< 10 000 fecal coliforms per 100 ml or mg (median basis)

The use of wastewater also includes risks for building up heavy metals in soils and crops.

7. Culture

Culture plays an important role in the evaluation process because it influences the acceptance (or rejection) of a sanitation system. This does not imply that cultural patterns are immutable and improved technologies should be designed around a fixed set of beliefs; rather, that culture influences behavioral change. The following section identifies three cultural influences that affect the acceptance (or rejection) of an alternative sanitation system: psychology, gender, and religion.

7.1. Psychology

The psychological aspects of treating human excrement are not well known. Although there is a universal consensus that body wastes are sordid, our elimination behavior and our feelings about it are all learned from our experiences, and evolve and change over time (Drangert, 1996; Kira, 1995). Tanner (1995) writes that every social group has a social policy for excreting: some norms of conduct will vary with age, marital status, sex, education, class, religion, locality, employment and physical capacity. As a result, there is no absolute right or wrong behavior or attitude, except within a cultural context.

With the exception of toilet training, the core of psychological literature is limited primarily to attitudes about human waste (but not waste treatment). Templer et al. (1986) developed the Body Elimination Attitude Scale to measure an individual's level of disgust toward human waste. Although the scale does not predict behavior towards a particular toilet system, it does reveal that those exposed to excreta are more tolerant of – and prepared to cope with – its undesirable characteristics. One reason being individuals accustomed to the smells of putrefaction, such as those involved in specialized occupations, modify or suppress a response which may have a biochemical basis (Loudon, 1978). Furthermore, one may find differences in male and female perceptions, owing to varying exposures to excreta, as in the care of infants, the elderly and incapacitated (Drangert, 1996).

An important point commonly overlooked is that perceptions towards urine are less negative than those held towards feces (Reid, 1991). In concept, the bridge between attitude and behavior appears obvious. That is, a positive attitude towards urine leads to its use, whereas a negative attitude towards feces leads to disassociation. We see this not only in historical taboos associated with feces but also in our contemporary marketplace. Drangert (1996) notes that of 22 manufactures of dry-system toilets, the word "feces" is rarely used in information material. The operable term is "compost". The choice of words might merely be marketing, i.e., to focus on the end product. Then again, the noticeable absence of the word "feces" might be the result of a general attitude towards that which is inherently repugnant.

The cultural acceptability of handling excrement varies throughout the world. Although some cultures do not mind handling human excreta (faecophilic cultures), and others find it abhorrent (faecophobic cultures), most cultures are somewhere in between these two extremes. But these attitudes are not fixed. Experts in ecological sanitation note that when people see for themselves how a well-managed system works, most of their reservations about handling human waste disappear (Winblad 1998).

However, a technically sound, well-managed sanitation system is not the sole criteria for acceptance. For many, in fact, the attraction to build a new sanitation system is not health and hygiene but prestige, comfort, privacy or a combination of social factors (Fang 1998).

The importance of cultural perceptions is magnified when we look at public facilities. In some cases sharing a toilet with strangers is just unacceptable (Fang 1998); in other cases we find the opposite. Nayana (1993) cites an example where women preferred public toilets merely because the facilities provided locations to rest and socialize.

7.2. Gender

Gender refers to the specific roles and responsibilities for women and men in a society. Gender is related to how we are perceived and expected to think and act as women and men because of the way society is organized, not because of our biological differences (World Water Vision, undated). If one considers demographics alone, worldwide the majority of toilet users are women. Gender issues are a concern when ecological sanitation systems are used for private households, multi-family or public facilities. Although ecological toilets are normally a private concern, they have been used for public service. For example, the Republic of Palau (in the Pacific Islands) installed seven compost toilet comfort stations for tourists (Del Porto 1998).

Toilet provision is essential to make public areas accessible, whether they are cities or villages. Greed (1995) notes that women generally have fewer facilities than men; and this lack of provision is critical, because women are more likely than men to be in public places either shopping, travelling on public transport (for essential food gathering) or making care-related trips. Several recent studies show that in many instances, women's toilets have only half as many fixtures as men's (Kira, 1995). This inequity is compounded by the fact that women, due to gynecological factors, tend to urinate more frequently than men do (Office of Research on Women's Health, 1991). In addition, women take twice as long to urinate as men, which is a consequence of anatomical differences and clothing (Kira, 1995).

Other gender concerns that are frequently overlooked by public planners include the following:

- Women use public toilets for reasons other than waste disposal: e.g., relief during pregnancy, periods and cystitis, breast-feeding and childcare, and to escape from a man (Greed 1995).
- Many women are uneasy that public conveniences tend to be located in pairs with men and women facilities (Centre for Accessible Environments,1992).
- Women often find facilities poorly designed with cubicles too narrow and lacking provisions for childcare.
- And some surveys suggest a majority of women would prefer to squat over rather than sit on a toilet seat (Cunningham & Norton, 1993).

The net result is that women tend to use public toilets for more reasons, more frequently, and for longer duration than men -- and yet they have fewer facilities, many of which fail to meet their needs. In addition, an ideal design for a woman's toilet does not appear universal because cultures vary.

Consider the design for privacy. Female perceptions of privacy appear quite diverse when one compares toilet stalls in Japan, which are always complete rooms with floor to ceiling partitions and doors, with stalls in other parts of Asia, which are only a meter high with no doors at all. Islamic women may feel too immodest to use western style public toilets, because conventional stalls have a ventilation gap between the floor and wall/door (Greed 1998). Contrariwise, some Japanese women share uni-sex toilets with men, and do not seem to be offended by seeing them; however, they tend to flush the toilet constantly to mask their personal elimination sounds (Kira 1995).

Gender issues are not limited to public and multi-family toilets. Within the private household, the toilet is shared between the sexes, but not equally. Women appear to use the toilet more frequently then men do for two reasons. First, in both developed and developing countries, women tend to dispose of food and kitchen waste more than men do, much of it deposited in a toilet. Secondly, women generally defecate at home more than men do. An explanation is in order. Defecation, unlike urination, is not normally a random activity. A review of medical literature indicates that defecation almost always takes place in the morning, triggered by breakfast. For persons with regular habits, this commonly takes place at home. For others, however, it occurs on the way to work or school, or immediately upon arrival. Under the circumstances of men at the workplace and women at home, it is not unreasonable to assume that women use the home toilet more than men do.

Lastly, since women (in most cultural contexts) have a greater role than men in domestic sanitation, gender-specific data are important in the evaluation process. Narayan (1993) notes that in the evaluation of sanitation systems, women in particular should be continuously involved.

7.3. Religion

Although Southeast Asia has a predisposition to using excrement in agriculture and aquaculture, the relationship between religion and waste treatment is as diverse as its religious base, which includes: Islam, Hinduism, Taoism, the teaching of the Buddha and Confucius, and ancestral worship cults.

One reason there is such diversity in the religion and waste treatment relationship is that when people are told that a new waste treatment method will make their environment "cleaner", they generally use their own interpretation of "clean" – which may have nothing to do with hygiene. Although most religious doctrines lack medical explanations of disease, they define the concepts of clean and dirty, purifying and polluting to promote health, both corporeal and spiritual. For instance, a religious doctrine might promote running water for drinking merely because it is exposed to sunlight and considered being "alive" and therefore "pure", whereas well water (which does not have these attributes) is deemed suitable only for washing (Franceys et al. 1992).

Water has always had special significance in purification rituals, but generally it has little to do with physical hygiene. One has only to see and smell the Ganges to know that the mass immersions in that holy river at Benares have no connection with hygiene.

There are, however, religious rituals that appear to be aimed at bodily hygiene. Moslem doctrine, for example, prescribes strict procedures to limit contact with fecal material and to use water to cleanse oneself after defecation. Although washing retards the transmission of pathogens, some argue the Islamic "proscriptions on cleansing after defecation are clearly a function of ritual purity and not hygiene" (Cross and Strauss 1985). The religious obligation to use water has direct implications for planning wastewater facilities. For example, the Malaysian Cabinet has directed local authorities to incorporate the water requirements of Muslims in the design of public toilets (Hooi and Hamzah 1995).

Despite the power and influence of Islamic law, hygiene behavior of Muslims varies because Koranic edicts are interpreted differently among Islamic movements. For example, the use of human excreta in agriculture and aquaculture – as well as the re-use of wastewater – are not condoned in Islamic society. In Iran, Shiite fundamentalism follows these prohibitions to the letter of the law (Cross and Strauss 1985). In West Java, however, the direct application of excrement in freshwater fish culture is an ancient cultural practice that has altered little under Islamic rule. Also note that although Islamic law requires the use of water for cleansing, we do find waterless toilets. In Yemen and Zanzibar, where dry toilets have been traditional, the users wash themselves away from the toilet opening. Since this has not posed a problem for a traditional waterless system, it might be an acceptable solution in other washing cultures. Winblad (1998) cites an example from India where a waterless system was successfully introduced to a water-based Hindu culture.

The principle Hindu text that details codes of conduct for rituals, the Atharva Veda, clearly specifies the use of water for sanitation. Van der Ryan (1978, p.17) explains:
Observant Hindus… carry a brass vessel filled with water to a secluded spot away from running water, public roads, or temples…. The feet are washed before elimination and anal region is cleansed with water afterwards. Ending the ritual is symbolized by rinsing the mouth eight times with water.
Note: there is no obligation to wash one's hands after defecation.

Although it is difficult to imagine entire urban populations following these rituals, one can see the impact of religion on water usage and excrement treatment – as well as class distinction. Followers of the Atharva Veda are primarily upper-caste Brahmins; those who carry away the "nightsoil" are lower-caste Hindus, the Untouchables, who do not have prevalent religious attitudes about handling excrement (Subramanian 1978).

Religious beliefs of China emphasize man's one-ness with nature rather than his supreme importance in the order of things. Ancestral cults existed in earlier days involving the worship of natural objects, such as the life-giving soil and water. The relationship to the soil – "man belongs to the soil and not the soil to man" (Cressey 1934 cited in Cross and Strauss 1985) – remains a continuing theme in China.

China's intensive cultivation practices evolved to feed large populations in areas of limited land availability, and this necessitated the careful use of all resources available to the community, including excreta. If Confucius had not advised, "Waste not waste," one of his followers probably did. In fact, a thousand years before the Christian era a Chinese emperor wrote: "The inspectors of agriculture will see to it that [human excreta] is not lost and not wasted… for it is the strength and health of the people" (quoted in Cressey 1955).

Nowhere do we find the inclusion of excrement greater than in Buddhism, the primary religion of Southeast Asia. An integral dimension of Buddhism is reincarnation, which preaches the natural process of recycling human energy – birth, growth, decay, death, and re-birth. Since reincarnation promotes the harmonious concept of recycling life's treasures, it is not surprising that Buddhist cultures treat earthly resources similarly. But keep in mind, the unenlightened had been applying excreta to crops 3000 years before Buddha.

Some might argue that the Southeast Asia considers excreta a resource rather than a waste because of the historic necessity to use it as a fertilizer. Others might argue that these cultures tend to be faecophilic because in Far East religions there is a noticeable absence of doctrine regarding the handling of excreta. Still others might claim Far East folk beliefs are not concerned with salvation or the supernatural, but are sustained by earthly fears and rewards (Cross and Strauss 1985.) In other words Taoism, Confucianism, and Buddhism are more oriented towards philosophy than theology; and most philosophies find a thing in itself neither good nor bad. How one uses the thing – whether it's enlightenment or excrement – is the rudimentary question. In contrast, Hinduism and Islam have specific edicts that outline waste treatment behavior. Behavior associated with doctrines, however, varies due to caste (in Hinduism) and regional interpretation (in the case of Islam).

8. Economy

The costs for ecological sanitation is lower than for conventional sanitation (Winblad et al., 1998). This is particularly important for developing countries where public institutions face stringent financial limits. Ecological sanitation require much less investments as they need neither water for flushing nor pipelines for transport of sewage, nor treatment plants and arrangements for disposal of toxic sludge.

However, ecological sanitation will involve costs for information, training, monitoring and follow-up that is greater than for conventional systems. Furthermore, an urban ecological sanitation system will generate costs for safe handling, storage of urine and transport of dehydrated or composted material for a number of sanitation devices.

The economy in sanitation projects is highly variable depending both on local financial, technical and natural conditions, on human relations and in many cases on international financial agreements. Economy is a very important aspect both for the implementation and sustainability.

Sanitation projects can financially either be externally supplied or self-supportive, or a combination of both. They can focus on the number of people being served for the money (cost/benefit), on internal economical or political aspects of the supplant (i.e. recycling a portion of the supplied finances), or also on economical and political aspects of the receiving part (i.e. favoring groups of people). Projects can have components of all 3 of these aspects but from a viewpoint of solving the sanitary problems at hand the cost-benefit should be the option with priority.

Successful sanitation relies on sound finances. In principle, households should fully repay investments and operational and maintenance costs to ensure the sustainability of the systems. Pilot peri-urban sanitation programs involving free or highly subsidized demonstration models are likely to fail in the long run when false expectations have been raised regarding the costs of the systems.

8.1. Costs

In the literature the single most useful figure for comparing costs is the total annual cost per household (TACH) including capital and recurrent costs. An alternative figure would be the total annual cost for the community (TACC). Here we would consider the total cost of the sanitation system as a whole, not only for the beneficiaries but also for communities downstream.

Table 20 shows that World Bank water and sanitation projects in the period from 1978 - 1998 had budgets varying from about 40-305 million USD, of which the sanitation component varied from 1.4-25 USD millions (4-43 % of the total). The World Bank loan component in the same projects varied from 6-185 million USD.

Table 20. List of World Bank sanitation projects (after Fang, 1998)

Country	Year	Title	WB loan Amt. (US$ million)	Total cost/San. (US$ million)
Indonesia	1993	WS&S for Low Income Communities	80.0	123.3 / 16.0
Sri Lanka	1993	Community WS&S Project	24.3	32.3 / 1.4
China	1992	Rural WS&S Project	110.0	189.1 / 5.9
Philippine	1990	First WS, Sewerage & Sanitation Sector P.	85.0	132.8/ 17.5
India	1988	Uttar Pradesh Urban Development Project	150.0	237.8 / 5.2
Malawi	1982 (I) 1986 II	First Lilongwe WS Engr. Project Second Lilongwe WS Engr. Project	24	4.0(I), 77.7(II) / 0.15
India	1985	Kerala WS&S Project	28.98	56.11 / 3
India	1984	Tamil Nadu WS&S Project	48.1 (IDA) 48.8(SF12)	171.0 / 2.88
India	1983	Gujarat WS & Sewerage Project	54.5	78.1 / 2.5
Indonesia	1983	Jakarta Sewerage and Sanitation Project	21.6	32.8 / 2.1
Philippines	1983	Rural WS&S Project	35.5	58.4 / 25.0
India	1980 1991 1993	Rajasthan Water Supply and Sewerage Maharashtra Rural WS & Environ. Sanit. Karnataka Rural WS & Environ. Sanit.	80.0 109.9 92.0	
Paraguay	1978 I 1981 II 1993 III 1998 IV	Rural Water Supply (I-IV)	6.0 (I) 11.8 (II) 23.0 (III) 40.0 (IV)	
India	1978 II 1986(III	Second, and Third Bombay Water Supply & Sewerage Project	185 (III)	304.3 (III)
Bangladeh	1988	Third Dhaka WS&S Project	29.6	47.22 /
Somalia	1983	Second Mogadishu Water Supply Project	7.5	40.2 /

In the early literature biological local sanitation systems were compared with various traditional sewage collection systems. For example, Hansen & Terkelsen, 1977, compared 6 different sanitation systems to cover a 300 ha area outside Lagos in Nigeria, under different population densities (125-400 persons per hectare) and economical conditions (annual interest rates from 0-15%). The general conclusion was that there was no general applicable solution, but that high-density urban development favors a piped water removal system, though not necessary a traditional western system.

The costs, however, varied a lot, especially if the interest rate were high, from about USD 30 per capita/year for full sewerage, to less than USD 10 per capita/year for a composting toilet system. Being schematic figures calculated in the 1970's, however, the absolute level of these costs is of little value today, but the relation between the system costs can still be valid.

Local production is one important economical aspect of ecological sanitation. The Mexican architect and entrepreneur César Añorve and the NGO Espacio de Salud (ESAC) developed an approach that combines health and environmental education with technical support and follow-up to ensure the long-term sustainability of this alternative sanitation approach. César's operation is deliberately unsophisticated and unpretentious. As a family-run business, his workshop produces approximately 30 urine-diversion toilet seat risers per week. More than 6000 toilet seats have been sold.

Table 21. List of World Bank sanitation projects (after Fang, 1998)

Type	Cost	Water Supply Requirement	Advantages	Disadvantages
Simple pit latrine	Low	None	Can be built by household	Insect and smell nuisance;
VIP latrine	Low	None	Can be built by household; Control of flies; Control of smell	Does not control mosquitoes; Extra cost of vent pipe;
Water seal pour-flush toilet	Low	Standpipe	Control of smell; Content of pit not visible; Gives users the convenience of a water closet; Can be upgraded; Latrine and pit can be located separately;	Needs reliable water supply; **UNSUITABLE WHERE SOLID ANAL CLEANING MATERIAL IS USED**
Compost toilet	Medium	None	A valuable humus is produced;	Requires careful operation; Additives must be added regularly; Urine is usually collected separately;
Septic tank	High	In-house tap connections	Gives the users the convenience of a water closet	High cost; Requires reliable and ample piped water; Only suitable for low-density housing; Regular desludging required; Permeable soil required;
Aqua-privy	Medium	Yard taps	No need for piped water; Less expensive than a septic tank;	Water must be available nearby; Not easy to maintain a seal; Regular desludging required; Permeable soil required;

To satisfy requests for dry toilets, modules are sold for 2 500 Mexican Pesos, or approximately USD 262, and local groups receive assistance in establishing small workshops to produce the seats and to generate local employment. Beginning with the establishment of three independent workshops in Oaxaca in 1990, there are now as many as 15 independent, small-scale manufacturers of urine-diversion units, in different parts of the country.

In Guatemala the Dry Alkaline Fertilizer Family toilet, known as the LASF toilet, was developed by the Centro Mesoamericano de Estudios sobre Tecnologia Apropriada (CEMAT). The toilet is modification of the Vietnamese double-vault composting toilet. The DAFF-toilet is an above-ground facility, based on urine diversion, comprising two alternating vaults constructed in brickwork and a simple bamboo superstructure.

Table 22. Example of how unit costs for sanitation components can be presented (prices from 1979, in USD, 1T.shilling = 0.002 USD) after Nielsen & Clauson-Kaas, 1980

component		unit	cost pr. unit USD
excavation	bulk	m^3	0.1
concrete	mass concrete placed	m^3	1.7
	reinf. incl shuttering, reinf. steel placing and compaction	m^3	2.8
manholes	type a, small	unit	3.5
	type b depth < 2 m	unit	5.2
local systems	VIP	unit	2.8
	elevated VIP	unit	7.4
	aqua privy	unit	8.4
	septic tank-drainfield	unit	22
local system superstructure		unit	4.6
communal toilets 4 stalls	aqua privy	unit	32
	sewer	unit	24
plot installation		plot	6,5
laterals		plot	7.4

The feces are deposited in the tanks and stored after use for 4-6 months. Urine is diluted and used for plant irrigation. The DAFF toilet costs about USD 70 to construct, training and promotion is set to USD 70. With a compost marked price of USD 12 per 50 kg the toilet costs can be recovered in little over a year, all in 1989 prices.(Mara & Cairncross, 1989). According to Cotton et al., 1995, the various sanitation systems installed in rehabilitation camps in Bangladesh had the following relative prices compared to a simple pit latrine with concrete rings and a bamboo floor:

simple pit latrine = 1.0; VIP toilet = 1.28; waterseal toilet = 1.39; 2-family aqua privy = 1.48; 5-family aqua privy = 1.61; double vault compost toilet = 3.14

Similar comparisons have been done in Botswana in the late 1970’s (Bellard, 1981): VIP toilet = 1.0; double pit toilet = 1.59; aqua privy = 2.46

Existing reports on economy imply that costs of sanitation vary from basically free systems that impose large risks for pollution, to about USD 100 or more for one household system of acceptable quality, depending on a number of factors.

8.2. Financing

Sound financial management requires that, as a general principle, costs are borne directly or indirectly by the users (Fang, 1998), not only by cost recovery (payment in advance, user charges, taxes etc.) but also the overall financial policies of the service-providing agency. Whenever possible, the users should finance their toilets/toilets themselves, or through a credit mechanism, and contract directly local private sector builders trained in toilet/toilet construction. A project that need external financing over time probably will not be sustainable.

9. Reuse of excretal nutrients

Basically from Cross & Strauss, 1985, Jenssen, 1999

There is a widespread need in many different areas to introduce or to expand and improve the practice of utilizing fecal and waste matter (Strauss & Blumenthal, 1990), and such reuse should be promoted to the extent dictated by the climatic, socioeconomic and cultural conditions of each specific country or locality. Table 23 shows examples of reuse practices around the world.

Table 23. Examples of excreta reuse practices (after Cross and Strauss, 1985)

Practice	Social unit	Countries
Soil fertilization with untreated or stored nightsoil	family or community	China, Korea, Taiwan, Japan, Thailand, India
Nightsoil collected and composted for use in agriculture	community or local authority	China, India
Nightsoil fed to animals	family	Melanesia, Africa
Use of composting or moldering latrines	family	Vietnam, Tanzania, Guatemala
Biogas production	family or community	China, India, Korea, Nepal, Cuba
Fish pond fertilization with treated or untreated nightsoil	family or community	China, Korea, Taiwan, Malaysia, Indonesia
Fish farming in stabilization ponds	family (illegal) or commercial farming	India, Israel
Aquatic weed production in ponds	family, community or local authority	Vietnam, SE. Asia, Cuba
Agricultural application of sewage	local authority or farmer	India, Saudi Arabia, Kuwait, Tunisia, S. Africa, Mexico, Peru, Chile, Argentina
Irrigation with stabilization ponds effluents	local authority or commercial farmer	Israel, India, Peru
Algae production in stabilization ponds	local authority	Mexico, Japan

9.1. Removal of end products

Local sanitation and treatment methods require the end products to be transported for either secondary treatment (e.g. post-composting for dehydrated and hygienic materials) or final use. Transport distance, - medium and –capacity are important factors to be decided for each sanitation project. Under favorable conditions the end products can be used near the toilets, but in other situations there will be some kind of transport, at least of solid materials. The hygienic safety and the attractiveness of handling the material will be important aspects for the transport.

9.2. Pathogen survival after application of end products

After entering the environment all pathogens eventually die or become incapable of causing disease after some time (Winblad et al., 1998). Exceptions are *Salmonella* and some other bacteria, which may temporarily increase.

Table 9 gives an overview of factors influencing the lifetime of pathogens.

There are wide variations in reported survival times of in soil, which reflect strain variation, differing climatic factors, and different analytical techniques.

Table 24. Survival times of selected excreted pathogens in soil and on crop surfaces at 20-30°C (Feachem et al., 1983)

Pathogen	Survival time (days)	
	In soil	On crops
Viruses		
Enteroviruses[2]	< 100 but usually < 20	< 60 but usually < 15
Bacteria		
Fecal coliforms	< 70 but usually < 20	<30 but usually < 15
Salmonella spp.	< 70 but usually < 20	<30 but usually < 15
Vibrio cholerae	< 20 but usually < 10	< 5 but usually < 2
Protozoa		
Entamoeba histolytica cysts	< 20 but usually < 10	< 10 but usually < 2
Helminths		
Ascaris lumbricoides eggs*	Many months	< 60 but usually < 30
Hookworm larvae	< 90 but usually < 30	< 30 but usually < 10
Taenia saginata eggs	Many months	< 60 but usually < 30
Trichuris trichiura eggs	Many months	< 60 but usually < 30

‘ Maximum recorded survival for *Ascaris* is 7 years

9.3. Horticulture

Gardens can be an acceptable area for reuse of treated excreta. Urine is a valuable fertilizer with high concentrations of nitrogen, phosphorous, potassium and essential trace elements needed for plant production (see Table 13). Undiluted it may even be too nutritious for the plants, and care has to be taken to either dilute the urine (one part urine with 2-5 parts of water) or spread it on the fields before sowing.

Reports (FAO, 1997; Jonsson, 1997; Drangert, 1996) estimate specified aerial needs of 50-250 m^2 per person to completely utilize the urine as plant nutrients. With intensive horticulture with tree annual crops 50-100 m^2 is needed. Simply to get rid of the urine about 1.5 – 10 m^2 is needed for a family of 5, depending on the soil type.

9.4. Agriculture

The primary benefits from the agricultural use of excreta are their nutrients values. In addition, nightsoil is a valuable supplier of moisture particularly where soils seasonally dry out. Nightsoil, like other organic fertilizers, also have long-term beneficial effects on the soil: It amends the soil’s organic and humus fraction, an advantage not offered my mineral fertilizers. Humus, in turn, helps to maintain moisture and air regulation as well as nutrient storage and release. Physiological measurements indicate that the amounts of plant fertilizer excreted via urine per person and year (2.5-4.3 kg N, 0.7-1.0 kg P and 0.9-1.0 kg K) are larger

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[2] Includes poliovirus, echovirus, and coxsackievirus

than the amounts excreted as feces (0.5-0.7 kg N, 0.3-0.5 kg P and 0.1-0.2 kg P) (Krichmann & Pettersson, 1995). In a pot experiment, higher gaseous losses and lower crop uptake occurred with urine N compared to mineral fertilizer N. The opposite was the case for P (Kirchmann & Pettersson, 1995).

Table 25. Excreta fertilizing potential for a 5-adult family in rice cultivation (Strauss & Blumenthal, 1990).

factor*	N	P**	K
Nutrient content %	8	3.5	2.5
daily production, g	8.8	3.8	2.7
annual per household, kg	16	6.9	4.9
nutrient requirement, kg	98	34	80
rice cultivation area fertilized	1600	2000	600

* nutrient content in dry weight %, daily per capita production in g, yearly production in kg, nutrient requirement in kg per hectare and year, rice area fertilizable by one family (m^2).

The fertilizer value of blackwater (i.e. a mixture of liquid and solid excreta in a low-flushing toilet system) is shown in Table 26. Only one half percent of the blackwater weight will be dry matter. Of this, about one quarter will be nitrogen

Table 26. Measured blackwater mean content in a low-flushing system (Jenssen, 1999)

Parameter	unit	mean	authorities*
pH		7.8	
dry matter	weight-% **	0.45	
Tot-N	weight-% ***	25	
NH4-N	weight-%	22	
Tot-P	weight-%	3.5	
Cu	mg/kg	61	650
Zn	mg/kg	658	500
Ni	mg/kg	7.4	50
Cr	mg/kg	8.5	100

* maximum accepted limit for sludge to be used in agriculture (MD, 1995)
** weight-% of total weight
*** weight-% of dry matter

The content of heavy metals is significantly below the recommended values for fertilizing sludges.

The nutritional value of various natural fertilizers is given in Table 27.

Table 27. Nutrient values (% of dry matter) in various natural fertilizers.

	Ntot	P_2O_5	K_2O
Human feces	5-7	3-5.4	1 – 2.5
Human urine	15-19	2.5-5	3-4.5
Fresh nightsoil	10.4-13.1	2.7-5.1	2.1-3.5
Fresh cattle manure	0.3-1.9	0.1-0.7	0.3-1.2
Pig manure	4-6	3-4	2.5-3
Plant residues	1-11	0.5-2.8	1.1-11
Compost	0.4-3.5	0.3-3.5	0.5-1.8
Biogas sludge	1.4	1.1	1.1

The largest risks associated with excreta reuse is the transfer of excreta-related infections, see Table 28.

Table 28. Factors determining the relative importance of excreta in transmitting disease (Strauss, 1996)

Pathogen	Survival in environment	Infective dose	Immunity	Routes	Latency	Important for
Helminths	Long	Low	None or little	Soil, crops	Long	Fish, host for flukes, tapeworms
Protozoa	Short	Low to medium	None or litter	Person-to pers., food, water	Zero	No data
Bacteria	Short to medium	Medium to high	Short to medium	Person-to pers., food, water	Zero	Fish, shellfish, crustacea
Viruses	Medium	Low	Long	Person-person	Zero	Fish, shellfish, crustacea

9.5. Aquaculture

Fish produced in ponds constitute an important food supply in many parts of the world. Aquaculture is practiced extensively in China, Taiwan, Indonesia, the Philippines, Thailand, Malaysia and West Bengal (India). It is reasonable to assume that informal as well as institutional fish production is also practiced in many other locations around the world. Human excreta or animal manure constitute important nutrient inputs. Easy access to food production may gain priority over soiciocultural norms, particularly if fish rearing is organized in an informal way.

The role of human excreta in fish production consists mainly of supply of nutrients for microbial growth added to the food chain. Nightsoil also acts as direct fish feed, as fish have been observed to gather at the input point of the material. Carp and tilapia are the most common fish produced.

Fish reach maturity and grow to marketable size within four to six months. Average annual productivity in fertilized ponds in rural areas amounts to a few hundred kg of fish per hectare. At a fish farm in Taiwan, an unfertilized pond produced 132 kg per hectare annually, a night-soil fertilized pond produced 619 kg per hectare. Productivities of more than 1000 kg are common for well-maintained nightsoil-fed ponds in Asia. Table 29 shows guidelines for microbiological quality of fish produced with reused excreta (Strauss, 1996)

Table 29. Guidelines for the quality of fish and crustacea (no/per g) (Strauss, 1996)

Indicator or pathogen	Int. commission on food		FAO/IAEA/WHO	
	Acceptable	Reject	Acceptable	Reject
Total bacteria	500,000	1,000,000	500,000	10,000,000
E. Coli	11	500	-	-
Salmonella	0		-	-

10. Examples of ecological sanitation

The collection of systematic experience from using composting and dehydration toilets is sparse, even on a global scale. As shown in Table 18, systems have been studied in China, El Salvador, Eduador, India, Mexico, and Vietnam. The definition of South East Asia in this project has been chosen to be the countries from Indonesia in the south to Vietnam in the north, see Figure 3. A major part of World Bank sanitation projects listed by Fang (1998) in Table 20 took place in Asia, although specifically not covering the area as defined above.

Much of Chinese sanitation is based on central composting of collected excreta where urine is diverted and the feces is stored in buckets. An investigation performed in China in 1993 showed that 86% of the population had access to some kind of latrines (Wang et al., 199), but only 14% could be regarded as safe as fecal sanitation facilities. Since 1997 a project sponsored by the Swedish development aid (Sida) program has introduced dry toilets with urine diversion. The project consist of 21 outdoor toilets in cold and dry climate, 90 units in a cold and humid climate, and 70 units in a hot and humid climate. The results show that the systems have been working well under all conditions, and are well received by the peasants in three provinces (Wang et al., 1999).

Experiences from China have shown that composting is often based on “four-in-one”, a mixture of human and animal excreta, soil and street sweepings (McGarry & Stainforth, 1978). The urine can be added to the compost but more commonly it is diluted with water (1 to five) and used directly on vegetable plots. In total this system is questionable because of many contact points and a relatively high risk of contamination. The operation and maintenance costs are also high.

In parts of Vietnam, as in China, it is common to fertilize rice fields with fresh excreta. (McMichael, 1976). In 1956 campaigns were started to construct double-vault toilets: a squatting slab which has two holes, footrests and a diverted channel for urine. After use people sprinkle two bowls of ashes over the feces to absorb moisture, neutralize bad odors and make the feces less attractive to flies (and to make the solids more hygienic due to increased pH). The process of decomposition is basically anaerobic,

Most Vietnamese live in rural areas, where only 17% of the households have hygienic latrines (Phi et al., 1999). There is an high infection incidence of parasitic diseases (60-80%) and diarrhea cases (1240 cases per 100 000 inhabitants). With support from Sida, The Swedish development aid agency, The Nha Trang Pasteur Institute and the Department of Preventive Health have developed a pilot project in Cam Doc. Sixty ecological sanitation systems in five different design, with varying types of dehydration toilets with urine diversion were tested for performance. The test organisms were the bacteriophages *Salmonella typhymurium* phages 28B and *Ascaris suum* eggs. It was found that it took 6 months of retention for fecal material to become safe. It was also found that only pH was significantly influencing the die-off in the excreta.

In India the attitude towards using human excreta is different from that in China. With few exceptions people do not use excreta to improve the soil (indirectly they do because most people still defecate in the fields). Most people use water for anal cleaning, and latrines often have a water seal. The amount of water needed for flushing is 2-3 liters. The double-pit pour-flush latrine was developed in India by the UNDP Global Project for low-cost sanitation (Roy, 1981). The water-seal pour-flush latrine has several advantages: there are no odors and no fly or mosquito breeding (if the lids of the pits are tight fitting) and the excreta are out of sight. It is unpleasant and hard work to empty a single-pit pour-flush latrine by hand. The contents are wet, malodorous and dangerous to handle. With the double-pit these problems are avoided. Where there is little water, flushing is a problem. There may also be problems in areas with high ground-water table (Institute of Social Science Trust, 1981).

In arid and hot climate areas drying of the feces is quick and simple. In Yemen there is a tradition for drop systems that can be constructed 5-9 stores high. A public bathhouse employee collects the receptacles to the bathhouse frequently, where it is spread out on the roof to dry. The dried excrement is later used as fuel for heating. The problem with these systems is frequent contact with fresh excreta.

A similar system in Ladekh, the Tibetian part of India, uses soil spread out on the toilet floor. The excreta are pushed down a drop hole together with some of the soil. Similarly, there is risk of contact with fresh excreta.

Excreta fed to pig-pen or other animals give a high risk for tapeworm infections. The tapeworm develops in the muscles of the animals, and is infectious to humans in undercooked or raw meat.

11. Evaluation of ecological sanitation

11.1. Evaluation: what is it?

11.1.1. Fundamentals of evaluation

Evaluation of ecological local sanitation systems requires the evaluation of several factors, all of which influence the success or failure of any given system: system technology, biological processes, level of cultural acceptance, and economic values.

Whether the evaluation system is crude or refined, whether it addresses a single component or a complex integration, it retains several common characteristics (Scriven, 1988):

1) Evaluation is a process of determining worth or merit. It may be qualitative or quantitative, or a mix of these. It is strongly although not sharply distinct from explanation.

2) There are four basic evaluative methods, one of which must occur in any evaluative conclusion (or be provided by that conclusion). These are grading, ranking, scoring, and apportioning (i.e. assigning a due share).

3) Much of the evaluation process – as in law and most practical life – applies probative logic. That is, evaluation is essentially inference to *prima facie* conclusions, not deduction or statistical inference.

In addition, there are three rudimentary criteria for a reliable evaluation: fair sample size, unbiased judgement, and professional scrutiny by qualified evaluators.

11.1.2. Standards

Standards, like criteria, are measures by which one judges a thing. But they differ in the sense that a standard applies an *authoritative* rule, principle or measure. A criterion may, or may not, be formulated into a rule or principle. The point here is to emphasize that standards are inherently authoritativ*e*. Evaluations often focus upon standards for two reasons: (1) they are established by authority, custom or general consent, and (2) they are models or examples to be followed. If one uses standards to evaluate sanitation systems, these two points require further scrutiny.

To begin with, we must address the issue of authority. In essence, who (or what) establishes standards for sanitation systems? Generally speaking, system requirements are designed by engineers and are planned by public authorities, both of which focus more on technical performance than human behavior. Consequently, standards might be technically sound but socially irrelevant.

Another consideration is that sanitation authorities tend to be dominated by men, which introduces gender bias. One of the key reasons why toilet provision has been inadequate to large sectors of the population is because of the nature and gender of decision-makers. The worlds of plumbing, services engineering, civil engineering, and building technology are particularly male dominated, especially at senior levels (Greed 1995, p. 194). This might explain why public toilet standards frequently fail to meet the needs of women (Kira 1995; Greed, 1995; ORWH 1991).

Standards are not necessarily based on science; they can be established by custom or general consent. This is critical when one considers applying standards from one culture to another. In the final analysis, the success of a sanitation system is not predicated merely on technical performance but also upon the *users'* standards of performance.

The word *standard* is sometimes used casually and recklessly by evaluators, because it has different meanings. For example, *standard* can be used as a modifier and mean a basic, minimal requirement: e.g., The standard removal efficiency for a given contaminant must be 60% of total contaminant input. Social scientists often use standard within this context to imply common behavior: e.g., The standard behavior of most people is to wash their hands after defecating. Here standard may mean exemplary behavior or normal behavior, or both.

In addition to serving as models or example to be followed, standards are frequently used as minimal requirements, and this poses problems. Scientists, especially ecotoxicologists, have well-founded reservations about standards that are, in fact, merely threshold values. The reason being that a given value of a pathogen does not necessary indicate its bioavailability. Environmental circumstances, such as soil, vary considerably and play major roles in the operational significance of quantitative values.

In summary, when standards are applied to the evaluation of sanitation systems, investigators must be acutely aware of their suitability, because they might well be misleading, irrelevant or unnecessary. We must ascertain the nature of each standard used: On whose authority, custom or general consent is the standard based? Is the standard an exemplary model or merely the lowest acceptable level? Careful analysis of these issues puts the evaluator in a better position to resolve the inevitable question: What if standards conflict?

11.1.3. Quantitative vs. Qualitative evaluation

Quantitative
Since any evaluation must include one of the predicates (ranking, scoring, grading or apportioning) most evaluations lend themselves to quantitative analysis. We generally see a numerical approach applied to evaluating components of a sanitation system, for example: the structural integrity of materials, the concentration of contaminants or nutrients, flow rates, etc. Quantitative measures are well suited when standards are used for comparison purposes; for measuring the specific performance of a system (e.g. removal of pathogens); and, of course, when statistical inferences are implied. These quantitative measurements tend to be static, in the sense that predicates reveal a value of a given object, state, or phenomenon at a given time (or duration).

The benefits are clear, but perhaps disputable. Quantitative evaluations appear objective. Numerically based data are efficient for tabular comparison and plotting graphical trends. And the use of statistics provides us with a sense of how likely our findings are.

The disadvantages of quantitative analyses are as great as their benefits. Numerical evaluations can be misapplied. For instance, standard threshold values associated with contaminants tell us nothing about their bioavailability in a specific environment. Even when numerical standards are appropriately used, we often fail to realize that standards are frequently revised. An unsuspecting evaluator, therefore, might use outdated references. And, of course, the evaluator might (willingly or not) use statistics to skew, persuade or bias what appears to be an impartial predicate.

Qualitative
Qualitative evaluation is often preferred when complex, integrated systems are being analyzed, for example, several multi-family units (consisting of different types of toilets) that feed fertilizer to agricultural land. Qualitative evaluation is also well suited for monitoring operations over time – say, comparing the performance of a system after one, five and ten years – because it expects change over time. Another qualitative application is scaling up a system's impact on general health, agriculture, and natural resources. And, of course, qualitative evaluation is required to determine the cultural acceptance of a system, based upon local beliefs, gender, etc.

The benefits of qualitative evaluation are essentially four-fold. First, it transforms data to information. Even quantitative analysis requires some qualitative evaluation. For instance, a statistical (quantitative) comparison of two systems might show that they are different. But operationally (qualitatively) they are not. In the final analysis, we are interested in determining real world merit not theoretical inference. The second benefit of qualitative evaluation is that it illustrates the importance of value judgment, both from the professional, e.g. environmental engineer or health expert, and the layman end user. Thirdly, qualifying analyses explain the "human" elements, such as why technically sound systems are often rejected by the user. And finally, qualitative evaluation helps explain the success or failure of a system.

The drawbacks are also profound. Qualitative evaluation is inherently subjective, therefore prone to bias. And because this approach often lacks substantive data it is susceptible to conjecture based upon anecdote rather than fact. As with quantitative methods, qualitative evaluations may make unfair comparisons and lead to groundless recommendations. Finally, the difference between opinion and approval is not always clear. To claim a given system is “good” does not necessarily mean it is recommended; likewise, an approved system is not necessarily a good one.

It seems obvious that a complete evaluation of sanitation systems should include both quantitative and qualitative evaluation, in order to examine how systems e.g. providing the best reduction in health risks, score among the users, and why.

11.2. Evaluation strategies

11.2.1. External Evaluation

The scope of methods to evaluate ecological sanitation systems is broad. Some rely upon laboratory tests, some are based upon *in situ* monitoring; others are little more than summaries of user questionnaire. But there is a dominating characteristic that narrows the scope of evaluation. External evaluations tend to be polarized towards either specific sanitation systems or general frameworks for evaluating water and sanitation programs.

For example, Martel’s (1987) *Evaluation of the Shasta Waterless System as a Remote Site Sanitation Facility* is a typical system-specific evaluation. A single compost toilet design was tested at six recreation sites across the U.S. The straightforward cost analysis (capital and annual maintenance) was supplemented with a telephone survey to learn more about the performance of these units, e.g. operational problems and odors. Although the evaluation was probably helpful to the toilet designer, its value goes little beyond that.

There are also evaluations designed specifically to compare systems, such as commercially available compost toilets. These evaluations, however, tend to focus primarily upon technical performance and costs. User acceptance, market and cultural considerations are generally ignored. Moreover, since most of these comparative studies are performed in a laboratory, it is not possible to evaluate the application of the tested systems in foreign environments.

At the other end of the spectrum we find general evaluations, which also have limited application. For instance, fifteen years ago the World Bank sponsored *A Monitoring and Evaluation Manual for Low-Cost Sanitation Programs in India* (Parlato, 1984). The purpose of the manual was to develop a method to evaluate the progress and identify potential problems associated with a United Nations Development Program (UNDP) Global Project initiated four years earlier. The UNDP project initiated feasibility studies for low-cost local sanitation and built more than 60,000 latrines. Admittedly, the UNDP project was specific – both in its objective (to construct demonstration latrines) and geographical scope (200 towns in India) – but the evaluation resulted in little more than a collection of survey outlines.

Parlato’s (1984) evaluation manual was designed to ”determine the nature and extent of operational problems and socio-economic constraints”, and was comprised of four surveys: financial/administrative, socio-economic, technical, and community. There is, however, no clear indication how a component is ranked, graded, scored or apportioned – much less integrated with the other three. Although the evaluation manual has been available for more than 15 years, its application is not revealed in the open literature.

Another generalized evaluation manual is the *Minimum Evaluation Procedure (MEP) for Water Supply and Sanitation Projects*, published by the World Health Organization (1983). This manual is more helpful than Parlato's (1984) because the guidelines are specifically designed for simple technologies. The evaluation concept is a systematic way to improve the function, use and impact of existing projects. The guidelines do not recommend research-oriented methods of establishing a link between sanitation, hygiene and health for particular systems. Nor do they provide methodologies to conduct cost/benefit analysis. The emphasis is rather on collecting basic information related to projects.

Although both the specific and general evaluations may be adequate for their intended purposes, neither strategy is suitable for a comprehensive geographically oriented evaluation of sanitation systems. To develop a system for evaluating ecological sanitation in Southeast Asia requires a conceptual framework that addresses the general factors (system technology, biological processes, cultural acceptance and economic values) with specific predicates (ranking, grading, scoring or apportioning). The scope of the task is daunting, but not without precedent.

11.2.2. Participatory Evaluation

In 1993 The World Bank published *Participatory Evaluation: Tools for Managing Change in Water and Sanitation* (Narayan, 1993), which outlined (what was then) a novel concept in evaluating sanitation systems. Since the mid-1980's policy and practice in sanitation projects have emphasized community involvement – and particularly women's involvement. Participatory development has an impact on evaluation in terms of: (1) the purpose and use of the evaluation, (2) the indicators to be included, (3) the way the evaluation is organized and carried out, and (4) who conducts the evaluation. Narayan's (1993) *Participatory Evaluation* focuses on specific indicators and practical ideas of how data collection can be carried out. The heart of participatory evaluation is that external experts work in partnership with the community or program staff, rather than deciding in isolation how the evaluation should be conducted (Narayan 1993, p.9). Other characteristics include:

- Local people – those who will be affected by the project – help decide and define the purpose of the evaluation and determine how the information is collected and used in follow-up actions;
- Self-evaluation tends to take place frequently, and the distinction between monitoring and evaluation becomes blurred;
- Data analysis techniques involve users in discussing findings and formulating recommendations;
- Participatory methods reach those who are often excluded in traditional decision-making, particularly women
- The volume of information and degree of accuracy in data collection are less than typically found in scientific, academic, rigorous research.[3]

These characteristics might not sit well with expert evaluators because, generally speaking, participatory evaluation calls for simple, shortcut methods throughout the entire

---

[3] For example, traditional household surveys accumulate detailed information on family size, household composition, income, etc. Whether as household size is 6.7 or 6.1 might have little implication for evaluating the performance of sanitation system. Ranking households into three categories may be all that is needed. Since rural communities usually have intimate knowledge about themselves, they can quickly rank families by size, wealth (rich, average, poor), presence of children under five years of age, adherence to religious beliefs, etc.

evaluation cycle, which runs contrary to conventional research methods. But there are many appealing features of participatory evaluation; not the least is identifying the most important elements – key indicators – to measure progress achieved in a sanitation project.

From the global experience already gained through field use of participatory evaluation, certain patterns have emerged (Narayan 1993):
Different communities find different indicators of greatest importance. For one it may be increased hygiene; in another it may be increased reliability of a toilet system; in a third, recycling nutrients from the sanitation system.
In the same community or project, the relative importance of indicators will vary with time. A given project might initially be concerned with improving hygiene; later cultural acceptance or cost-recovery is the primary indicator; then reliability is paramount.
Gender differences can influence the chosen indicators of success. Women are more likely to be concerned with the health and hygiene than men. In addition, women and men often have different social perceptions about toilets.
Indicators of success differ for community people. Community leaders, project staff, and end users have their own specific interests.
Community people have the ability to select and evaluate key indicators. Community groups have developed locally relevant indicators of health and poverty. The problem is usually not the capacity of the community people, but external evaluators to work with them in supportive ways.

11.2.3. Methological problems

Evaluations and surveys infer the opinion of groups of people. Surveys are aimed at a variety of public and private affairs, but can generally be divided in surveying measurable and non-measurable objects/goods. The quality of a survey depends on two questions: are the right persons asked (representative sample), and do they give the “true” answer (acceptable measurements).

It is difficult to produce reliable predictive results using surveys. The contingent valuation methods uses survey questions to elicit people’s preferences for public goods by finding out what they would be willing to pay for specified improvements, by finding their willingness to pay (WTP), or willingness to accept (WTA) for a specific loss, in fiscal amounts.

The methodological challenge in surveys is asking the right questions. Seemingly slight changes in word order may convey unexpected meanings. A story of two priests who discuss whether it is a sin to smoke and pray at the same time, and consults their superior on the matter, gives an example: The Dominican says: “Well, what did your superior say?” The Jesuit responds, “He said it was alright”. “That’s funny”, the Dominican replies, “my superior said it was a sin.” “What did you ask him?” “I asked him if it was all right to smoke while praying.” “Oh”, said the Jesuit, “I asked my superior if it was all right to pray while smoking.” Another aspect of asking questions is the sequence. Experience has shown that questions about the respondent’s personal characteristics-the background questions-are best left to the end of the questionnaire, when the respondents is more relaxed about being questioned. Controlled experiments have shown that independent of strategy the amount of WTP (willingness to pay) is more than 60% of the true WTP value (Mitchell & Carson, 1989).

12. Conclusions and recommendations

It is reccomended to use project sustainability, including environmental sustainability, as the central criterion to identify problems and issues in a project analysis. An investigation on local sanitation should start with a team skilled persons to evaluate the relevant issues: climate, topography, technology, ecology, hygiene and health, environment, social and cultural aspects, infrastructure, user participation and education.

Evaluation is a systematic way of learning from experience both to improve the planning of future projects and also to take corrective action to improve the functioning, utilization and impact of existing project. The evaluation itself does not improve anything. It should not be a listing of problems and their possible causes, but should also include recommendations.

- **Laboratory methods**

A local laboratory capable of reliable measurements of biological, chemical and physical factors is necessary in order to comply with standards or criteria. International co-operation, e.g. on higher education, can be an effective way to ensure this.

Existing reports on economy seems to imply that costs of sanitation vary from no cost systems that impose large risks for pollution, to about 100 USD or more for one household system of acceptable quality, depending on a number of factors.

- **Collect urine - don't mix before the tank:**

Systems for local sanitation, and specifically urine diversion combined with composting or dehydration, or both, will probably be the most frequent systems applied. In special cases composting without urine diversion, and improved pit latrines may also be used. Many previous sanitation projects have reported that it is difficult to determine and measure pit latrine contamination of groundwater, but new techniques have shown that pit latrines do pollute to a greater extend than previously expected. Experiments using biotracers have found that pathogenic organisms may spread up to 1000 m, considerably more than the "safe" distance of 30 m between pit latrines and wells as generally recommended.

- **Mix additives in the tank:**

The fundamental processes both in compost toilets, dehydration toilets and pit latrines must be maintained. To obtain this the process chamber must be observed and additives must be used at all times.

- **Collect urban urine:**

Given that (1) most of the excreted nutrients are in the urine, (2) urine is generally free of pathogens, and (3) office buildings have urinals, it appears logical that urine should be collected from the workplace also. Why the workplace in particular?

- Safe urine comes from healthy people, and sick people generally don't go to work
- Most office excrement is urine. Defecation usually takes place in the morning, triggered by breakfast
- Most offices have urinals
- Modification of toilet behaviour is not required

Discharge pipes can be retrofitted to a collection tank. This will also reduce the volume of blackwater. If half of the urine from each worker is collected at the workplace, this would mean about 200 L per person annualy. This equals a fertilizer potential of 20-50% of the food requirement for one person. In developing countries urban centers are bordered by agricultural areas, thus transport also might be a minor challenge.

Although ecological sanitation is relatively new and field investigations are limited, its future holds promise for most situations in rural or peri-urban areas in low income countries.

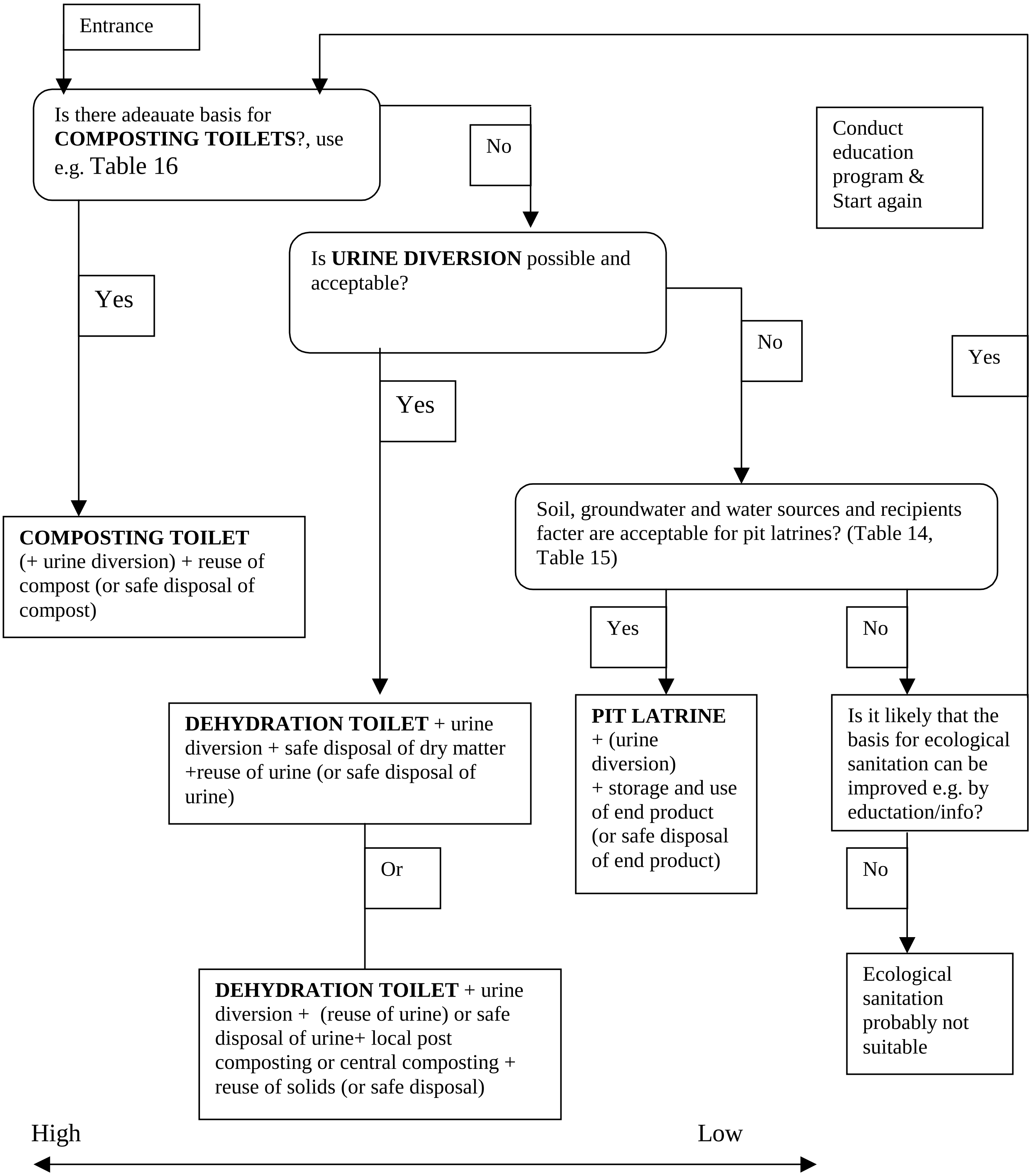
The following forms are examples of text and layout for decisions, calculations and evaluation of sanitation aspects discussed in this report (Chapters 12.1-12.5). We stress that they are examples that must be adapted to specific cases. An evaluation prior to installation of a sanitation system should be based on the following parameters/factors:

- General:
    - Construction (groundwater level, building materials, geography, climate etc.)
    - Cost
    - Cultural aspects
- Loading capacity including peaks
- Storage time and pathogen destruction
- Odor control

A simplified way of to determine the most suitable ecological sanitation system is to follow the Decision key 1. Note that the decision must consider costs, cultural aspects and loading aspects (large systems favours composting, smaller dehydration).

12.1. Areas without prior sanitation

Decision key 1. Example of sanitation system technology decicion scheme (paranthese indicate optional)



(Scale shows relative costs, benefits to health and environment, and loading capacity)

12.2. Evaluation of fundamentals & technology

The sanitation system technology can be evaluated based on the fundamental processes described in Chapter 4, specifically from
The most important process factors and criteria are listed in Table 16 and Table 17.
Table 16 and Table 17, and based on the technology described in Table 19.

Calculation form 1. Estimating excreta volumes and size of receiving/processing and storing chambers*

---

1. Number of people (PE) in household? ________PE

Annual urine volume = (no PE *1.5)*365: _________(1)

Annual feces volume = (no PE *1.5)*73: _________(2)

Both volumes (1) and (2) should be covered by at least 2 tanks, e.g. if the total urine volume is 1000 L, the storage should be at least 2 x. 500 L.

---

* PE = persons (adults and children) we suggest to use a safety factor (here 50% on volume, due to e.g. visitors) annual urine volume = 365 L per person (1 L per day), annual feces volume= 73 L per person (0.2 L per day), total annual urine volume per household of 5=2200 L, total annual feces volume=450 L, minimum storage time for urine and feces (mixed or diverted)=6 months, minimum total storage volume of urine=2x1100 L, minimum storage volume of feces=2x225 L, total storage volume=2650 L

Technical evaluation

The technical performance of ecological sanitation should contain:

- Background data (operation time, climate, social & cultural data)
- Actual loading rate
- User acceptance
- Maintenance needed
- Actual operation record (additives, storage time, use of end product)
- Pathogen survival (samples or existing data)
- Change in soil fertility (possible)
- Chagne in excreta related disease (see health)

Evaluation form 1. General perfomance data

Description of the toilet system		
What kind of toilet is used?	Composting toilet, dehydration toilet, Pit latrine, with/without urine diversion	
Name of system		
Amount of containers		
Has there been any performance testing of the toilet after or before it was set up?		
What is the expected loading capacity?		
Was there any information (written or oral) to the use of the toilet?		
Climate data		
Mean air temperature		
Mean annual rainfall/precipitation		
Are there periods of extrem weather (heavy rainfall, flood, frost)?	No	Yes:_______________
High groundwater levels?		
Is water readily available for washing/flushing?		
Soil type?		
Performance data		
How long has the toilet been in operation?	years	
How many people are using the toilet daily (no. visits per day if only part-day use)?	Persons	Visits
Has the toilet been emptied?	Solids:	Urine:
Who is responsible for the empying?	Solids:	Urine:
What is the average storage time?	Solids:	Urine:
Where is the end product used?	Solids:	Urine:
Do the toilet require use of additives?		
Which additives has been used and how much?		l/day
Has there been a need for maintenance of the toilet?		
Technical user acceptance		
Is the toilet used by everyone?		
How is the user acceptance?	Very high, high, medium, low, very low	
Reason for high/low user acceptance	Comment:	
Has the toilet produced odors?	Never, sometimes, often	
Flies and other vectors nuicanse?	Never, sometimes, often/many	
Has the toilet been pade by the users?		
Has the toilet been built/installed by the users?		
Hygiene and utilisation of end product		
Have there been taken samples for hygienic control of the end products? (Otherwise these should be taken)	Yes/no	Results:
Has there been any improvement of the soil production after applying human waste end products?	Investigations/own judgements	Improvement:

Evaluation form 2. Technical sustainability for sanitation COMPONENTS and SYSTEMS.

System/ Component	Expected lifetime years	Manufactured locally*	Imported*
SUPERSTRUCTURE			
earth works			
foundations.			
superstructures **			
roof **			
indoor toilet adjustment			
TOILET			
toilet stool			
piping			
ventilation			
pumps			
ACCESSORIES			
storage for additives			
storage for used paper			
closing lid			
TOTAL SYSTEM			

* Yes/no ** For outdoor facilities

12.3. Evaluation of health

Hygiene and health aspects are usually considered by measurements of indicator organisms or pathogens (Coli bacteria, *Ascaris* eggs), or based on medical statistics of prevalence of different diseases. If possible hygiene and health is best considered on the project level, but this will usually not be identical with the base of medicine statistics.

Evaluation form 3. General health aspects

Personal level

How do you rate improvement in the following factors for reducing the health risk in your personal environment?

	not important	desirable	important	required
Personal hygiene:	_____	_____	_____	______
Water supply:	_____	_____	_____	______
Sanitation;				
Toilet devise**:**	_____	_____	_____	______
Toilet use**:**	_____	_____	_____	______

Handling and storage of

urine:	______	______	______	_______
feces:	______	______	______	_______

Reuse of

urine:	______	______	______	_______
feces:	______	______	______	_______

Do you apply/reuse urine for the production in/of;

	Always	Usually	Sometimes	Rarely
Gardens:	_______	_______	________	______
Grain crops:	_______	_______	________	______
Vegetables:	_______	_______	________	______
Fodder:	_______	_______	________	______

Do you apply/reuse compost for the prodcution in/for;

Gardens:	_______	_______	________	______
Grain crops:	_______	_______	________	______
Vegetables:	_______	_______	________	______
Fodder:	_______	_______	________	______

What is the total processing and storage time for:

	Composting toilet	Dehydration toilet	Pit latrine	Other
Urine:	______________	______________	_________	__________
Solid/feces:	______________	______________	_________	__________
Mix/nightsoil:	______________	______________	_________	__________

Community/village/regional level

Factor	**Measured value***	**Best estimate**	**Reference**
Number of people to be served by the sanitation system	_________________	_______________	________________
Community child < 3 yrs. mortality	_________________	_______________	________________
Community expected lifetime	_________________	_______________	________________

Measurements of indicator organisms ________ in ____________	________________	______________	_______________
Toilet system hygienic performance measured as prevalence of __________ organism(s)	________________	______________	_______________
Previous health improvement in ____________disease	________________	______________	_______________
Pre-project prevalence of ____________disease	________________	______________	_______________
Post-project prevalence of ____________ disease	________________	______________	_______________

* if this column is used the reference must be given, otherwise give a best estimate

Evaluation form 4. Health aspects of excreta, urine and wastewater reuse

The reuse of excreta*** or wastewater can be considered either by the time of storage of the end products, see chapter 4, or by specific measurements of indicator bacteria, pathogens or chemical constituent in the end product. The storage volume should be considered on the unit scale, i.e. for each treatment unit (on an average basis).

Factor	**Measured value***	**Best estimate**	**Reference**
Storage volume/unit	________________	______________	_______________
No. of persons (PE.)	________________	______________	_______________
Produced volumes per __________	________________	______________	_______________
Storage time	________________	______________	_______________
End products content of TCB or other indicator microorganisms	________________	______________	_______________

End products
content of pathogens of
_____ organism: _______________ _____________ ______________
_____ organism: _______________ _____________ ______________
_____ organism: _______________ _____________ ______________

End products
content of chemical indicators
of fecal contamination** _______________ _____________ ______________

For toilets: number of units with distance from water well/water source:

0-10 m: ___________
10-50 m: ___________
50-100 m: ___________
> 100 m: ___________

For spreading fields: number of wells/water sources with the following mean distance to spreading field:

0-10 m: ___________
10-50 m: ___________
50-100 m: ___________
> 100 m: ___________
Equipment for spreading
end product ______________________________________
Date for spreading: _______________________________
Available crops: ______________________________________

Yes No
Reports on problems
with operation
& maintenance _____________ ______________

---

* if measured value is entered the reference must be given
** e.g. coprostanol
***Reports (FAO, 1997; Jonsson, 1997; Drangert, 1996) estimate a specified aerial need of 50-250 m^2 per person to completely utilize the urine as plant nutrients. With intensive horticulture with tree annual crops 50-100 m^2 is needed. Simply to get rid of the urine about 1.5 – 10 m^2 is needed for a family of 5, depending on the soil type. This area can be developed just below the toilet thus no extra space is needed for this purpose. This show that, in principle, even in the most crowded parts of the world, such as e.g. in Khayelitsa in Cape Town with about 20 m^2 of open space per person, it is always possible to dispose of the urine locally.

Evaluation form 5. Environmental effects

The environmental effects from emissions from sanitation systems have traditionally been a factor depending on the water consumption in the sanitation and the fact that industry has been connected to the same discharge. Neither will be the case in the systems considered here.

Factor	**Measured value***	**Best estimate**	**Reference**
Chemical analysis of end product			
liquids: parameter			
________	________	________	________
parameter			
________	________	________	________
solids: parameter			
________	________	________	________
parameter			
________	________	________	________
air: parameter			
________	________	________	________

- if this column is used the reference must be given, otherwise give a best estimate

12.4. Evaluation of cultural issues

Evaluation form 6. To be administered (probably preferably by a female to the dominant female) of the household.

Generally speaking, how do you rate your toilet[4] facility for:

	Good	Adequate	Poor	Bad
Function	____	____	____	____
Sanitation	____	____	____	____
Comfort	____	____	____	____
Appearance	____	____	____	____
Privacy	____	____	____	____

---

[4] Where appropriate, the word “toilet” should be replaced with “squat plate” or suitable local term that identifies the waste disposal device, site, or system in question.

Please rank the importance of the following for your toilet:
1 = most important, 6= least important
___Privacy ___ Appearance ___Comfort ___Sanitation ___Odor free ___Maintenance free

How important is that toilet design and use adhere to local customs or religious doctrine?

___ very important
___ somewhat important
___ not important

Number of people in your household: ___ infants (<3 yrs) ____ women ____ men

Is kitchen waste deposited in the toilet? ____Yes ____ No

Is the toilet or toilet room used for purposes other than relieving yourself and depositing kitchen waste? If yes, please specify.
___No ___ Yes:____

In order to handle composted waste, how important is it that the material is:

	not important	desirable	important	required
dry:	______	_____	______	______
odorless:	______	_____	______	______
light weight**:**	______	_____	______	______

How important is recycling toilet:

	Not important	Somewhat	Important	Very important
nutrients	_______	_________	_________	__________
energy	_______	_________	_________	__________

May the same toilet be used by both sexes? ____Yes ____No

May different ages groups use
the same toilet? If no, explain _____ Yes ___No__________________________

May guests use your toilet? _____Yes ___No__________________________
If no, please explain.

Is the toilet room large enough for your purposes?
____Yes ___No, ideal dimensions should be:___x____meter

Do you believe urine is harmful or dangerous? ____Yes ____No

Do you believe **infant** feces are harmful or dangerous? ____Yes ____No

Preferred toilet location: ___Indoor ___Outdoor ___not important

Is privacy adequate? If not, explain.____Yes ___No:__________________________

Water is	flushing	washing	other
required for:	______	______	______________________
preferred for:	______	______	______________________
not required for:	______	______	______________________

Are there other factors that influence one handling composted waste?

____

When should excrement be applied to the soil? (Select only one.)

___ immediately ____when storage bin is full
___ store for 6 months ____ store for 2 years
___ not important

What is the preferred position to use a toilet? ____Sitting ___Squatting

What is the preferred anal cleaning method? ___Paper ___Water ___Other:_____________

After members of your family use the toilet, they wash their hands:
____Always ____Usually ___Sometimes ___Rarely

If human waste is composted and safe to handle, is somebody in your home willing to handle it?
___ never ____reluctant ___willing

When you prepare vegetables for eating do you:
___ always cook them ___ usually cook them ___rarely cook them

What is your religion:________________________________
What religious concerns, if any, influence your toilet requirements or behavior:

____

Are there any gender issues that influence your toilet requirements or behavior?
For women____
For men____

Are sanitary napkins deposited in the toilet? ____Yes ____No

12.5. Evaluation of economy & finance

The economy in a sanitation project depends on the standards desired or required, the costs for selected systems, financial resources available, the users and beneficiaries willingness to apply for loans and to pay, and local, regional or international financial opportunities. Costs are broken down to unit parts. Usually both capital costs and operation & maintenance (including labor) costs are calculated as annual present values depending on the lifetime of the components, the time period for downpayments, and the interest rate.

Ideally the cost reduction due to money saved on water consumption and water treatment by introducing dry sanitation systems should be included in the costs. This will be particularly important when comparing alternative sanitation systems. An example of how this is done is given in the appendix.

It is possible to survey the acceptance or ranking of a proposed subset of sanitation systems among the beneficiaries of a project. It can be difficult however to link this ranking to the costs of the project. A ranking of sanitation systems based on (social) acceptance is probably best suited only for selecting systems: firstly between systems that are unacceptable and acceptable, and the some kind of individual ranking (which might be random) between the acceptable system.

Calculation of present value of a future payment

The present value can be calculated from the following equation:

$$K = K_0 * \frac{1}{(1+r)^t}$$

where r = annual interest rate (e.g. 5% per year=0.05)
t = number of time steps, e.g. no of years
K = payment

Example: If an investment of USD 1000 is needed in 5 years, and the interest is 5%, the present value is USD 783.

Calculation of the annuity of an investment

If on the other hand, regular incomes (e.g. sanitation fee) say of 100 USD per year, for the lifetime of the system, say 20 year, at an interest rate of 5%, the present value is USD 1250 calculated by:

$$A = A_0 * \frac{(1+r)^t - 1}{r * (1+r)^t} = 100 * \frac{(1+0.05)^{20}}{0.05 * (1+0.05)^{20}} = USD1250$$

The annuity is the constant value by which a downpayment of a loan is paid back. It is the reciprocal of the factor in the previous example.

Evaluation form 7. Economical aspects, given in _____ currency, or based on foreign currency _USD___ with an exchange rate of ___1 local = 0.1 USD_____

Factor	**Value**
HOUSEHOLD LEVEL	
Number of people to be served by the sanitation system	___________8_________
Gross income	______1000/month_____
Income tax	______100/month______
Sanitation fee	_______10/month______

ANNUAL COSTS COMMUNITY LEVEL	**Measured value***	**Best estimate**	**Reference**
Number of people to be served by the sanitation system(s)	____5,000______	_____________	_Report xx______
Average & range, gross income	_______________	_200/month (10-15000)______________	
Average & range, income tax	_______________	__20/month (10-150)	_____________
Average & range, sanitation fee	_______________	___10/month______	______________
Capital costs for sanitation system (present value**)	_______________	__120,000_______	______________
Operational and maintenance costs for sanitation system	_______________	___20,000/year___	______________
Total costs for sanitation system	_______________	___36,000/year___	______________
Estimated sanitation fee	_______________	____5/month/household	_____________

Cost reduction (negalitres)
due to savings on water
consumption/water treatment/
wastewater treatment ________________ ______________ _______________

Cost reduction due to savings
on fertilizer consumption ________________ ______________ _______________

COST/BENEFIT

Sanitation system
cost efficiency based on
pathogen removal*** ________________ ______________ _______________

Sanitation system
cost efficiency based on
health improvement*** ________________ ______________ _______________

Sanitation system
cost efficiency based on
nutrient removal***
(e.g. USD/kg N) ________________ ______________ _______________

Sanitation system
cost efficiency based on
nutrient recycling***
(e.g. USD/kg) ________________ ______________ _______________

* if this column is used the reference must be given, otherwise give a best estimate
** see above *** these factors will generally be difficult to calculate

Evaluation form 8. Cost estimates for sanitation COMPONENTS and SYSTEMS, for explanation see Figure 7

System/ Component	Expected lifetime years	proportion produced locally %	total price	Comments
STRUCTURE				
earth works				
foundations.				
superstructures (incl. roof)				
indoor toilet adjustment				
TOILET				
toilet stool				
piping				
ventilation				
pumps				
squatting slab				
ACCESSORIES				
lights				
paint				
storage for additives				
storage for used paper				
closing lid				
TOTAL SYSTEM				

Evaluation form 9. Financial sources

1. LOCAL FINANCIAL RESOURCES

Source	**Assumptions**	**Terms**	**Comment**

2. REGIONAL FINANCIAL RESOURCES

Source	**Assumptions**	**Terms**	**Comment**

3. BILATERAL FINANCIAL RESOURCES

Source	**Assumptions**	**Terms**	**Comment**

4. INTERNATIONAL FINANCIAL RESOURCES

Source	Assumptions	Terms	Comment

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14. References & citations

(including appendices)

Adamsson, M., Dave, G. 1996. Toxicity of human urine, its main nitrogen excretory and degradation products to *Daphnia magna*. Environmental Reserach Forum, Vols. 5-6.

Almedom, A.S., Blumenthal, U., and L. Manderson. 1997. Hygiene Evaluation Procedures: Approaches and Methods for Assessing Water- and Sanitation-Related Hygiene Practices. International Nutrition Foundation for Developing Countries. pp: 122.

Beiser (1988). Physical Science. 2.ed. McGraw hill book comp.

Bellard, B. 1981. Financing low-cost sanitation schemes in the urban areas of Botswana. In: Sanitation in developing countries. Proceedings of a workshop on training held in Lobatse, Botswana, 14-20 aug. 1980, IDRC, Ottawa, pp 131-134.

Bogner, J.,Spokas, K. & Jolas, J. (1993). Comparison of measured and calculated methane emissions. Chemosphere, vol 26, no 1-4, pp 369-386.

Borrego, J.J., Moringo, M.A., Devicente, A., Cornax, R., Romero, P. 1987. Coliphages as an indicator of fecal pollution in water-its relationship with indicator and pathogenic microorganism. Water Research, 21, No. 12, 1473-1480.

Brandes, M. 1978. Journal of Water Pollution Cont. Fed., Nov, p 2547.

Brenner, F.J., Brenner, E.K., Schwartz, T.E. 1999. Use of Plaque Assay to Detect Enteric Viruses in a Rural Watershed. J. Environ. Qual., 28: 845-849.

Brix, H. 1993. Wastewater treatment in constructed wetlands: System design, removal processes and treatment performance. In: G. A. Moshiri (ed.). Constructed wetlands for water quality improvement. Lewis publishers, pp. 9-22.

Brush, C.F., Ghiorse, C., Anguish, L.J., Parlange, J-Y., Grimes, H.G. 1999. Transport of *Cryptosporidium* parvum Oocycts through Saturated Columns. J. Environ. Qual. 28: 809-815.

Carlander, A., Aronsson, P., Allestam, G. Stenstrøm, T.A., Perttu, K. 1999. Transport and retention of bacteriophages applied as tracers in two types of willow-cropped zero-tension lysimeters. Proceedings of the 4th International Conference: Managing the Wastewater Resource, Ås, Norway, part 6, 7 p.

Centre for Accessible Environments (CAE) 1992. *WC facilities for women in public buildings:* Seminar report. London: Author.

Cotton, A., Franceys, R., Pickford, J., Saywell, D. 1995. On-plot sanitation in low-income urban communities: a review of litterature. Water, Engineering and Development Centre, Loughborough, UK, 40 pp.

Crabbe, D. & McBride, R. (1978). The World Energy Book. Kogan page ltd. UK.

Cressey, G.B. 1955. *Land of the 500 Million: a Geography of China*. McGraw Hill, N.Y.

Cross, P. 1986. Health Aspects of Nightsoil and Sludge Use in Agriculture and Aquaculture. Part 1: Exiting Practices and Beliefs in the Utilization of Human Excreta. Dubendorf, International Reference Centre for Waste Disposal (Report No. 04/85.

Cross, P. & Strauss, M. 1986. *Health Aspects of Nightsoil and Sludge Use in Agriculture and Aqualculture*. IRCWD Report No. 04/85. Duebendorf. Switzerland: International Reference Centre for Waste Disposal: I-1 – I-23.

Crutzen, P.J. (1991). Methane's sinks and sources. Nature, vol. 350, pp. 3810-3811.

Cunningham, S. and Norton, C. 1993. *Public inconveniences: Suggestions for improvements*. London: All Mod Cons and the Continence Foundation.

Current, W.L. 1986. *Cryptosporidium*: Its biology and potential for envrionmental transmission. CRC Crit. Rev. Environ. Control 17: 21-51.

Davies-Colley, R.J., Donnison, A.M., Speed, D.J., Ross, C.M. & Nagels, J.W. 1999. Inactivaiton of fecal micro-organisms in waste stabilization ponds: interaction of environmental factors with sunlight. Wat.Res. Vol. 33, 5, 1220-1230.

Deborde, D.C., Woessner, W.W., Kiley, Q.T., Ball, T. 1999. Rapid transport of viruses in a floodplain aquifer. Wat. Res. Vol. 33, 10, pp. 2229-2238.

Del Porto, D.1998. Sustainable Strategies Provides Ecologically Engineered Solutions To Sewage Problems In Developing Island Nations of The Pacific. Earthwise Publications. Moss Side Manchester, UK. 7 pp.

Del Porto, D., Steinfeld, C. 1999. The Composting Toilet System Book. Published by The Center for Ecological Pollution Prevention (CEPP), PO Box 1330, Concord, Massachusetts 01742-1230, USA. pp. 234.

Drangert, J-O. 1996. Perceptions of human excreta and possibilites to re-use urine in periurban areas. Stockholm Water Symposium, August 6-9, Stockholm.

Ehrig, H. & Scheelhaase, T. (1993) Pollution potential and long term behaviour of sanitary landfills. In: Christensen, T.H., Cossu, R. & Stegman, R. (Eds.): Proceedings Volume 2. Sardinia'93. Cisa, V. Marengo 34, I-09123 Ca, Italy.pp. 1203-1225.

Emberton, J.R. (1986). The biological and chemical characterization of landfills. In; Emberton & Emberton. Energy from landfill gas. Farquhar, G.J. & Rovers, F.A. (1973) Gas production during refuse decomposition. Water, Air & Soil Pollution 2, 483-495.

Esrey, S.A., Potash, J.B., Roberts, L. & Shiff, C. 1991. Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis and trachoma. Bulletin of the World Health Organization, 69 (5), pp 609-621.

Fang, F. 1998. Review of Bank-Supported On-Site Sanitation Programs. Draft 2. The World Bank, Washington, USA, 38 pages.

Feachem, R. G., Bradley, D.J., Garelick, H., Mara, D.D. 1983. Sanitation and disease: health aspects of excreta and wastewater management. World Bank Studies in Water Supply and Sanitation 3, John Wiley & Sons, Chichester, New York.

Franceys, R. , Pickford, J. and R. Reed. 1992. A Guide to the Development of On-Sire Sanitation. World Health Organization. Geneva, 237 pp.

Fulford, D. 1998. A short history of biogas. Renewable Energy World, Jully 1998, pp. 44-47.

Gallaher, M.M., Herndon, J.L., Nims, L.J., Sterling, C.R., Grabowski, D.J., Hull, H.F. 1989. Cryptosporidiosis and surface water. Am. J. Public Health 79: 39-42.

Gaut, A. 1998. Natural wastewater treatment. Final report (In Norwegian), Jordforsk, Centre for Soil and Environmental Reserach, 1432 Aas, Norway.

Greed, C. H. 1995. Public toilet provision for women in Britain: an investigation of discrimination against urination. *Women's Studies International Forum*. Vo. 18, Nos. 5/6: 573-584.

Greed, C.H. 1998. Personal correspondence (14/9/98).

Haarstad, K., Mæhlum, T. 1999. Important aspects of long-term production and treatment of municipal solid waste leachate. Waste Management and Reserach. In press.

Hansen, J.A., Therkelsen, H. 1977. Alternative sanitary waste removal systems for low-income urban areas in developing countries. Polyteknsik forlag, Viborg, DK, pp. 143.

Heerenklage, J. & Stegman, R. (1995). Overview on mechanical-biological pretreatment of residual MSW. In: Christensen, T.H., Cossu, R. & Stegman, R. (Eds.): Proceedings Volume 1. Sardinia'95. Concepts, Processes, Technologies & Operation. Cisa, V. Marengo 34, I-09123 Ca, Italy. pp. 913-926.

Hellstrøm, D., Johansson, E. & Grennberg, K. 1999. Storage of human urine: acidification as a method to inhibit decomposition of urea. Ecological Engineering 12, pp 253-269.

Hellstrøm, D., Karrman, E. 1996. Nitrogen and Phosphorous in fresh and stored urine. Envrionmental Research Forum, Vol. 5-6, 221-226.

Hoeks, J. (1983). Significance of biogas production in waste tips, Waste Management & Research 1, 323-335.

Hooi, Y. & Hamzak, H. 1995. The design of public toilets in Kuala Lumpur from the aspects of culture, behaviour and social habits of users. *In Proceedings 1995 International Symposium on Public Toilets*, Hong Kong, May 25-27, 1995: 84-89.

Høglund, C, Stenstrøm, T.A., Jønsson, H. 1998. Evaluation of fecal contamination and microbial die-off in urine-separating sewage systems. IAWQ 19th biennal International Conference, Vancouver, Canada, vol. 16, 16-23.

Hsu, B-M., Huang, C., Hsu, C-L.J., Hsu, Y-F., Yeh, J.H. 1999. Occurrence of *Giardia* and *Cryptosporidium* in the Kai-Ping riwer and its watershed in Southern Taiwan. Wat. Res. Vol. 33, No. 11, pp. 2701-2707.

IEA Bioenergy. 1998. Biogas and more! Anaerobic digestion systems and markets overview. Resource Development Associates, Washington DC, USA.

Jenssen, P.D. 1999. Utprøving og demonstrason av avløpsrensing basert på vakuumsystem og kildeseparering av avløp. *Testing and demonstration of wastewater treatment based on vacuum-systems and source separation*. In Norwegian. Vann, 1b, 192-198.

Jones, H.A. & Nedwell, D.B. (1990). Soil atmosphere concentrations and methane emmisions rates in the restoration covers above landfill sites; equipment and preliminary results. Waste management & research, 8, pp 21-31

Jordforsk (1996). Unpublished measurements from Norwegian landfills.

Karki, A. B. 1998. Biogas and natural resources management (BNRM) Nepal, No. 57, 1-6, Consolidated Management Services Nepal, GPO box. 10872, Minhgawan, Kathmandu, Nepal.

Kightley, D., Nedwell, D.B. & Cooper, M. (1995). Capacity for Methane Oxidation in Landfill Cover Soils Measured in Laboratory-Scale Soil Microcosms. Applied & Env.

Kira, A. 1995. Culture and behaviour of public toilet users. . *In Proceedings 1995 International Symposium on Public Toilets*, Hong Kong, May 25-27, 1995: 9-12.

Kirchmann, H., Pettersson, S. 1995. Human urine-Chemical composition and fertilizer use efficiency. Fertilizer Research, 40, 149-154

Kunz, C.O. & Lu, A-H. (1980). Methane production rate studies and gas flow modelling for the fresh kills landfill. New York State energy research and development authority interim report, New York State dep. of health, Albany.

Lane, J., Windblad, U., Kemper, K. 1996. Water and health: Reducing the risk of water-related diseases. Proceedings. Stockholm Water Symposium. Publication no. 6, pp. 157-159.

Loudon. J.B. 1978. On body products. In: John Blacking (ed.) *The Anthropology of the Body*. ASA Monogrpah 15. Academic Press, London.

MacKenzie, W.R., Hoxie, N.J., Procotor, M.E., Gradus, M.S., Blair, K.A., Peterson, D.E., Kazmierczak, J.J., Addiss, D.G., Fox, K.R., Rose, J.B., Davis, J.P. 1994. A massive outbreak in Milwakee of *Cryptosporidium* infection transmitted through the public water supply. New Engl. J. Med. 331: 161-167.

Mara, D and Cairncross, S. 1989. Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture - Measures for public health protection. WHOGeneva: WHO; 1989.

Martel, C. J. 1987.Evaluation of the Shasta waterless system as a remote site sanitation facility. Special Report 87-17. Cold Regions Research and Engineering Laboratory. US Army Corps of Engineers Hanover, NH. : 39 pp.

Matthess, G, Pekdeger, A. 1985. Survival and transport of pathogenic bacteria and viruses in ground water. Ground water quality. Eds.: H. Ward, W. Giger & P. L. McCarty, J. Wiley & Sons, Inc., 472-482.

Matthess, G., Bedbur, E., Gundermann, K-O., Loof, M., Peters, D. 1991. Investigation on Filtration Mechanisms of Bacteria and Organic Particles in Porous Media. *Zbl. Hyg., 191, 53-97.*

Mcbean & Farquhar (1980). An examination of temporal variations in landfill-generated methane gas. Water, soil & air Pollution 13, pp 157-172.

McGarry, M., Stainforth, J. eds. 1978. Compost fertilizer and biogas production frm human and farm wastes in the People’s Republic of China. IDRC, Ottawa, Canada.

McMichael, J.K. ed. 1976. Health in the third world – studies from Vietnam. Spokesman Books, Nottingham, UK.

MD, 1995. Avløpsslam. *Septic sludge*. In Norwegian. The Royal Ministry of Environment, Oslo, Norway, 22 pp.

Mitchell, R.C., Carson, R.T. 1989. Using surveys to value public goods: the contigent valuation method, Resources for the future, Washington DC, USA, pp. 463.

Moore, A.C., Herwaldt, B.L., Craun, G.F., Calderon, R.L., Juranek, D.D. 1993. Survellance for waterborn disease outbreaks-United States 1991-1992. Morbidity Mortality Weekly Rep. 42 (SS-5): 1-22.

Narayan, D. 1993. Participatory Evaluation: Tools for Managing Change in Water and Sanitation. World Bank Tech. Paper No. 207, Washington, D.C: 122 pp.

Naturvårdsverket. 1995. Vad innehåller avlopp från hushåll. Characterization of household wastewater. In Swedish. Naturvårdsverket, Rapport 4425, Kundtjanst, S-106 48 Stockholm.

Nielsen, J.H., Clauson-Kaas, J. 1980. Appropriate sanitation for urban areas. Cowiconsult, 45 teknikerbyen, DK-2830, Virum, Denmark. pp. 138.

Noonan, M.J., McNabb, J.F. 1979. Movement of bacteriophages in groundwater in New Zealand. Ann. Mtg. Am. Soc. Microbiol. 221.

Nordisk Miljømerking. 1997. Testmetode for avløpsfrie klosettsystemer. *Test method for dry toilet system*. In Norwegian. Stiftelsen Miljømerking. Kr. Augustsgt. 5, N-0164 Oslo, Norway.

Parlato, R. 1984. A Monitoring and Evaluation Manual for Low-Cost Sanitation Programs in India. TAG Technical Note No. 12. United Nations Development Programme. World Bank. Washington, D.C : 80 pp.

Paulsrud, B.; Nedland, K.T. 1991. "Treatment and management of sludge at larger wastewater treatment plants. Final report." Norvar report 20-1991, 91 pp. (in Norwegian).

Phi, D.T., Chien, B.T., Chung, B.C., Ngyen, H.N., Stenstrøm, T.A., Carlander, A., Westrell, T., Winblad, U. 1999. Dry sanitation in Vietnam. In: Urban stability through integrated water-related management. The 9th Stocholm Water Symposium, Stockholm, Sweden, 393-395.

Pekdeger, A., Matthess, G. 1983. Factors of bacteria and virus transport in groundwater. Environmental geology, 5, 2, 49-52.

Pickford, J. 1994. Affordable sanitation for low-income communities. 20th WEDC (Water engineering development center) Conference, Colombo, Sri Lanka, obtainable from WEDC, UK.

Rasmussen, G., Jenssen, P.D., Westlie, L. 1995. Greywater treatment options. 2nd Int. Conference on Ecological Engineering for Wastewater treatment. Waedenswil, Schweiz.

Refsgaard, K., Etnier, C. 1998. Naturbaserte avløpsløsninger i spredt bebyggelse. *Rural natural wastewater treatment systems.* NILF-rapport 1998:4, 47 pages (in Norwegian)

Reid, D. 1991.*Paris Sewers and Sewermen. Realities and Representations.* Harvard University Press, Cambridge (Mass).

Robertson, L.J., Campell, A.T., Smith, H.V. 1992. Survival of *Cryptosporidium* pavrum oocycts under various envrionmental pressures. Appl. Environ. Microbiol. 58:3494-3500.

Rohrer, T. 1996. High quality compost from composting toilets. Environmental Research Forum, Vols. 5-6, 417-420.

Schaffer, F.W. 1997. Detection of Protozoan Parasites in Source and Finished Drinking Waters. In: Manual of Envrionmental Microbiology, ASM Press, Washington D.C., USA, pp. 153-155.

Schønborn, A., Zust, B. 1994. gwa. 8/84, 74 Jahrgang.

Scriven, M. 1998. The new science of evaluation. *Scandinavian Journal of Social Welfare*. 1998 (7): 79-86.

SEPA (Swedish Environmental Protection Agency. 1995. Vad innehåller avlopp från husholl. *What is the content of household wastewater.* In Swedish. Report 4425, Stockholm, S.

SI (1971). Chemical Data. Aylward & Findlay. J. Wiley & sons.

Siegrist, R.L., Boyle, W.C. 1981. Proc. of the 3rd National Symp. on Individual and Small Community Sewage Treatment, Chicago, Ill., ASAE, P176.

Smith, H.V. 1990. Envrionmental aspects of *Cryptosporidium* species: A review. J. R. Soc. Med. 83: 629-631.

Stevik, T.K., Ausland, G., Jenssen, P.D., Siegrist, R.L. 1999. Removal of *E. Coli* during intermittent filtration of wastewater effluent as affected by dosing rate and media type. Wat. Res. 33, No. 9, 2088-2098.

Strauss, M. Blumenthal, U.J. 1990. Use of human wastes in agriculture and aquaculture: utilization practices and health perspectives. Dubendorf, Switzerland. Int. Refererence centre for Waste Disposal (IRCDW, now SANDEC).

Subramanian, S.K. 1978 Biogas systems and sanitation, *Sanitation in Developing Countries,* Pacey, A (ed), Chichester, John Wiley and Sons.

Sundin, K.A., Leeming, R.L., Stenstrøm, T.A. 1999. Degradation of fecal sterols in urine for assessment of fecal cross-contamination in source-separated human urine and urine storage tank sediment. Wat. Res., Vol. 33, 9, 1975-1980.

Tanner, R. 1995 Excreting, excretors and social policy. Some cross-cultural observtions on an underresearched activity. *J. Preventative Medicine and Hygiene.* 1995. 36 (N) ¾: 1-10.

Templer, D.I., King, F.L., Brooner, R.K., and M. Corgiat. 1986. Assessment of body elimination attitude. *Journal of Clinical Psychology*, Vol. 40, No. 3: 755-759.

Thornloe, S.A., Barlaz, M.A., Peer, R., Huff, L.C., Davis, L. & Mangino, J. (1993). Waste management. Nato ASI Series vol. 113, Springer Verlag, Berlin.

US EPA. (1993). The potential effects of global climate change on the United States. EPA-230/05-89-050, December 1989.

De Vincente, A., Aviles, M., Borrego, J.J., Romero, P. (1988). Die-off and survivial of Pseudomonas aeruginosa in freshwater. Zbl. Bakt. Hyg. B 185, 534-547.

Van der Ryan, S. 1978. *The Toilet Papers*. Capra Press, Santa Barbara, CA. 124 pp.

Wang, J.Q, Sun, F.Y., Wang, B.W., Xiao, J., Xue, J.R., Zhang, Y.H., Pan, S.C. 1999. Reduction of microorganismsin dry sanitation due to different adsorbents under low temperature conditions. In: Urban stability through integrated water-related management. The 9th Stocholm Water Symposium, Stockholm, Sweden, 396-398.

WHO - Regional Office for Europe, Copenhagen. EURO Reports and Studies 90. Appropriate technology for the treatment of wastewaters for small rural communities. Lyon; 1982.

WHO, 1982. Approprate technology for the treatment of wastewater for small rural communities. EURO Reports and Studies 90, World Health Organization, Copenhagen.

WHO, 1991. Manual on water and sanitation for health in refugee camps. CEHA Document No. TLM-1, Amman, Jordan.

Winblad, U. 1992. The productive homestead-report of a study tour. Winblad Consult AB, Pataholm 5503, S-384 92 Ålem, Sweden, pp. 11.

Winblad, U. 1997. Ecological sanitation-a global overview. In: Drangert, J-O., Bew, J., Winblad, U. (eds.). Ecological alternatives in sanitation. proceedings from Sida worshop Balingsholm, Sweden, Pub. no. 9, Dept. of Natural Resources & the environment, S-10525 Stockhom, pp. 3-6.

Winblad, U. 1998. (ed) *Ecological Sanitation.* SIDA. Stockholm, 92 pp.

Winblad, U., Kilma, W. 1985. Sanitation without Water. MCMillan Press LTD, 161 pp.

Øberg, S and Molland, O (NLH, Mikrobiologisk Institutt). Biologiske klosetter i praktisk bruk. Ås; 1982.

Østeraas, T., Køhler, J.C., Ensby, S., Fredriksen, O.F., Jenssen, P.D., Høstmark, A.K.S. 1986. Saksbehandling, grunnundersøkelse og kontroll av avløpsanlegg i spredt bebyggelse. GEFO, 1432 Ås.

15. Glossary

Actinomycetes: unicellular, mostly aerobic microorganisms found in soils and composts. many produce antibiotics.

Aerobic: process with access to air

Additive: added to toilet system receptable chamber to enhance internal processes

Amino acids: 20 or more organic acids, building blocks for proteins and necessary for metabolism and growth

Antibody: protein that destroys or neutralizes bacteria, viruses or other harmful toxins

Antigen: substance that stimulates the immune system to produce antibodies, usually bacteria or viruses

Antiseptic: sterilized, clean of any microorganism

Ascaris: roundworm, large worms that live in people’s intestines

Aseptic: without the presence of pathogens

Bacteria: the simples and smallest (0.1-5 μm) of living organism

Bactericidal: can kill bacteria

Bacteriophages: viruses that can kill bacteria

Biogas: produced during anaerobic decomposition of organic matter, contains methane

Blackwater: water that contains excreta

BOD: biochemical oxygen demand (mg/L)

C/N-ratio: weight percent of carbon and nitrogen, important factor for composting

Carrier: organism that carries a virus

Cohort: a group of individuals with some common characteristic

COD: chemical oxygen demand (mg/L)

Coliform: nonsporing, facultative rods that ferment lactose with gas formation within 48 hours at 35 °C. Examples of coliform bacteria are members in the genera Escherichia (e.g. *E. Coli*), Klebsiella (e.g. K. pneumoniae), Enterobacter (e.g. E. cloacai), and Citrobacter (e.g. C. freundii).

Composting: a biological process breaking down organic material

Coprostanol: the principal human fecal sterol used as an indicator of fecal contamination

Cryptosporidium: gastro-intestinal protozoan parasite

Culture: growing microorganisms in the lab to identify

Cyst: dormant transition form of protozoa

Cytotoxic: toxic to cells

Defecation: discharging feces from the body

Dehydration: removing water, drying

Dermal: relating to the skin

Diarrhea: abnormally frequent and liquid defecation

E. Coli: a common bacteria found only in the intestine, indicator of fecal bacteria, mostly harmless but some cause diseases, see coliforms

Ecological sanitation: economically and ecologically sustainable sanitation systems based on total cost and benefits (including dowstream concequences)

Endemic: diseases associated with particular locales or population groups

Enteric: excreted

Enterovirus: virus relating to the intestines or gastrointestinal tract

ESAC: Espacio de Salud, NGO in Mexico

EVASAN: Evaulation of ecological sanitation

Excreta: human feces and urine

Fecal coliforms: bacteria commonly found in feces

Feces: undigested material discharged from the intestines

Flukes: worms infecting the liver causing disease, in blood: schistosomiasis
Fungi: plantlike organisms with cells that have distinct nuclei surrounded by nuclear membranes as well as other specialized cell parts, but incapable of photosynthesis. Most fungi are decomposers of waste and dead bodies of other organisms; a few are parasitic. Yeasts, molds, mildew, and mushrooms are all fungi. Many produce antibiotics.
Germs: very small organisms that can grow in the body and cause infectious disease
Giardiasis: common protozoal infection from Giarida lamblia, via contaminated food or water or person-to-person
Greywater: water from washing
Helminths: parasitic worms
Hepatitis: An inflammation of the liver caused by any of several causes. Often accompanied by jaundice, enlarged liver, fever, fatigue and nausea, and abnormal liver function blood tests
Hepatitis B: A viral liver disease that can be acute or chronic and even life threatening, articularly in people with poor immune resistance. Like HIV, the hepatitis B virus can be transmitted by sexual contact, contaminated needles or contaminated blood or blood products. Unlike HIV, it is also transmissible through close casual contact
Hepatitis C: A recently recognized viral disease that causes inflammation of the liver, and cause severe, life-threatening liver damage. Hepatitis C was formerly called non-A/non-B hepatitis
Humus: degraded organic material with large molecular weight
ICR: Implementation Completion Report
Immunity: natural or acquired resistance to a specific disease
In vivo: studies conducted in living organisms
In vitro: studies conducted in an artificial environment
Larvae: young worm-like that come from insect- or parasite eggs
Lasf: Letrina abonera seca familiar, Central American version of the Vietnamese double-vault toilet
Latrine: usually a very simple form of toilet system, e.g. pit latrine
meq/L: milliequivalents per liter
Micronutrient: a trace element, an organic compound like a vitamin that is essential in small amounts
NGO: Non-governmental organization
Nightsoil: fresh human excreta collected for use as fertilizer (can be mixed with soil)
Nutrient: any item of food that nourishes or promotes growth and metabolism
Oocycts: dormant and resistant transition form of *Cryptosporidium*
Parasite: A plant or organism that live on or in the host, include fungi, yeast, bacteria, protozoa, worms and viruses
Pathogen: any disease-producing microorganism or material
PPAR: Project performance audit report
Protozoa: family of unicellular organisms including amoebas, flagellates and ciliates, simplest form of animal life, *Cryptosporidium* and Giarida are among the most harmful protozoa
Respiration: a metabolic process in living organisms, a controlled oxidation of food:
sugar (organic substrate) + oxygen = carbondioxid + energy + water
Salmonella: a common family of bacteria that can cause serious disease
Sanitation: disposal of human excreta and household refuse: a state of cleanliness and healthy environment
SAR: Staff appraisal report
Schistosomiasis: bilhariza, snail fever
Seat-riser: the base for the toilet seat

Spore: dormant transition form of protozoa
Super-structure: construction above ground
Systemic: throughout the body, in all cells
Squatting pan: toilet receptable used standing up (without a stool)
Taenia: group of large tapeworms (flattended, intestinal). Can be parasitic in humans.
TOC: total organic carbon (mg/L)
TCB: thermostable coliform bacteria, human fecal indicator bacteria colonized at 44 deg. C
Toilet: installation for collection and transport of excreta, usually some kind of elaborate technical units compared to a simple pit
Trachoma: eye infection
Urine: liquid produced by the kidneys and periodically discharged
Vault: a chamber: two chambers=double vault
Vector: Anything capable of moving or transferring pathogens, e.g. insects
VIP toilet: ventilated improved pit toilet
Virus: A group of infectious agents characterized by their inability to reproduce outside of a living host cell. The smallest of all biological entities (0.02 μm)
Washer: person using water for anal cleaning
Waste: stuff that can’t be used for any purpose (human excreta for reuse is by definition not waste)
WC: water closet, flush toilet
Wiper: person using paper, leaves, stick, stones etc. for anal cleaning

APPENDICES

CONTENT:

INTRODUCTION

The appendices in this section are divided in 5 categories: A. General evaluation forms, B: Evaluation forms applicable for a specified region (here exemplified for South East Asia), C: Component evaluation, D: field tests and E: Other technical information. Section A is general in the sense that the forms probably should be modified to meet specific situations, assumptions or other requirements. A potential evaluator could start with modifying the forms suitable for the specific case at hand, or design new forms based on the information in the text or other sources.

Evaluation assumes an ongoing process of using – learning – modifying. Projects rarely find fresh fields where it is possible to start with blank sheets. Projects usually start with collecting or using existing information to select sanitation systems or evaluating existing systems, or both.

A. Additional ecological technology- dry systems

Additional technologies that has been used as sanitation technology, but is considered either inferior to the technologies described in the report, or include the use of water, and thus the production of wastewater, is described here. The can, however, be regarded as ecological, and are based on natural treatment processes.

Open defecation

The apparently simplest system when there are no latrines (available) is defecation in the open, in special places or indiscriminately. Special places might be defecation fields, rubbish and manure heaps or under trees. Open defecation encourages the spreading of diseases and should not be tolerated in villages and other build-up areas.

Shallow pit

People working on farms may dig a hole each time they defecate and then cover the feces with soil, sometime known as the “cat” method. Pits about 0.3 m deep may be used for several weeks. Excavated soil is heaped beside the pit and some is used for cover after each use. Decomposition is rapid but flies breed in large numbers and hookworm larvae spread around the holes. Hookworm larvae can migrate from 1 m deep pits and penetrate the soles of the feet of the users.
The shallow pit latrine involves no cost and can benefit farmers with nutrients. They make considerable fly nuisance and spread hookworm larvae.

Borehole toilet

A borehole excavated by a hand or machine auger can be used as a toilet. The diameter is often about 0.4 m, and the depth between 6-8 m.

The latrine can be excavated relatively quickly if the equipment is available and suitable for short-term use (disasters).

Overhung latrine

A latrine built over the sea, a river, or other body of water, into which excreta drop directly, is known as an overhung latrine. If there is a strong current in the water, the excreta are carried away. Local communities should be warned of the health risk resulting from contact with or use of water into which excreta have been discharged.

Bucket latrine

This latrine has a bucket or other container for the retention of feces (and sometimes urine and anal cleaning material), which is periodically removed for treatment or disposal. Excreta removed in this way are sometimes termed nightsoil.

Aqua-privy

An aqua-privy has a watertight tank immediately under the latrine floor. Excreta drop directly into the tank through a pipe. The bottom of the pipe is submerged in the liquid in the tank, forming a water seal to prevent escape of flies, mosquitoes and smell. The tank functions like a septic tank. Effluent usually infiltrates into the ground through a soakpit. Accumulated solids (sludge) must be removed regularly. Enough water must be added to compensate for evaporation and leakage losses.

B. Additional ecological technology- wet systems

Figure 1. Cesspools/septic tanks

B.1. Tank systems

Septic tanks

A septic tank is an underground watertight settling chamber into which raw sewage is delivered through a pipe from plumbing fixtures inside a house or other building. The sewage is partially treated in the tank by separation of solids to form sludge and scum. Effluent from the tank infiltrates into the ground through drains or a soakpit, or is collected and treated, or directed to emitting points. The system works well where the soil is permeable and not liable to flooding or waterlogging, provided the sludge is removed at appropriate intervals to ensure that is does not occupy too great a proportion of the tank capacity.

Vaults or cesspits/cesspools

In some areas, watertight tanks called vaults are built under or close to latrines to store excreta until they are removed by hand (using buckets or similar receptacles) or by vacuum tanker. Similarly, household sewage may be stored in larger tanks called cesspits or cesspools, which are usually emptied by vacuum tankers. Theses systems may be emptied when they are nearly full or on a regular basis.

Costs: In Scandinavia,
price from manufacturer, USD 11000 for a 6 m3 volume

Sewerage

Discharge from WC's and other liquid wastes flow along a system of sewers to treatment works or to direct emissions into the sea or a river. Sewers of smaller diameter than usual (small-bore sewerage), built nearer to the surface than usual, and sewers with flatter gradient than usual have been tried and found to be suitable for providing sanitation simultaneously for a large number of high-density dwellings.

Liquid treatment – filtering techniques

Greywater, or sullage, is wastewater where toilet waste is excluded. Reported mean quality of greywater is given in Table xx.

Table 1. Greywater quality (mg/L except for bacteria = log(no/100 mL))

	References							
Wastewater variable	a)	b)	c)	d)	e)	f)	g/pe* day	g/pe** day
Dry matter								80
Suspended solids	100-300	162	45			39	35	16
BOD	100-300	149	178	289	142	116	35	28
COD	200-600	366	456	520	320		80	
Tot-Phosphorous	10-25	1.4	4.4	4.1	9.5	4	1.3	0.6
Tot-Nitrogen	12-100	12	16			36	1.3	1.0
Tot-coliforms	4-6							Confirmed
Tot-fecal coliforms	3	6	5					

a) Østeraas et al., 1987, b) Brandes, 1978, c) Siegrist & Boyle, 1990,
d) Bahlo & Wach, 1990, e) Schønborn & Zust, 1994 f) Rasmussen et al., 1995.
*) Rasmussen et al., 1995 **) Naturvårdsverket 1995

Table 2. Removal mechanisms in filtration/macrophyte-based treatment system (After Brix, 1993)

Wastewater constituent	Removal mechanism
Suspended solids	sedimentation/filtration
BOD	microbial degradation (aerobic & anaerobic) sedimentation (sludge production) + sludge degradation (optional)
Nitrogen	ammonification + microbial nitrification (aerobic) + denitrification (anaerobic)
Phosphorous	soil sorption (adsorption-precipitation) with Al, Fe, Ca, Clays or other high CEC media
Pathogens	sedimentation/filtration

natural die-off/sun radiation
UV-radiation
excretion of antibiotics from roots of macrophytes

B.2. Wastewater treatment

In many cultures wastewater is discharged into nature where, in most cases, an aquatic ecosystem degrade the waste until, if unmanaged, it diminishes or fails. The so-called natural part of wastewater treatment uses ponds, wetlands, vegetation and soil as treatment media in a designed and engineered purification system. These systems can be relatively low-cost and low-maintenance, at least compared to traditional/technical treatment systems, if open space is available and loading rates are low, assuming correct construction, operation and maintenance.

Stabilization ponds

Sunlight exposure is considered to be the most important cause of natural disinfecting in wastewater stabilization ponds, inactivating both E.coli and other fecal microorganisms.

Aquatic treatment systems

Aquatic macrophyte-based treatment systems may be classified according to the life form of the dominating macrophyte into freefloating or rooted submerged emergent systems. Typical examples of freefloating systems are water hyacinths and duckweed. Examples of rooted submerged systems are common reeds and cattails.

Wetlands

Natural processes counteract negative impacts from pollution. More knowledge on wetlands has produced alternatives for wastewater treatment. The systems can be the combined use of septic tanks, distribution systems and vertical and horizontal subsurface flow systems through wetland filters with or without plants.

Figure 2. Constructed wetland

Table 3. Removal in greywater treatment system *(Jenssen, 1999)

Parameter	septic mg/L	pretreatment filter mg/L	wetland mg/L	removal filter %	total removal %
BOD	73.2	21.5	3.9	71	95
Tot-N	6.8	3.5	2.2	49	68
Tot-P	0.82	0.21	0.04	75	95
log TCB **	5.7	5.3	2.6		

* concentration out of the different treatment plant units
** log of thermotolerant Coliform bacteria

Costs:
In Scandinavia, for a 7 household system, USD 36 000 exclusive taxes

Land treatment systems

Land treatment of wastewater use soil infiltration as natural treatment. Large quantities of water means soil with high hydraulic conductivity and good purification qualities, i.e. sand and/or gravel deposits. Large infiltration systems receive water from more than 35 pe. and use open pools as infiltration volume. Smaller systems usually depend upon piped feeding systems either based on free drainage or pumps. These feed systems can be covered by soil or exposed to air.

Costs, infiltration systems in general:
In Scandinavia, for a 1 household system, USD 5300-8000.
Large infiltration systems:
In Scandinavia, for a 10 weekend house system, USD 40 000.

Area intensive systems (Nat-technology)

Cost-efficient treatment of greywater in combination with EvaSan is a complete wastewater system. A special compact filtration unit is developed as and alternative to septic tank treatment of greywater, separating the sludge into portable units making the transport independent of vacuum tanker transportation in areas non accessible to trucks. If secondary treatment is added the treated water can obtain acceptable health standards.

Costs, In Scandinavia, for a 1 household system, USD 5700-6400 exclusive taxes
1 weekend house system USD 4400-5200.

Figure 3. Compact treatment units

B.3. Biogas

Anaerobic sanitation – Biogas

Although anaerobic sanitation solutions are not discussed thoroughly in this work a small introduction into the special characteristics of anaerobic treatment systems is given.

By treating the human waste in an air tight tank, anaerobic conditions lead to production of biogas. The biogas equally contains carbon dioxide and methane (CO2 and CH4). The gas can be used for heating, cooking purposes, producing electricity, or fuel. The biogas yield from anaerobic decomposition of human waste depends on the nutrition mix in the waste. As biogas yields from human excrement are relatively low, such units are normally combined with animal manure and organic household waste. Biogas tanks can be buried beneath the toilet room, with a gas outlet leading to the kitchen.

Lower temperatures in anaerobic treatment units may be compensated by an increased storage time.

Figure 4. The energy line for treating waste.

Removal of pathogens

Anaerobic decomposition releases less energy than aerobic decomposition (composting). A great part of the available energy in the waste is converted to biogas. Thus anaerobic treatment may have difficulties reaching temperatures where pathogens are destroyed. If no treatment is planned after removal, the sludge may still contain pathogens (Taenia, for instance).

With a slurry detention time of 1 month and digester operation temperatures between 25-35 °C, pathogen survival is probably high (Cross & Strauss, 1986). Helminths and bacteria, such as salmonellae, will survive and be found in the effluent. Up to 50% of Ascaris eggs have been found to survive after 4-9 months of digestion. There is, however, a considerable improvement in hygienic quality in the material compared to e.g. nightsoil.

Farmland units

The original idea of on-farm units has not caught on in many parts of the world, but some places in Latin-America but especially in Asia, like e.g. Nepal, the technology has been used to a great extent. A Chinese program was launched on a very large scale, with 7 million on-farm family sized plants build in the early 1980s. The technical quality of these plants appears to have been poor and the plant themselves do not seem to have lasted longer than more than a year or two. In India some of the local plants have lasted longer than 30 years. In Nepal a program launching more than 20 000 units was carried out from 1992 with a target of 100 000 units.

The choice seems to be either large metal tanks sited above ground, which are expensive and can be difficult to heat adequately, or rectangular concrete tanks placed underground, which are difficult to make gas-tight. The Indian and Chinese experience suggests that cylindrical or spherical shapes are required to reduce the possibility of leakage in concrete structures. Few farmers anywhere in the world would be willing to build biogas plants without a subsidy, except maybe if there is a serious deficiency in energy supply.

Community latrine-cum biodigester

This concept utilizes the human waste from public toilets and urinals. Experience e.g. from Nepal with an installation dimensioned for 4 females and 6 males, and 3 (male) urinals, has shown that these systems can be attractive and even overloaded in spite of charging a user fee for entrance (Karki, 1998). This gives a potential for operating and maintaining the systems. Experience also show that a biogas plant does not function until due attention is paid towards the quality control, operation, maintenance and after-sales-services. Effective monitoring and evaluation has secured 90% of installed capacity to be in good operative conditions.

C. Laboratory testing

The a priori testing and evaluation should preferentially cover all criteria that EvaSan systems are set up to meet. In practice there are several aspects that are not or only with huge efforts possible to evaluate a priori. The limitation set to a priori testing is also depending on the applied sanitation technology. It is obvious that laboratory testing of pre-manufactured units like composting toilets is easier to conduct than on home-manufactured solutions like pit latrines or wetlands. One should have this in mind when evaluating different technologies a priori. The need for monitoring after installation is hence apparent and complementary to the a priori evaluation.

The nature of a priori evaluation is similar to that of normal decision making process (when selecting between different offers). Some kind of evaluation is therefore always taking place prior to an investment in an EvaSan system.

Why a priori evaluation?

The advantages of applying a priori evaluation lies in the possibility to predict the result prior to a given installation. The main issue of a priori testing is hence to evaluate a given EvaSan system or a set of alternative sanitation systems in their ability to comply with the specific criteria for an installation. With a priori evaluation technical and other weaknesses can be predicted at an early stage and performance failures can be avoided. In this sense a priori testing may also be used for the manufacturer of a sanitation system to improve the system.

Principles of a priori evaluation

The principle of a priori evaluation is to take use of the experience from former installations prior to a new decision taking on installation. Thus the link between field monitoring and a priori testing becomes apparent. Existing laboratory test methods for composting toilets are based on experience from field-testing. A priori evaluation methods must be part of a continuously quality process where the experience from field-testing is considered. Also the adjustment part of the evaluation criteria must be based on this experience.

Limitations of a priori evaluation

Difficulties by weighting different technologies sets limits to the extent at which a priori evaluation should be used. Furthermore the conservative nature of standards may be limiting innovation. If possible, focus should therefore be on the obtained results and not on the methods.

Existing standards for EvaSan systems (technical, health and environment)

There are several national and international standards regarding toilet equipment of traditional sanitation systems. For on-site sanitation systems there are especially two standards that shall be pointed out here.

Nordic swan label –closed toilet systems

The Nordic Ecolabelling was adopted by the Nordic Council of Ministers in 1989 to provide information to consumers to enable them to select products that are the least harmful to the environment. The Ecolabelling is also intended to stimulate environmental concern in product development.

The criteria are based on evaluation of the environmental impacts during the actual products’ life cycle. Based on a thorough examination the criteria set requirements towards a number of factors considered environmentally harmful. Upon application all products found to meet the requirements of the criteria are awarded the environmental label (the Nordic Swan).

The Criteria document for Closed Toilet Systems is applicable for toilets that do not require a connection to a drainage system or systems for retrieving feces and urine. The product group encompasses closed toilet systems that do or do not require an electrical power supply. The end product should be utilizable as a means of soil improvement. It is principally toilet systems based on processes of biodegradation that will satisfy the requirements.

Ansi/nsf standard 41 – non-liquid saturated treatment systems

NSF International is an independent, non-profit organization situated in USA that is dedicated to public health safety and protection of the environment by developing standards, by providing education and by providing superior third-party conformity assessment services while representing the interest of all stakeholders.

The purpose of the standard NSF 41 is to establish minimum materials, design and construction, and performance requirements for non-liquid saturated treatment systems. These are systems that do not utilize a liquid saturated media as a primary means of storing or treating human excreta or human excreta mixed with other organic household materials. It is intended to protect public health and the environment as well as minimize nuisance factors. The standard also specifies the minimum literature that manufacturers shall supply to authorized representatives and owners. Management methods for the end products of these systems are not addressed by the standard.

Table 4: Requirements in two standards for ecological on-site sanitation systems

Standard	Nordic “Swan”	NSF 41
Technical requirements	Production (materials) Material & design (electrical parts, impact & burn resistance etc.) Durability Performance (capacity, discharge of liquids and odor emissions)	Material & design (impact resistance, burn resistance etc.) Durability Performance (capacity, discharge of liquids and odor emissions)
Environmental requirements	Production (materials, additives) Performance (emission of liquids and odor) End product (solids content, pH, C/N-ratio, consistency, odor and N-content)	Performance (emission of liquids and odor) End product (solids content, odor)
Hygienic requirements	End product (maximum content of fecal Coliform bacteria)	End product (maximum content of fecal Coliform bacteria)

Test methods

The Nordic Ecolabelling test methods distinguish between two test procedures. All toilet systems must be tested in terms of 1) materials and design and 2) function. Materials and design is tested in a laboratory. In testing function manufacturers who have sold over 50 units which have been in operation for over 2 years may choose between a field test and a laboratory test. Urine separating toilet systems may only be tested in field tests.

Other systems must undergo a laboratory test. In the laboratory test the toilet system is basically tested in accordance with the manufacturers manual instructions for use.

The NSF standard also distinguishes between laboratory testing and field-testing. For mature systems (systems having end products characteristic of routine operation) the field-test is compulsory and additional to the laboratory test.

For a summary of both test procedures see App. 1 A.

Test institute

An important part of the Nordic Ecolabelling is the use of impartial and competent analysis laboratories. The laboratory conducts the testing procedures and reports the result to the responsible Ecolabelling administration, which then decides if the product is to be granted with the Ecolicence.
The product for which an Ecolicence has been granted may thereafter be subject to controls by an impartial test institution.
The Ecolabelling organization must be furnished with documentation demonstrating that the analysis laboratory institution operates in accordance with the EN 45001 standard or ISO-IEC Guide 25 or is an officially approved GLP laboratory.

Within the NSF standard all performance testing and evaluation shall be conducted at a location that excludes the manufacturer or the authorized representative from controlling access to the system.
General demands for a priori evaluation of EvaSan systems applied to SE Asia
The test procedures described above are developed for closed toilet systems to be operated under Western conditions. This is especially apparent for the Nordic Ecolabelling, developed for Nordic cottages and rural residents. The testing temperatures in the laboratory test are an example of, this with temperature of 18°C and 9°C in the loading period and composting period, respectively.
For purposes in South East Asia this conditions would have to be adjusted to local climates and use of EvaSan systems.
Different to Western demands for EvaSan systems one of the major task of EvaSan in SE Asia would be to provide sanitation systems that is affordable and hygienic to a broad population including urban citizens.
Apparently, if a priori testing is to be applied for the selection of EvaSan systems in SE Asia, some of the demands must be revised.
On a general basis, when comparing different EvaSan systems, the criteria must be on a general basis. When comparing EvaSan-systems utilizing the same principles, the criteria may be more specific as the standards above.

Table 5: Suggestions for general criteria for EvaSan systems to be used in SE Asia are listed below. *): The criterion can be tested prior to installation.
Criterion Demand Comment
Health
(Solid end product) Storage of minimum 2 years, or
test certificate*) of pathogen destruction (e.g. 200 fecal Coliform bacteria) within shorter time, or
a guaranteed secure utilization or disposal of the end products 2 years are considered a secure treatment time even if conditions are unfavorable for pathogen destruction
Health
(Liquid end product) Storage of minimum ½ year, or
test certificate*) of pathogen destruction (e.g. 200 fecal Coliform bacteria) within shorter time
½ year is considered a secure treatment time even if feces are mixed together with the urine
Leakage No leakage from the system allowed*). Exception can be made if the system is to be installed high above ground level and is equipped with sufficient filtration area and material. See chapter II B Liquid treatment
Performance (technical, end product) No objectionable odor released *) (can only be applied for pre-manufactured units, with lab-testing or field-testing)

Table 6. Suggestions for general criteria for EvaSan systems to be used in SE Asia are listed below

Criterion Demand Comment
Health
(Solid end product) Storage of minimum 2 years, or
test certificate*) of pathogen destruction (e.g. 200 fecal Coliform bacteria) within shorter time, or
a guaranteed secure utilization or disposal of the end products 2 years are considered a secure treatment time even if conditions are unfavorable for pathogen destruction
Health
(Liquid end product) Storage of minimum ½ year, or
test certificate*) of pathogen destruction (e.g. 200 fecal Coliform bacteria) within shorter time
½ year is considered a secure treatment time even if feces are mixed together with the urine
Leakage No leakage from the system allowed*). Exception can be made if the system is to be installed high above ground level and is equipped with sufficient filtration area and material. See chapter II B Liquid treatment
Performance (technical, end product) No objectionable odor released *) (can only be applied for pre-manufactured units, with lab-testing or field-testing)
* The criterion can be tested prior to installation

C. Component evaluation

Table 7. General test criteria Nordic Swan and American National Standard Institute (NSF 41)

Nordic Ecolabel “Swan” ANSI/NSF 41*
Subject of labeling/standard Closed toilet systems (toilets that are not required to be connected to a drainage system for retrieving feces and urine) Non-liquid saturated treatment systems
Purpose of labeling/standard Provide information to consumers to enable them to select products that are the least harmful to the environment. Ecolabelling is intended to stimulate environmental concern in product development. Establish minimum materials, design and construction, and performance requirements for non-liquid saturated treatment system. It is intended to protect public health and the environment as well as minimize nuisance factors. This standard also specifies the minimum literature that manufacturers shall supply to authorized representatives and owners.
Materials:
Requirements on additives to plastics (heavy metals) and the manufacture of insulation materials (ozone layer). No requirements
Design and durability:
General requirements (e.g. electrical components).
Test on tightness, impact resistance, rigidity, flammability and strength of materials and wear. The toilet must have a five-year warranty. General requirements (e.g. electrical components).
Test on tightness, impact resistance, rigidity, flammability and strength of materials and wear.
Ventilation Through roof or similar solution. No requirements
Capacity: The toilet must have a capacity of at least 4 p.e.
Actual capacity is tested. (performance testing) No requirements.

Actual capacity is tested.

(performance testing)
Agitators (manual and mechanical) General and special performance testing Performance testing
Energy effect
Power supply must not exceed 320 W.
Additives: Use of the toilet must not necessitate the use of chemicals harmful to health or the environment. Use of the toilet must not necessitate the use of chemicals harmful to health or the environment.
Discharge of liquids: The system shall preclude infiltration of ground water into the system and exfiltration of liquid out of the system. Surplus liquid must be channeled to the internal or an external container, or satisfy the requirements specified for end products.
Performance testing. The system shall preclude infiltration of ground water into the system and exfiltration of liquid out of the system.
All devices shall provide for containment of liquid

Performance testing.

End products:
Solid end product
–No objectionable odor or recognizable human source material
–Dry solids content >25%
-Fecal Coliform bacteria <2/g
–pH = 6-8
–C/N ratio >15/1
–N-content>1%
Urine:
-No objectionable odor
-Fecal Coliform bacteria <2/g
Solid end product:
-No objectionable odor
–dry solids content > 35%
-Fecal Coliform bacteria <200 MPN per g.

Urine:
-No objectionable odor
–Fecal Coliform bacteria <200 MPN per g.
Instructions for use: Requirements for the contents of instructions for use, assembly and installation instructions and marketing material. Requirements for the contents of instructions for use, assembly and installation instructions and marketing material.
* ANSI/NSF 41: National Sanitation Foundation, ANSI: American National Standards Institute

Table 8: Performance test
General
Functioning of the toilet systems must be tested in accordance with specified test methods (performance test).

Manufacturers who have sold over 50 units, which have been in operation for over two years, may choose between a field test and a laboratory test. All others must undergo laboratory testing. Urine separating toilet systems may only be tested in field tests. Functioning of the toilet systems must be tested in accordance with specified test methods.
Mature systems (having end products characteristic of routine operation) shall be subjected to a field test.
In addition to the field test one system shall be subjected to a controlled laboratory test.
Testing institution -impartial and competent
-operating in accordance with the EN 45001 standard or ISO-EC Guide 25 or an officially approved GLP laboratory All performance testing and evaluation shall be conducted at a location that excludes the manufacturer or the authorized representative from controlling access to the system
Field test Selection of a minimum of 5 systems (from representative climatic zones) currently in operation.
Operation and installation shall correspond to the system design.
Questioning sheets with the objective to chart significant operating conditions.
End products shall meet the performance criteria above. Selection of a minimum of 3 systems currently in operation.
Operation and installation shall correspond to the system design.
End products shall meet the performance criteria above.
Laboratory test Duration:
The test may last between 8 and 48 weeks in accordance with the instructions of the manufacturer and consist a filling period and a composting period

Test climate:
-50-60% relative humidity
–Loading period: 18ºC +/-2ºC
–Composting period: 9ºC +/-2ºC
Loading material:
-Dehydrated raw sewage sludge
–Artificial urine
–Toilet paper
Loading patterns:
-Routine operation
–Overload stress (2 x normal)
–Party stress (3 x urine)
–Vacation stress (2 w. no use) The test shall be conducted under the operation conditions that are characteristic of the intended installation conditions.
Distinguishing between residential systems, day-use park systems and cottage systems.
Test climate:
Not specified/characteristic for intended installation

Loading material:
Actual human excreta

Loading patterns:
Depending on system design e.g. residential systems:

-Routine operation
–Overload stress (2 x normal)
–Party stress (5 x urine)
–Vacation stress (17 d. no use)

D. Field tests

The following is an example of a test system for dry toilet systems from Nordisk Miljømerking (Stiftelsen Miljømerking, 1997). It is used as a standardized field test in connection with application for approval from Nordisk Miljømerking. It is a field test with the following equipment: local map (1: 50 000), flashlight, measuring scale, sampling equipment (sterile for TCB), pH, electrical conductivity, equipment for cooling compost samples, interview form, personal safety equipment.
This test is intended for Nordic conditions and thus doesn’t comply with all specific conditions in other parts of the world, and is first and foremost and example of an authoritative field test.

Table 9. Interview Form for Field Test
A brief interview must be conducted with the host family by the test institution (not the applicant) with a view to ensuring the representatively of the test and to clarify significant operational conditions, deviations etc. such as times of use, daily operations, any problems encountered etc.

1 Identification

Date: (day/month/year)

Owners name Address Telephone Fax Comments

Applicant's company name

Interviewer's name

Location

Country Iceland Norway Sweden Finland
County:
Municipality:
House/cabin No. Site.
Map (M=1:50-100 000).
Height above sea level.

2 Installation

What type of toilet has been installed?
Manufacturer:
....
Model:
....

qWith power connection (220/230 volt).   q The toilet has a heating element.

q Without power connection, including 12/24 volt.

The toilet is installed in: Dwelling q   Holiday home/cabin q
When was the toilet installed? .... (year).

Is the toilet used in combination with outdoor (external/outer) compost tanks ?
q External uninsulated compost tanks. No. of tanks ....
q External insulated compost tanks. No. of tanks ....
q Large insulated home compost tanks. No. of tanks ....
q Other ....

Were any particular problems encountered during installation or assembly
....
....
....

Is part or all of the toilet located in an unheated room?
q The toilet (including bowl, decomposition tank etc.) is located in a room that is heated at all times (>15C).

q The toilet bowl is located in a room that is heated at all times, but where the decomposition tank(s) is located in a cold room and/or under the floor.

q The toilet bowl is located in a room that is only heated during use and where the decomposition tank(s) is located in a cold room (<15C) and/or under the floor.

q The toilet (with bowl, decomposition tank etc.) is located in a room that is cold at all times.
q Other ....

How is the toilet ventilated?

q The toilet is ventilated by means of an air duct from the decomposition tank. The air duct is mechanically ventilated by means of:
  q Electrical fan (220/230 V).
  q Electrical fan (12/24 V).
  q Other .... (describe).

q Ventilation of the toilet is based on a draught through the vent from the decomposition tank.
q The vent has one or more bends.
q The vent extends over the roof ridge.
q The vent is connected to some form of filter. Describe ....
....
q The vent is insulated.
q The vent is partially insulated.
q The vent is not insulated.
q The air can enter the processing chamber through the access door (undesirable)

Have there been any problems with odors ?

q The toilet is virtually free of odor/has an acceptable odor.
q Indoors.
q Outdoors.
q During emptying of the toilet.
q During emptying of external compost tanks.
Please describe the problem: ....
....

3 Use and care

How many adults usually use the toilet ? .... (number)

How many children usually use the toilet ? .... (number)

Is the toilet used by everyone or do some people go elsewhere to urinate ?

q The toilet is used by everyone and has sufficient fluid capacity.
q Sometimes some people go elsewhere to urinate.
q Some members of the family frequently go elsewhere to urinate because of the low fluid capacity of the toilet.

State the number of days (24-hour periods) that the toilet is in use during the year ?

q 1 to 30 days
q 30 to 60 days
q 60 to 90 days
q 90 to 180 days
q 365 days (the whole year).

At what times of the year is the toilet most in use ? ....

Is food waste put into the toilet ?

q Food waste is not put in.
q Food waste of the order of .... liters or kg per week is put in.
q Just as much food waste as other waste is put in.
q More food waste than other waste is put in.

Is water put into the toilet ?
q Water is not put into the toilet or external tank.
q Water is put into the toilet or external tank. Amounts ? .... liters per week.

Is fluid drained off the toilet ?

q Fluid is not drained off the toilet or external tank.
q Fluid is drained off the toilet or external tank. Amounts ? ..... liters per year.

How many times per day are pellets added to the toilet?
q Every time the toilet is used.
q Once per day.
q Other ....(describe)

What quantity of pellets is added to the toilet per day ?

q 1 to 5 dl
q 0.5 to 5 liters
q Other .... (describe)

What type of material is used as pellets ?
q Turf.
q Bark.
q Woodchips/sawdust.
q Grass/leaves etc.
q Other (describe) ....

Are any special composting materials used ?

q Composting materials are not used.
q Composting materials are used. Type/manufacturer: ....
Quantity: ....

4 Emptying

When was the toilet and/or external compost tank last emptied ?

Date: ....
q Less than 4 weeks ago.
q 1 to 3 months ago.
q 3 to 6 months ago.
q 6 to 12 months ago.
q More than 1 year ago.
q More than 2 years ago.
q More than 3 years ago.

How frequently is the compost emptied from the toilet ?
q More than 12 times per year.
q 5 to 12 times per year.
q 2 to 4 times per year.
q Once per year.
q Every other year or less frequently.

Describe the condition of the compost at the time of emptying ?

q The compost is dry or relatively dry.
q The compost is dripping wet or relatively wet.
q The compost is porous and air-filled and easy to handle/empty.
q The compost is hard and solid. It is difficult to empty.
q The compost is wet or partially fluid and difficult or unpleasant to handle/empty.
q The smell of the compost is acceptable (smells of earth).
q The compost smells unpleasant (smell of ammonia, acid, feces, etc.)

q The compost is dark brown to black in color.
q The compost has more or less the same color as feces.
q There are few insects and/or larvae in the compost.
q There are a great many (i.e. >100) insects and/or larvae in the compost during emptying.

How much compost is emptied from the toilet ?
State approximate amount in liters ....

How is the compost used?
__ The compost is used to enrich the soil/fertilize our own garden/land.
__ The compost is buried in our own garden/land.

Any comments:
....
....
....
....
....

E. Additional economic data

It can be illustrating to compare costs of ecological sanitation to conventional systems In Norway about 20% of the population lives in rural areas, where more than 800 000 inhabitants are connected to separate treatment systems. The total annual per capita emissions of nutrients in Norway is about 0.55 kg P and 10.4 kg N, of which 0.38 P and 4.79 N comes from the wastewater sector (Refsgaard & Etnier, 1998). The total agricultural area is about 10 million decares.

The annual costs for local sanitation systems in Scandinavia vary from USD 240 for multiple family systems, and from USD 480 for single household systems. The total annual communal costs for transportation and treatment of wastewater is USD 433 million, 237 millions on operation & maintenance, and 196 millions on capital costs, or a mean value of USD 375 per household. The household payments covered about 95% of the real costs. Weighted for the number of inhabitants the mean annual cost per household is about USD 267. The size distribution of the costs is USD 275-525.

Table 10. Annual costs for transportation and treatment for wastewater in Norway (after Refsgaard and Etnier, 1998), costs in USD *

Community size	No pe	No communities	Annual cost pr. household
Minimum	< 1000	110	525
Small	1000-5000	193	342
Medium	5000-10000	61	299
Big	10000-50000	61	304
Maximum	> 50000	10	269

 Based on administrative, maintenance- and operational, and capital costs. 1 household=3 pe. 1 USD = 7.5 NOOK

The total annual costs for handling household waste was about USD 267 million, or about USD 60 per habitant. The wet organic fraction of the waste is about 25% weight. Table 5-8 show estimated costs for different alternative sanitation systems in Norway based on recent (1998) prices.

Table 11. Construction and operational costs (USD) for piped rural wastewater treatment in Norway

Costs for 100 m									
House- and main									
Pipeline		No	Unit cost		Construction		Annual		
Costs									
Toilet and house									
Pipeline				1100	95				
pipeline to mains			100	41	413	275			
Extra main pipe-									
Line and pump.									
Station	100	87	8667	576					
Main pipeline, treatment plant & sludge handling									400
Costs reductions for water supply							-3200	-213	
Total per household					10693	1133			

Table 12. Cost (in USD) and treatment effect for different sanitation systems in rural areas, for 1 house, based on a plant for 10 households (after Refsgaard & Etnier, 1998)

	A	B	C	D	E	F	G	
costs								
construction		8667	8800	4267	11333	8267	5600	
annual o&m		133	93	80	200	200	347	2073
annual total		880	853	480	1226	893	827	813
Cost-effect		NOK/kg		recalculated				
phosphorous		662	603	651				
nitrogen		135	232	99				
Cost-effect		NOK/kg		removed		nutrient		
P	488	472	287	733	963	490	497	
N	90	87	122	187	136	209	282	
TOC or BOD		32	31	20	52	38	35	21
annual	emission		after	treatm.	kg/pe			
P	0.01	0.01	0.01	0.06	0.31	0.06	0.07	
N	1.05	1.05	1.05	3.07	2.19	3.07	3.50	
TOC/BOD		0.49	0.49	0.49	1.97	1.97	1.97	2.37

* interest rate 6 %, 1 toilet per household, wet composting includes 100% recalculation of P and 80% of N, 1 USD = 7.5 NOK

System description:

System	Toilet	Black water treatment	Grey water treatment
A	waterless	wet composting	soil infiltration
B	vacuum	wet composting	soil infiltration
C	wc	soil infiltration	no
D	wc	wetland	no
E	wc	wetland	no
F	wc	small treatm. syst.	no
G	wc	pipeline to treatment plant	no

* Black water and organic waste collected together

Table 13. Costs, in USD, and effect, for different wastewater treatment systems in rural areas (after Refsgaard, Høyås & Mæhlum, 1998)

	I	J	K	L
costs				
construction	5774	71 000	83 500	2933
annual o&m	157	1600	600	40
annual total	684	83 000	6933	240
annual total pr. household	684	416	693	240
filter area m2	50	1000	430	38
pe	5	100	50	5
total liquid volume m3/year	50	1000	6200	274
specific loading rate mm/day*pe	4	0.2	2.5	4
Cost-effect* USD/kg recirc.				
phosphorous	245	149	450	197
nitrogen	104	63	106	33
TOC	17	11	18	14
Total	366	222	575	244

* total annual nutrient recycling per pe: 0.56 kg P, 1.31 kg N & 7.88 kg TOC

General economical level, tax level

Wastewater treatment system description:

System	pretreatment	pe	final treatment	filter type
I*	septic tank	5	soil infiltration	natural/half normal size
J*	septic tank	100	soil infiltration	natural/half normal size
K	septic tank	50	sand filter	natural/normal size
L	septic tank	5, grey water	soil infiltration	natural/half normal size

□ Model systems based on experience

Table 14. Model calculation of alternatives for sanitation and water in the year 2015 (after Winblad & Vargas, unpublished), all in USD

Cost	Full conventional. sewage A	No conventional sewage B
O&M-A	26 600 000	10 800 000
Total investment	8 900 000	1 900 000
Financial surplus sanitation	-1 590 000	2 075 000
Pay pr. household	65.82	26.90

* Number of households = 70 000, total income (including hidden): USD 350

F. Other technical information

Table 15. Main characteristics of methane (CH4)a , the energetically important fraction of biogas

Mean atmospheric concentration	1.7 ml/liter (ppmv) b
Density (at standard air temp. and press.) c	716 g/m3 = 716 mg/liter
Molar weight	16.0 g/mol
Molar volume (of all gasses at STP d)	22.4 liter/mol
Specific energy (heat)	9.3-11.4 kWh/m3 = 14 kWh/kg
Specific energy of oil	12 kWh/kg
Specific energy of wood	4 kWh/kg
Volume ratio gas/liquid (LNG)	600

a References: Crabbe & McBride (1978), SI (1971), Beiser (1988), Crutzen, 1991
b ppmv = parts per million volume
c changes in atmospheric pressure are usually within 10 %. An increase in temperature from 0
d STP = gas at 15.56 deg C and 1 atm. pressure

Table 16. Measured or calculated methane production in landfills and other organic waste a

Reference	Production of CH4		Comments	
Kunz & Lu (1980)		25	App. value for specific production	
Ehrig (1993)		10	Max. value specific prod. (fig 2)	
Kightley et.al (1995)		12	Landfill 20 m deep, mean value?	
Emberton (1986)		450	Max. value, landfill 50 m depth	
do.	0.15	10	Mean value from 10 landfills	b
Thornloe et.al. (1993)	1.7 - 5.4		CH4/kg dry weight refuse	c
do.	0.3		Annual production/ wet weight	d
do.	19		Total production/ wet weight	e
Jordforsk (unpubl.)	57		Dim. criteria, Norway	
Heerenklage et.al.(95)	54		Total production/wet weight	f
Bogner & Spokas.(93)	43 - 64		Total production/ dry weight	g
do.	62 - 125		Total production/ dry weight	h
Hoeks (1983)	0.6		Total production/dry weight	i
Wang et.al. (1997)	215 +/- 7.6		Total production/dry weight	j
Rintala&Jarvinen	158 - 125		Total production/wet? weight	k
Metcalf & Eddy (1991)	150		Total production/dry weight	l
Metcalf & Eddy (1991)	250		Total production/dry weight	m
Paulsrud & Nedland (91)	440		Total production/dry weight	n
McBean & Farquhar (1980)	43.2 - 55.8 %		Methane content, mean values	
Jones & Nedwell (1990)	55 - 70 %		Methane content	

a Measured and estimated methane production from MSW
b Measured in columns over > 50 days, based on mean landfill depth of 13 m, mean = 204 cm3/kg*day, 84 % between 0-300 cm3
c Measured in test cell over 1597 days (4.4 years), probably low estimate
d Used for estimating the dimensions of gas extraction, not verified in field measurements
e Total methane production based on eq. (1).
f Based on a methane content of 50 % in biogas.

g Maximum total production based on field and laboratory measurements
h Used as basis for commercial gas production, probably too high
i Total methane production based on eq. (2)
j Total methane production from anaerobic degradation of food waste seeded with 70 % old coposted waste
k Total methane production from anaerobic co-digestion of MSW and sewage sludge
l Total methane production from anaerobic digestion of sludge, calculation example, BOD/TSS=0.96
m Total methane production pr. kg COD at STP
n Total methane production pr. kg C degraded at NTP

Table 17. Physical and chemical processes influencing methane production

Reference	Factor	Values	Comments
Farquhar & Roves (73)	pH	6.4—7.2	Recomm. for sewage sludge digestion
do.	Alkalinity	> 2000 mg/l	Necessary for CH_4 production in sew.sl.
Paulsrud, 91	water content	>85%	
Paulsrud, 91	Tot.alk.	>30 mekv./l	
Paulsrud, 91	HCO_3-alk.	>15 mekv./l	
do.	NH_3	> 100 mg/l	Necessary for CH_4 production in sew.sl.
Wang et al. (97)	N/P	< 20	nutrient ratio
do.	Organic acids	< 3000 mg/l	Max.level in sludge, CH_3COOH
Paulsrud, 91	volatile org.	<300 mg/l	<200 is optimal
do.	Redox. Pot.	< 200 mV	Recomm. for sewage sludge digestion
do.	Temperature	20 - 55 ° C	Recomm. for sewage sludge digestion
Paulsrud, 91	Temperature	+/1 ° C/day	Recomm. max. variation in process
do.	Pressure	< 35 psi	Recomm. for sewage sludge digestion
do.	Hydrocarbons		hydrocarbons, lignin and ether cannot be degraded during methanogenesis