

ECOLOGICAL SANITATION

revised and enlarged edition

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2004

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First published 1998
Second edition 2004

Published by

Stockholm Environment Institute
Box 2142, S-103 14 STOCKHOLM, Sweden

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Printed by

Arket Officin AB, Stockholm, Sweden

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Winblad U & Simpson-Hébert M (editors): *Ecological sanitation – revised and enlarged edition*. SEI, Stockholm, Sweden, 2004.

The document is the result of a Sida commissioned study but the views expressed in the document are solely the responsibility of the authors.

ISBN 91 88714 98 5

ACKNOWLEDGEMENTS

Writing this book was a team effort and the team included a number of colleagues whose names do not appear on the title page. We are grateful to all friends and colleagues for their help. Special thanks are due to Ingvar Andersson and Bengt Johansson of the Swedish International Development Cooperation Agency (Sida) for their support to the earlier SanRes R&D programme (1993–2001) and the current EcoSanRes programme (2002–ongoing).

A key role has been played by all those people in the field who are responsible for implementing ecological sanitation projects in urban and rural communities around the world. In addition to those listed in the first edition of the book we acknowledge our debt to Ms Li Lingling and Mr Lin Jiang in Guangxi Autonomous Region, China. Thanks to their spirited work and the support from the NPHCC and the Ministry of Public Health in Beijing a small pilot project for 70 households in Tianyang County in Guangxi, carried out in 1997–98 as part of the SanRes programme, has now spread to 685,000 households in 17 provinces.

Thanks are also due to government and agency officials in other parts of the world for supporting and facilitating the development of ecological sanitation. In the first edition of the book we listed them. Since then there has been such a rapid development in a large number of countries that we can no longer provide a comprehensive list.

Finally we wish to acknowledge the contribution made by Steve Esrey. He played an important role in the development of the concept of ecological sanitation and in the drafting of the first edition of this book. Those of us who were there will never forget his inspiring opening speech at the First International Conference on Ecological Sanitation in Nanning, China, in November 2001. He was unable to come to Nanning due to the illness that a month later led to his death, but nonetheless he prepared a wonderful, voiced powerpoint presentation for the opening session. The results of this very successful conference have been incorporated into this book.

Stockholm and Addis Ababa
July 2004
The Editors

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FOREWORD

Sida has a long-standing commitment to the development of water and sanitation services for all people. Early on Sida recognized that shortages of water resources and financial resources in many parts of the world are among the main barriers to progress. Thus, in the early 1990s, Sida put its support behind a new effort, a new way of thinking about this challenge, and the development of new concepts. In sanitation the new approach was to think in terms of developing systems that would save water, prevent water pollution and recycle the nutrients in human excreta. These new solutions should also save money and optimise the meagre financial resources of many cities, towns and government agencies around the world. The idea was to find solutions that were ecologically sound and would improve the environment while putting up barriers to water-borne diseases. Today we call this new approach “ecological sanitation.”

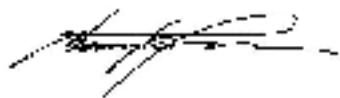
Sweden put its resources behind this effort because Sweden, a country with abundant water resources, was in fact polluting its fresh and salt waters. As early as the 1960s, Swedish researchers, inventors and planners were seeking new approaches to sanitation that would prevent this pollution. Ideas began to emerge that looked promising and this stimulated interest in further research and development of sustainable systems. Perhaps some of these ideas and experiences could be further developed and then shared with other countries? Perhaps ideas and experiences from other countries could be shared through a wider joint effort?

This book presents the findings of over ten years of research and development in ecological sanitation supported by Sida. We are grateful to the small group of dedicated professionals who have written the book.

Since 2000, the UN’s Millennium Development Goals and its targets for water supply and sanitation have reaffirmed that the development community, and agencies such as Sida, need to continue to search for more viable and sustainable solutions to sanitation. This book contributes to that search and presents proven solutions.

We hope that this book will inspire different actors such as government agencies, NGO’s, private sector, water companies, municipal authorities and individuals to work with ecological sanitation systems. It can be used in developed as well as developing countries and aims also at stimulating different actors to include ecological sanitation systems in all their activities in the water and sanitation sector.

Stockholm in July, 2004



Bengt Johansson
*Director, Water Division
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Chapter 1

INTRODUCTION

1.1 Challenges

This book is about sanitation for the future, in a world where most people will live in towns and cities. Over the next 25 years the world's population is expected to reach 8 billion, with 5 billion living in urban areas. More than half of the 8 billion will face water shortages and 40% of the urban population might be living in slums.¹ Already today billions of people, in urban as well as in rural areas, have no proper sanitation.

With this in mind, an international group of planners, architects, engineers, ecologists, biologists, agronomists and social scientists have developed an approach to sanitation that saves water, does not pollute and returns the nutrients in human excreta to the soil. We call this approach 'ecological sanitation', or 'eco-san' for short.

The major global challenges faced by the sanitation sector are the many people without sanitation, the health effects of poor sanitation, water shortage and pollution, food insecurity, urban growth and the inadequacy of current sanitation options.

People without sanitation

An often quoted figure is that the total number of unserved is about 40% of all people in the world.² If present trends continue, the number of unserved is going to increase.

Health effects of poor sanitation

Approximately 6000 children die every day from diarrhoeal diseases related to inadequate sanitation and hygiene.³ About 1 billion people worldwide, mostly children, are infested with intestinal worms and as a result suffer nutritional deficiencies and poor growth.⁴ Both of these groups of diseases are transmitted through human faeces in the environment.

Water shortage

Already today many areas are suffering from chronic freshwater shortages and the demand for freshwater has tripled in the past 50 years. By 2030 more than half the world's population will face a shortage of water.⁵

Water pollution

Sewage discharges from centralized, water-borne collection systems are a major component of water pollution all over the world. Only about 300 million people in the world today have end-of-pipe treatment of sewage to a secondary level (see 2.4) before the sewage is discharged into open bodies of water.⁶ Pollutants also leak into groundwater from sewers, septic tanks, pit toilets and cesspools.⁷

Food insecurity

In today's urban societies the flow of plant nutrients is linear: nutrients are taken up from the soil by the crop, transported to the market, eaten, excreted and discharged. In a sustainable society the production of food must be based on returning the plant nutrients to the soil. The use of chemical fertilizers is not sustainable, since their production relies on non-renewable resources.

Urban growth

Over the next 25 years 90% of the world's population growth will be absorbed by the urban areas of the less developed regions, where the population will increase by 2 billion. Today 50% of the urban population live in cities of under 500,000 people. These smaller cities have less in the way of sanitation facilities and development than larger cities. Cities in developed countries have, according to UN-Habitat, 32 times as much money per person to spend on infrastructure and other urban services as cities in least developed countries.⁸

Inadequacy of current options

The sanitation practices promoted today are either based on hiding human excreta in deep pits ('drop-and-store') or on flushing them away and diluting them in rivers, lakes and the sea ('flush-and-discharge').

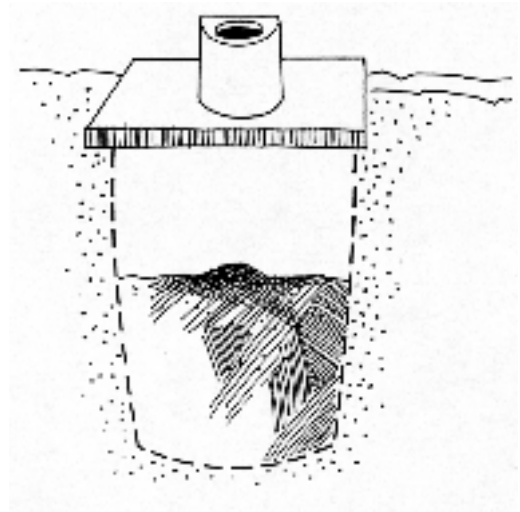


Figure 1.1 Drop-and-store.

Drop-and-store systems can be simple and relatively low-cost but have many drawbacks. Often they cannot be used at all in crowded areas, on rocky ground, where the groundwater level is high or in areas periodically flooded. They require access to open ground and the digging of new pits every few years.

Flush-and-discharge systems require large amounts of water for flushing, and for many municipalities unaffordable investments in pipe networks and treatment plants. Over a year for each person some 400-500 litres of urine and 50 litres of faeces are flushed away with 15,000 litres of pure water. Water from bath, kitchen and laundry may add up to another 15,000-30,000 litres for each person.

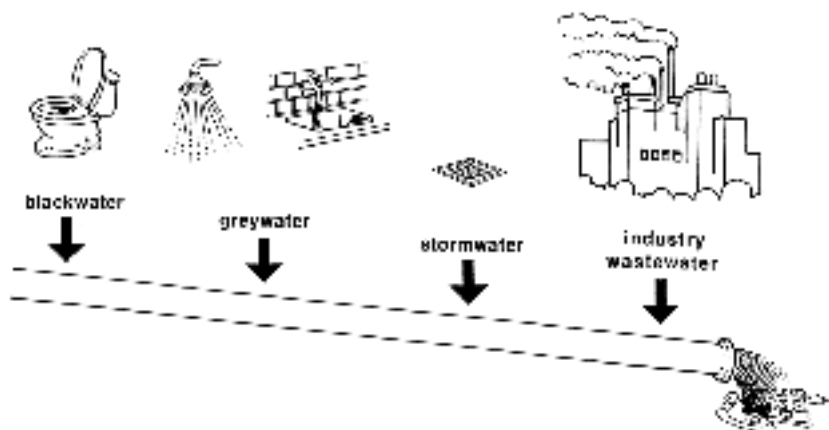


Figure 1.2 Flush-and-discharge.

Further down the pipe rainwater from streets and rooftops and wastewater from industries are often added. Thus at each step in the flush-and-discharge process the problem is magnified: the really dangerous component, the 50 litres of faeces, is allowed to contaminate not only the relatively harmless urine but also the huge amount of pure water used for flushing and an equal or even larger amount of greywater.

Leaders, professionals and communities are currently faced with two options: expand existing sanitation approaches, with all their limitations and weaknesses, or seek entirely new solutions. Existing approaches to sanitation are not viable or affordable to the vast majority of people, neither do they offer people an approach towards a sustainable society.

1.2 Response

Ecological sanitation is based on three fundamental principles: preventing pollution rather than attempting to control it after we pollute; sanitizing the urine and the faeces; and using the safe products for agricultural purposes. This approach can be characterized as ‘sanitize-and-recycle’.

This approach is a cycle – a sustainable, closed-loop system. It treats human excreta as a resource. Urine and faeces are stored and processed on site and then, if necessary, further processed off site until they are free of disease organisms. The nutrients contained in the excreta are then recycled by using them in agriculture.

An essential part of eco-san is to contain and sanitize human excreta before they are recovered and reused. Human faeces, rather than urine, are responsible for most diseases spread by human excreta. Thus, a method is needed to sanitize faeces. Two methods are discussed in this book: dehydration and decomposition. Dehydration, or drying, of faeces is easier if they are not first mixed with urine and water. When faeces decompose, the pathogens in them die and are broken down. Thus, with either method, viruses, bacteria and worm eggs are destroyed. It is only then that faeces can be recycled. Urine is usually safe enough to be used in agriculture without further treatment, either directly or after a short period of storage.

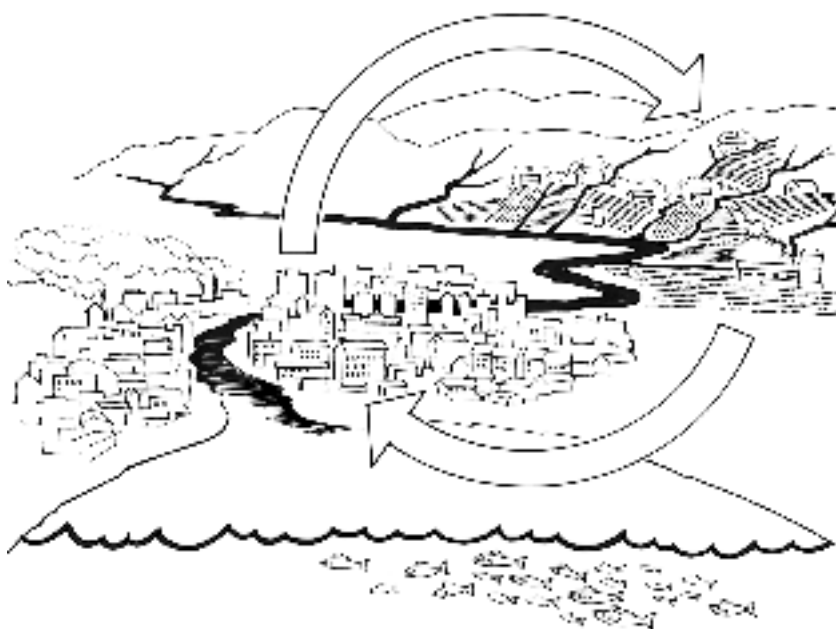


Figure 1.3 *Ecological sanitation replicates nature by returning the plant nutrients in human urine and faeces to the soil. Instead of polluting the environment, human urine and faeces are used to improve soil structure and supply nutrients.*

In summary, key features of eco-san are prevention of pollution and disease caused by human excreta, management of human urine and faeces as resources rather than as waste, and recovery and recycling of the nutrients. In the natural world, excreta from humans and other animals play an essential role in building healthy soils and providing valuable nutrients for plants. Conventional approaches to sanitation misplace these nutrients, dispose of them and turn the cycle into a linear flow.

Box 1.1 *A new public health revolution*⁹

“Ecological sanitation could be the beginning of a new public health revolution. During the 20th century we have witnessed several public health revolutions including universal childhood immunizations, the eradication of smallpox, improved water supplies, the green revolution with its improved food yields and expansion of primary health care. The one public health problem that has proved intractable this past decade has been a lack of sanitation for about half the population of the world.”

1.3 Criteria

Sanitation is a key determinant of both equity in society and society's ability to sustain itself. If we cannot meet the sanitation challenges described above, we will not be able to provide for the needs of the present generation without hindering that of future generations. Thus, sanitation approaches must be resource minded, not waste minded. Similarly, there can be no equity as long as half the world's population goes without even basic sanitation.

A system of sanitation that contributes towards the goals of equity and a sustainable society must meet or at least go some way towards meeting the following criteria:

Disease prevention

A sanitation system must be capable of destroying or isolating faecal pathogens.

Environment protection

A sanitation system must prevent pollution and conserve valuable water resources.

Nutrient recycling

A sanitation system should return nutrients to the soil.

Affordability

A sanitation system must be accessible to the world's poorest people.

Acceptability

A sanitation system must be aesthetically inoffensive and consistent with cultural and social values.

Simplicity

A sanitation system must be robust enough to be easily maintained with the limitations of the local technical capacity, institutional framework and economic resources.

Successful implementation of these criteria requires an understanding of sanitation as a system. The criteria also require that all the components of the system are considered together, not just one or two, when designing and making sanitation systems work. The main components of that system are nature, society, process and device.

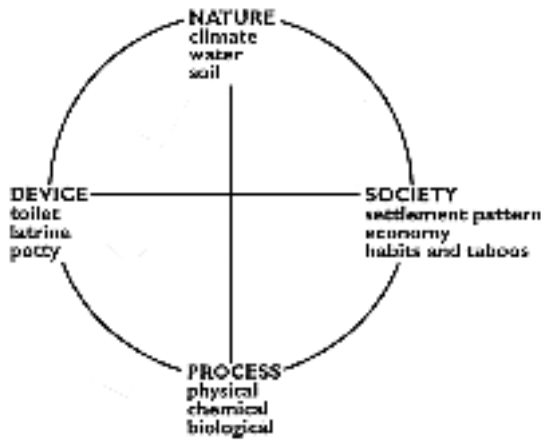


Figure 1.4 Sanitation is a system where the main components are nature, society, process and device. All these components must be considered together.

- The most relevant **nature** variables are climate (temperature, humidity), water (amount available, groundwater level), and soil (stability, permeability, pickability).
- **Society** includes settlement pattern (concentrated/dispersed, low/high rise), attitudes (faecophobic/faecophilic), habits (washers/wipers), beliefs and taboos related to human excreta as well as the economic status of the community in question.
- By **process** we mean the physical, chemical and biological processes by which human excreta are turned into a non-dangerous, inoffensive, useful product. In this book we discuss two such processes: dehydration and decomposition.
- By **device** we mean the on-site structures specifically built for defecation and urination. Much of the literature on sanitation is focused on devices, without relating them to the other components of the sanitation system.

The principles underlying eco-san are not novel. In different cultures sanitation systems based on ecological principles have been used for hundreds of years. Eco-san systems are still widely used in parts of East and South-East Asia. In Western countries this option was largely abandoned as flush-and-discharge became the norm, but with a growing realization that conventional sewerage is unsustainable there is now a revival of interest in ecological approaches to sanitation.

Applying the criteria above and developing and implementing a systems approach to sanitation requires a change in our thinking. We must move away from an approach based on disposal to one aimed at zero-discharge and recycling.

1.4 This book

This book does four major things: it treats sanitation as part of a larger ecological system, it systematizes experience from different parts of the world, it describes how to proceed when developing and implementing eco-san approaches, and it provides a vision for urban applications of the eco-san concept.

In this first chapter we have explored the global challenges that we are facing in the next 25 years and how eco-san can help meet those challenges. We have also introduced the criteria for an eco-san system. In Chapter 2 we explain how human excreta can be sanitized in a two-step process to render it safe for re-use in agriculture. In Chapter 3 we introduce a great variety of eco-toilets and eco-san systems suitable for rural homesteads and urban residential areas. In Chapter 4 we go into the details of the design and management of eco-san systems. In Chapter 5 we report on recent and on-going research on the re-use of excretal nutrients in agriculture and how they affect plant growth and crop production. In Chapter 6 we turn our attention to handling greywater. Chapter 7 discusses the important area of planning, promotion and support to ensure the success of new projects. And finally Chapter 8 provides a vision for the future, describes how ecological sanitation could work in urban areas, and summarizes its advantages over conventional approaches.

This book is neither a technical nor a policy manual although it does deal with technical and policy issues. It is rather a down-to-earth discussion of the options available. The eco-san concept is particularly relevant to cities where water and money are scarce. But it should not be regarded as a second-rate solution only for the poor. Eco-san options are available for a whole range of socio-economic conditions, as clearly shown in the wide variety of examples offered in Chapter 3.

Chapter 2

SANITIZING HUMAN EXCRETA

One of the main goals of ecological sanitation is to capture the nutrients present in human excreta and recycle them back to agriculture. Thus a key part of an eco-san system is the destruction of most or all disease-producing organisms before re-use of excreta products. Results from scientific studies of pathogen destruction in eco-san systems are now providing us with guidelines for the treatment of urine and faeces before re-use as fertilizer.¹

2.1 Urine

Urine contains few disease-producing organisms, while faeces may contain many. Storing undiluted urine for one month will render urine safe for use in agriculture. Undiluted urine provides a harsher environment for micro-organisms, increases the die-off rate of pathogens and prevents the breeding of mosquitoes.^{1,2}

At the homestead level, where crops are intended for the household's own consumption, urine can be used directly. It is recommended, however, that there should be 1 month between urine application and harvesting.

When urine is collected from many urban households and transported for re-use in agriculture, the recommended storage time at temperatures of 4–20 °C varies between 1 and 6 months depending on the type of crop to be fertilized.

Box 2.1 *Recommended Swedish guideline storage times for urine mixture^a based on estimated pathogen content^b and recommended crop for larger systems^{c,1}*

Storage temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4°C	>1month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	>6 month	Viruses	Food crops that are to be processed, fodder crops ^d
20°C	>1 month	Viruses	Food crops that are to be processed, fodder crops ^d
20°C	>1 month	Probably none	All crops ^e

^a Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l.

^b Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized as causing any of the infections of concern.

^c A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from which the urine was collected.

^d Not grasslands for production of fodder.

^e For food crops that are consumed raw it is recommended that the urine be applied at least 1 month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

2.2 Faeces

The main concerns about the safety of excreta are with the faeces. The most important pathways for the transmission of diseases from faeces are hands, flies, water, soil as well as food that have been contaminated by any of the first four factors. The F-diagram below summarizes these main pathways. (Each of these factors has been given a name beginning with the letter 'F' in order to make it more easily remembered.)

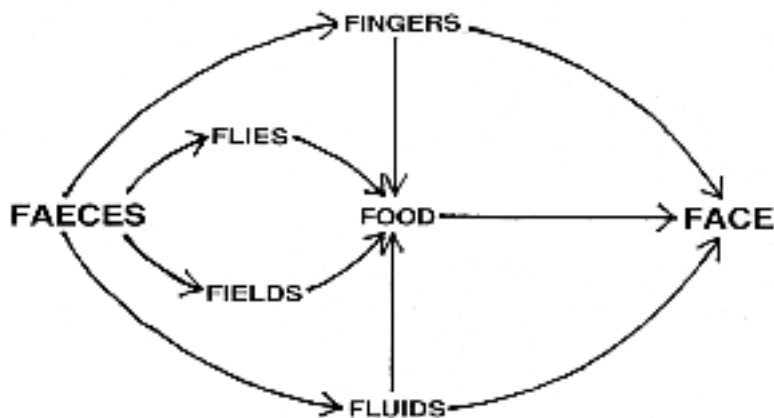


Figure 2.1 The F-diagram summarizes the main ways faecal pathogens are spread by contaminating fingers, flies, fields, food and fluids and then eventually being swallowed.

One purpose of an eco-san system is to form a set of barriers between faeces and flies, fields and fluids. This is done by containment of the faeces in a processing chamber or shallow pit where pathogens are reduced to an acceptable level before re-use. Then the contents may be removed for further secondary treatment to make them even safer.

Every eco-san system should also include a device for hand washing in order to block this remaining important pathway for faecal-oral transmission. Every eco-san educational campaign must emphasize not only proper use and management of toilets but also the importance of hand washing after defecation, after helping a child who defecates and before preparing food or feeding a child. (This is of course not unique to eco-san. Hand washing is as important in the use of conventional sanitation facilities.)

2.3 What kills pathogens in faeces?

A number of environmental factors are known to kill off faecal disease organisms. These are increases in storage time, temperature, dryness, pH, ultraviolet radiation, and competing natural soil organisms.

Table 2.1 *Physiochemical and biological factors that affect the survival of micro-organisms in the environment.*⁴

Temperature	Most micro-organisms survive well at low temperatures (below 5°C) and die off rapidly at high temperatures (above 40° C). This is the case in water, soil and sewage and on crops. At temperatures of 55–65°C all types of pathogens (except bacterial spores) die within hours.
pH	Highly alkaline conditions will inactivate micro-organisms. Inactivation is rapid at pH 12 but takes longer at pH 9.
Ammonia	Pathogens in excreta can be inactivated by the addition of ammonia.
Dryness	Moist soil favours the survival of micro-organisms. Dehydration of faeces in an eco-toilet processing chamber will decrease the number of pathogens.
Solar radiation	The survival time of pathogens on soil and crop surfaces will be reduced by UV radiation.
Presence of other organisms	The survival time of micro-organisms may be shortened by the presence of other organisms. Different types of organisms affect each other by predation, release of antagonistic substances or competition for nutrients.
Nutrients	Bacteria adapted to living in the gut are not always capable of competing with other organisms in the general environment for scarce nutrients. This may limit the ability of faecal bacteria to reproduce and survive in the environment.
Oxygen	Most enteric bacteria are anaerobic and thus are likely to be out-competed by other organisms in an aerobic environment.

2.4 Primary and secondary processing

Eco-san systems are designed to use some of the physiochemical and biological factors listed in Table 2.1 to kill disease organisms in faeces. This occurs usually in two steps: primary processing and secondary processing.

Primary processing

The purpose of primary processing is to reduce the volume and weight of faecal material to facilitate storage, transport and further (secondary) treatment. Primary processing takes place in chambers below the toilet (Figure 2.2). Here the faeces are kept ('contained') for a certain period. During this containment the number of pathogens will be reduced as a result of storage time (6–12 months), decomposition, dehydration (ventilation and the addition of dry material), and increased pH (addition of ash, lime, urea) as well as the presence of other organisms and competition for nutrients.

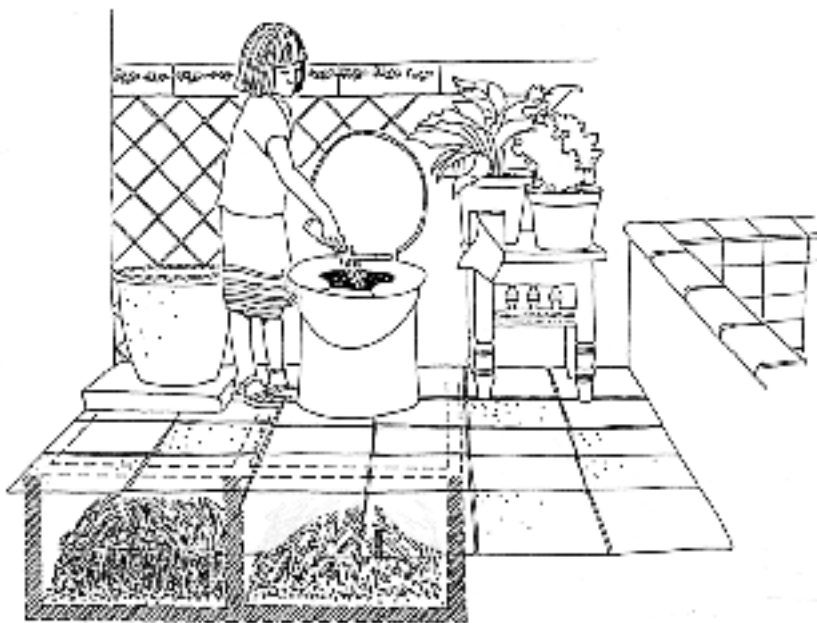


Figure 2.2 An eco-toilet with processing chambers. The toilet has a moveable seat-riser with urine collector. The processing chambers below the bathroom floor can be emptied from outside. (Design: César Añorve, Cuernavaca, Mexico, 1992).

In some of the basic models developed in Zimbabwe the processing takes place in a shallow pit beneath the eco-toilet (Figure 2.3).

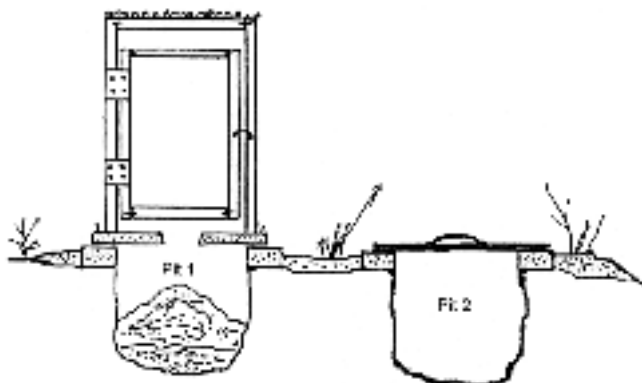


Figure 2.3 A basic eco-toilet from Zimbabwe with processing chambers in the form of shallow pit. During the first year the squatting slab and super-structure are mounted over Pit 1. Next year they are shifted to Pit 2 (see also 3.1.4). (Design: Peter Morgan, Harare, Zimbabwe, 1998).

Secondary processing

The purpose of secondary processing is to make human faeces safe enough to return to the soil. Secondary processing takes place either on site – in the garden, or off site – at an eco-station. This step includes further treatment by high temperature composting or pH increase by the addition of urea or lime as well as longer storage time. If a completely sterile end product is required the secondary processing could be carbonization or incineration.

In areas where ambient temperatures reach up to 20 °C , a total storage time of 1.5 to 2 years (including the time stored during primary treatment) will eliminate most bacterial pathogens (if kept dry) and will substantially reduce viruses, protozoa and parasites. Some soil-borne parasite eggs may persist. In areas where the ambient temperatures reach up to 35 °C , a total storage period of 1 year will achieve the same result, as pathogen die-off is faster at higher temperatures.¹

Where high temperature composting, 50–60 °C , can be carried out, either in an open compost or in a mechanical composting bin (see Figure 8.2) the storage period could be further reduced.

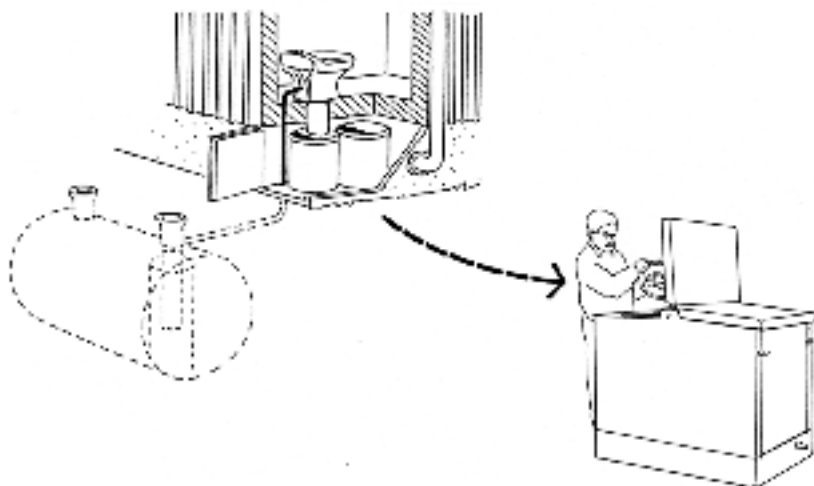


Figure 2.4 Primary processing in a chamber directly under the urine-diverting eco-toilet followed by secondary processing at an eco-station.

Treatment with alkaline materials also requires time for pathogens to die off to an acceptable level. A pH over 9 for at least 6 months to 1 year is sufficient in most climates to kill most pathogenic organisms. For additional safety the material can be bagged (in sacks) and stored for a further period. Where there is concern about the persistence of intestinal worm eggs, carbonization or incineration as the secondary treatment will ensure a sterile product.

2.5 Dehydration and composting

Before explaining these pathogen destruction systems in detail, we must step back and explain at this point that there are three main eco-san systems that operate in slightly different ways to achieve more or less the same result. These are dehydrating systems, composting systems, and soil composting systems. These three, and the different toilet designs that go with them, are exemplified in Chapter 3. For now, to understand how pathogens are destroyed, it is only necessary to understand the broad outlines of these systems. Figures 2.4–2.6 show the key points of the three systems.

Dehydration

In a dehydrating system, like those described in Chapter 3, we direct urine away from faeces to keep the processing chamber contents dry and the volume of material small. This also makes it possible for us to use the urine separately as a fertilizer. Faeces are dropped into a processing chamber where they are safely kept out of the environment for a period of 6–12 months, and ash, lime or urea is added after each defecation to lower the moisture content and raise the pH to 9 or higher. The system thus creates conditions of dryness, raised pH and time for pathogen die-off. The partly treated faecal material is then removed from the processing chamber and subjected to one of the four secondary treatments (high temperature composting, alkaline treatment, further storage, carbonization/incineration).

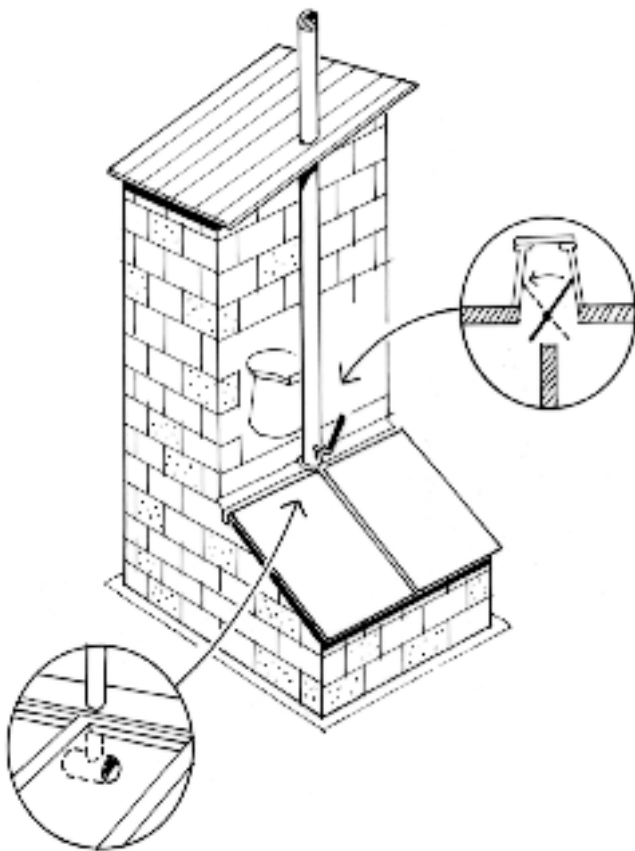


Figure 2.5 *A double-vault composting toilet in Cancun, Mexico², see 3.13 Composting toilets – Mexico. (Design: Uno Winblad, Stockholm, Sweden, 1980).*

Composting

In a composting toilet human faeces, or in some cases faeces plus urine, are deposited in a processing chamber along with organic household and garden refuse and bulking agents (straw, peat moss, wood shavings, twigs, etc).

A variety of organisms in the pile break down the solid into humus – just as eventually happens to all organic materials in the natural environment. Temperature, airflow, moisture, carbon materials and other factors are controlled to varying degrees to promote optimal conditions for decomposition. After a certain retention time (normally 6–8 months) the partly decomposed material can be moved to a garden compost or an eco-station for secondary processing through high temperature composting.

Soil composting

In a soil composting system faeces, in some cases faeces and urine, are deposited in a processing chamber together with a liberal amount of soil. There are two main sub-types with slightly different processes: with a shallow pit or a raised processing chamber (see 3.1.4). Ordinary soil is added after each defecation, often with wood ash as well. Most pathogenic bacteria are destroyed within 3–4 months as a result of competition with soil-based organisms and unfavourable environmental conditions.³ The material is then removed and can be subjected to any one of the same four secondary treatments or, within one family homestead, can be directly spread on fields and worked into the existing soil. A period of 12 months of composting in shallow pits is recommended before application to gardens. There further pathogen die-off occurs because of UV radiation, dryness and competition with other soil organisms. After 1 month, crops that are not eaten raw can be sown with relative safety.⁴

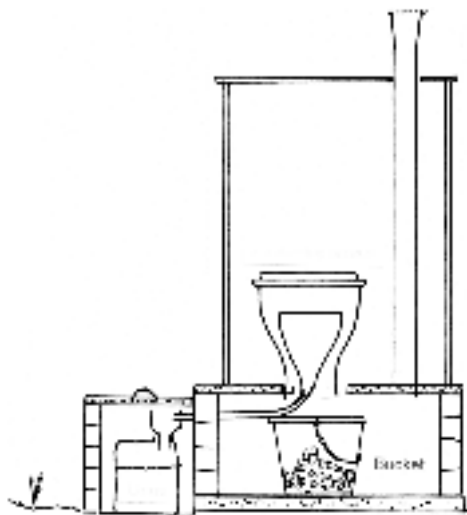


Figure 2.6 Soil composting in above-ground vault, the 'Skyloo' in Zimbabwe, see 3.1.4. (Design: Peter Morgan, Harare, Zimbabwe, 2001).

In the shallow pit type (see Figure 2.3) all of the above applies equally except for one design called the 'Arborloo' (see Figure 2.7 and Section 3.1.4) where a homestead owner may plant a tree directly in the shallow pit when it is almost full and has been topped up with soil. In this case no further contact is made with the composted human excreta. The efficient conversion into compost by the addition of other materials to the excreta, and the shallowness of the pits (max 1.5 m deep) reduces the risk of contamination of underground water supplies.⁵

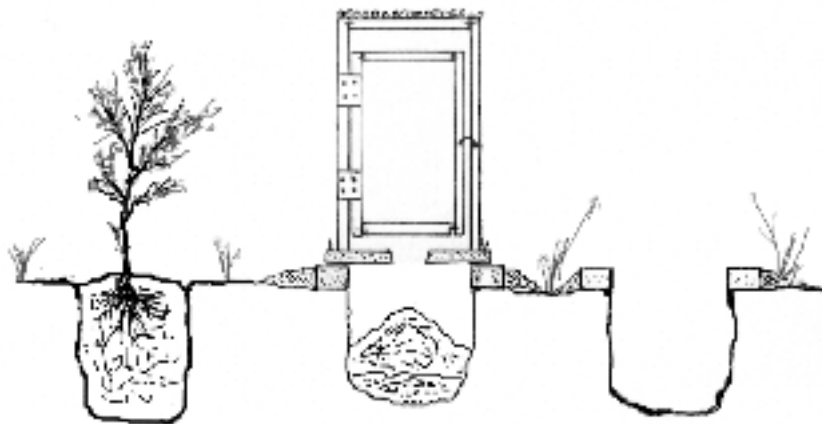


Figure 2.7 Soil composting in a shallow pit, the 'Arborloo' in Zimbabwe (see 3.1.4). (Design: Peter Morgan, Harare, Zimbabwe, 2001).

The application of these systems will result in a community environment that is better than the conditions often found in homestead and urban areas where sanitation services are poor and where open defecation may occur. The simple containment of faeces in processing chambers or shallow soil composting pits is a great improvement on open defecation.

2.6 Homestead vs urban systems

Eco-san systems for homesteads and urban areas will be different. In homesteads, households will handle and recycle their own excreta products. In urban areas, these products will be handled and further treated by a communal service, see 4.5.

For urban areas we recommend dehydrating systems with primary and secondary treatment. Municipal authorities will collect all excreta products after primary treatment and take them to a special collection point for secondary treatment (see 4.5.2 and 8.1.3). In homesteads, secondary treatment can be as simple as adding it to a garden compost pile or manure pile, or additional storage for one or two more years. Urine poses little risk and can be used immediately to fertilize crops to be consumed by the family.

2.7 Summary

Urine

In homesteads urine can be used directly. In large-scale systems urine should be stored for about 1 month before use. Don't apply urine less than a month before harvest on vegetables, fruits (except fruit trees) and root crops that are to be consumed raw.

Faeces

Faeces contain most of the pathogens in human excreta and are the main source for transmission of enteric infectious diseases and parasites. Therefore we should treat faeces based on the principles as below:

Keep the volume of dangerous material small by diverting the urine and not adding water to the faeces.

Prevent the dispersal of material containing pathogens by storing it in some kind of secure device (processing chamber, tank)

until safe for recycling.

Reduce the volume and weight of pathogenic material by dehydration and/or decomposition to facilitate storage, transport and further treatment.

Reduce pathogens to a harmless state by sanitization through primary treatment on site (dehydration/decomposition, increase in pH, retention) followed by secondary treatment on/off site (high temperature composting, increase in pH by the addition of lime or urea, and, if necessary, carbonization or incineration).

In properly maintained toilets, there will be no bad smell, wetness or fly breeding. The product is inoffensive and resembles soil, is light and easily handled without producing dust. However, these more pleasant aspects of the product should not be taken as proof of their safety and care should still be taken in handling the product. To further minimize risk, workers could wear gloves when emptying processing chambers or pits and bathe well afterwards – including careful hand washing. However, for a well-managed eco-toilet or processing chamber, pathogen counts should be considerably reduced after primary treatment.⁶

Chapter 3

ECO-SAN EXAMPLES

The purpose of this chapter is to show what eco-san may look like in practice, how eco-toilets function, and how they are operated. We present a number of examples, both ancient and modern. In its own context each of the examples does, to a certain extent, meet the criteria listed in Chapter 1: disease prevention, environmental protection, return of nutrients, affordability, acceptability and simplicity. All of the examples have a great potential for disease prevention and all of them protect the environment and conserve water. The variety of eco-san solutions available today makes it possible, in most cases, to find one that is culturally acceptable. Affordability is relative and while some of the systems described here are high-tech and expensive, others are simple and extremely low-cost.

The examples that follow are organized according to the type of habitat where they may have their main application: homesteads or municipal areas. ‘Homesteads’ here mean rural or low-density urban habitats where each household has direct access to a yard or garden and where the household itself is responsible for primary and secondary processing and end-use. Under ‘municipal areas’ we have grouped examples located in or suitable for medium- to high-density development and multi-storey apartment blocks. Here it is not necessary for each household to be directly involved in processing, transport and end-use. All operational and management procedures that take place outside the household’s own toilet room can be handled by some kind of community organization as described in Chapter 7.

3.1 Homesteads

3.1.1 *Dehydrating eco-toilets*

Vietnam

The classic example of an ecological sanitation system is the Vietnamese double-vault toilet. It is widely used in northern Vietnam and over the past 25 years the concept has also been introduced in a number of countries around the world, for example China, Mexico

and Sweden.

In northern Vietnam it used to be common practice to fertilize rice fields with fresh excreta. As this was a dangerous practice, in 1956 the health authorities started campaigns to construct double-vault dry toilets. The campaigns were followed by long and persistent health-education programmes. The objective of the new toilet design was to kill pathogens before the faeces were spread on the fields.¹

A precursor to the Vietnamese system was developed around 1950 at the Kanagawa Prefectural Public Health Laboratory in Yokohama.²

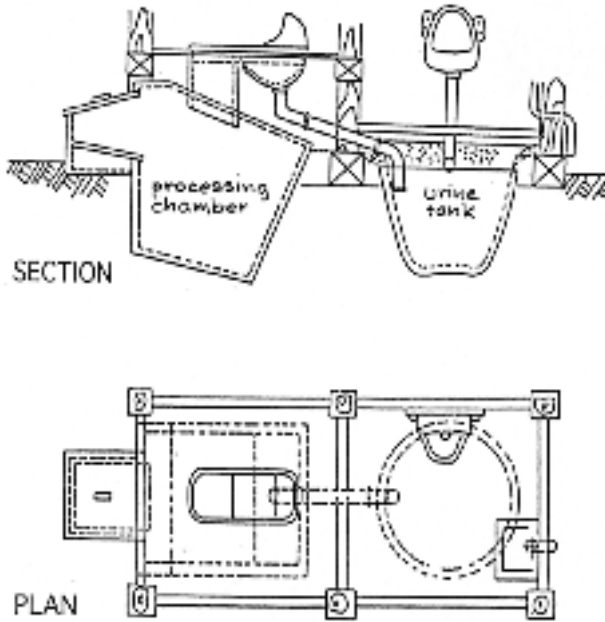


Figure 3.1 Section and plan of a urine diverting toilet ('Benjo') developed at the Kanagawa Prefectural Public Health Laboratory, Yokohama, Japan, around 1950.

The Vietnamese toilet consists of two processing chambers each with a volume of about 0.3 cubic metres. The toilet is built entirely above ground with the processing chambers placed on a solid floor of concrete, bricks or clay. The floor is built up to at least 10 cm above ground so that heavy rains do not flood it.

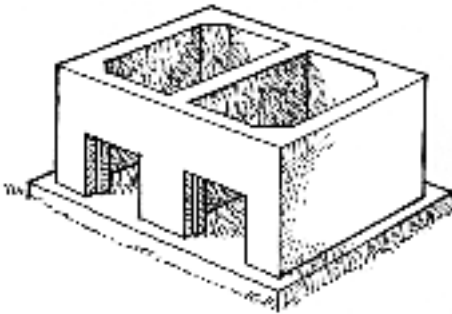


Figure 3.2 The processing chambers of the Vietnamese double-vault toilet. Each vault is 80 x 80 x 50 cm. The picture also shows the two 30 x 30 cm openings for removal of dehydrated material.

The processing chambers are covered with a squatting slab that has two drop holes, footrests and a groove for urine. Both holes have tight-fitting lids (not shown in Figure 3.3). At the back there are two openings, 30 x 30 cm, for the removal of the dehydrated material. These openings are kept sealed until it is time to empty one of the chambers.

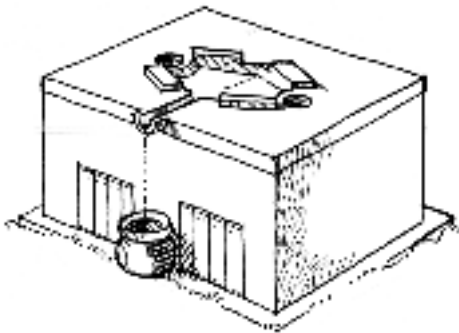


Figure 3.3 The processing chambers of Figure 3.1 provided with a squatting slab for urine diversion, a pot for collecting urine and doors for the two openings for removal of dehydrated material. The drop hole not in use should be closed with a stone and sealed with mud or mortar.

People excrete in only one chamber until it fills. Before the vault is used for the first time, the household members cover the floor with a layer of powdered earth. The purpose of this earth is to absorb moisture from the faeces and to prevent them from sticking to the floor. After each use people sprinkle two bowls of ashes over the faeces. The ashes absorb moisture, neutralize bad odours and make the faeces less attractive to flies.

Urine drains away through the groove in the slab and collects in a jar behind the toilet. Paper used for anal cleaning is dropped in a box or jar and burnt. Thus in the receptacle there are only faeces, ashes and soil. The contents are therefore fairly dry and compact. The jar for collection of urine can be placed in position either empty or partly

filled with water, lime or ashes. The urine or the urine-soaked ashes are used as a fertilizer.

The first vault can be used for about 4–5 months by a household of 4–6 persons. When it is two-thirds full, someone in the household levels the content with a stick. He or she then fills the vault to the brim with dried, powdered earth, and seals the vault. All openings are tightly closed with lime mortar or clay. The other vault now comes into use instead. When the second vault is nearly full, he or she opens and empties the first vault. The dehydrated faeces, now odourless, are used as fertilizer. The Nha Trang Pasteur Institute recommends a retention time of 6 months and in cool climates 10 months.³

In Vietnam the experience of this system is mixed. There is no doubt that it does function well when properly used. A problem in northern Vietnam used to be that some farmers emptied the processing chambers whenever they needed fertilizer, regardless of the retention time. This means that partly processed and even fresh faeces were occasionally spread on the fields. As a result of persistent health education this behaviour is nowadays less common.

China

In 1997–1999 modified versions of the Vietnamese double-vault dehydrating toilet were introduced in several provinces in China by the Sida-funded SanRes programme in cooperation with Unicef and the Chinese Ministry of Health.⁴ In Wucun town (Tianyang county, Guangxi province, southern China) the project (managed by the Provincial Health Bureau in Nanning under Ms Li Lingling and Mr Lin Jiang) covered 70 households in Dalu village.⁵ The toilets are placed indoors, usually on the second or third floor. Faeces drop through a 20 cm wide PVC chute down to a ground level double-vault processing chamber.

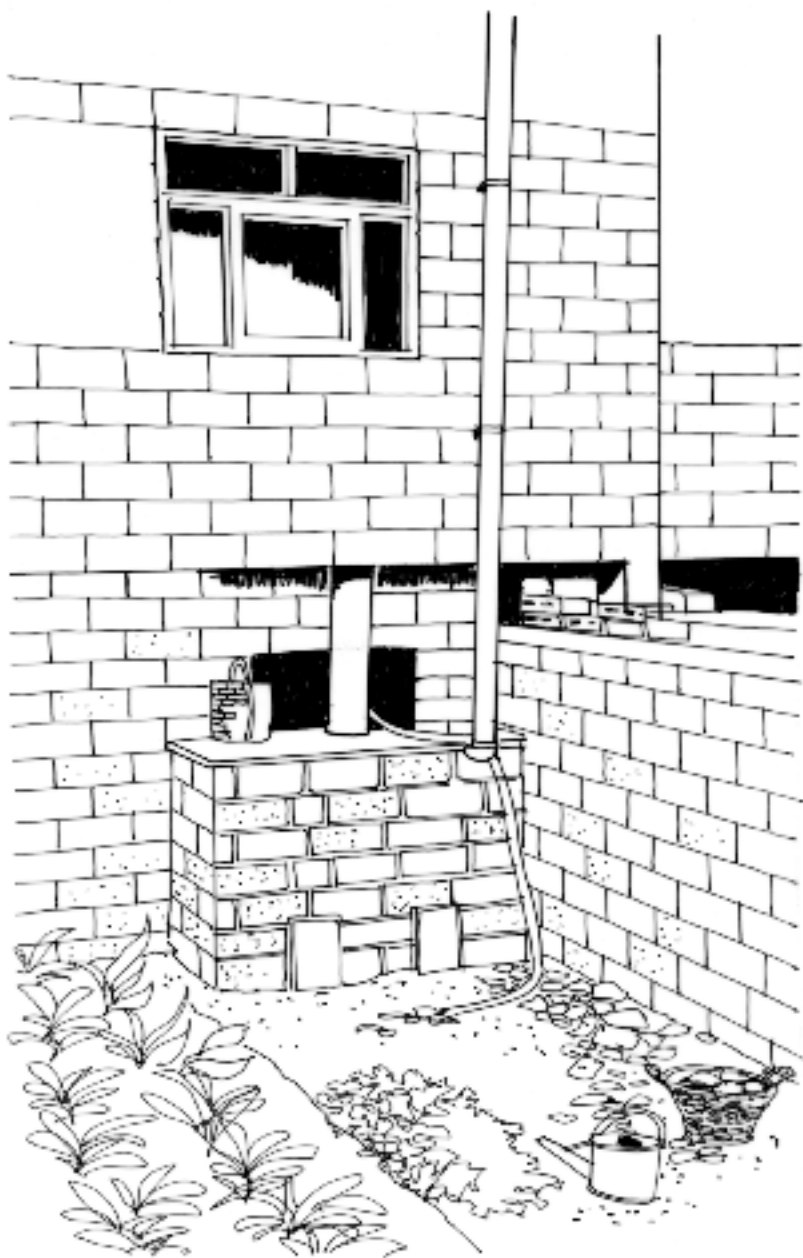


Figure 3.4 In Dalu village, Guangxi province, China, all households have placed the eco-toilet indoors and upstairs. Faeces drop through a chute into a double-vault processing chamber at ground level. (Design: Lin Jiang, Nanning, China, 1998).

A baffle, similar to the one shown in Figure 2.5, directs the faeces to one of the vaults. A specially designed squatting pan diverts the urine to a ground level collection point from where it is either fed to the household pigs or used as fertilizer in the household's own vegetable garden. A ventpipe extending above the roof of the building ventilates the toilet room via the processing chamber.

Following the success of the Dalu village pilot project the Yongning county party committee and government in Guangxi province decided to introduce eco-toilets in a comprehensive village environmental improvement programme.⁶ By the end of 2000, 45 villages with a total population of nearly 10,000 had introduced the 'eco-village' package, including double-vault eco-toilets with a urine diverting fibreglass squatting pan. School toilets have pedal-operated ash dispensers developed specifically for the programme (see Figure 4.11).⁷

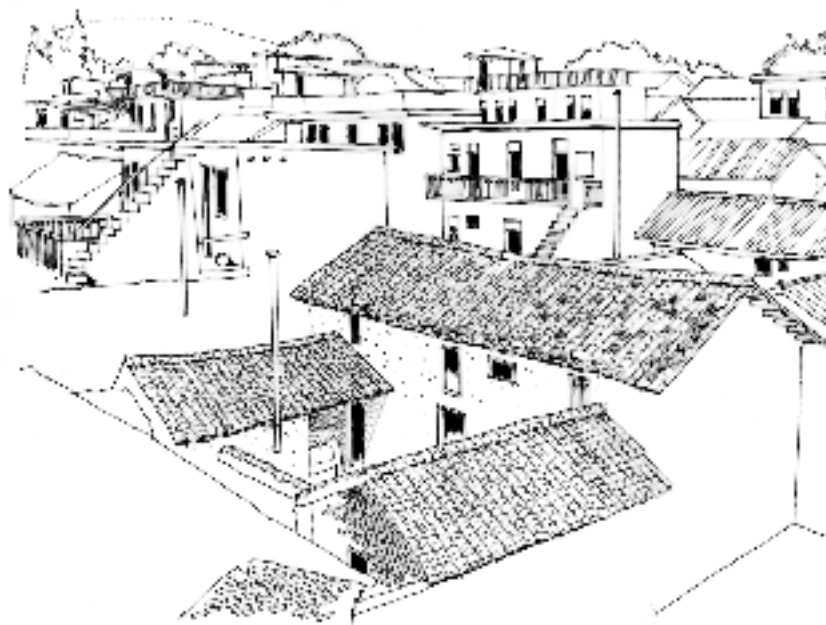


Figure 3.5 A compact village in Yongning county, Guangxi province, China, where every household has been provided with an eco-toilet.

Box 3.1 *The Yongning eco-village programme*

The success of the Yongning eco-village programme was, according to Mr Luo Daguang, County Magistrate, Yongning county, due to the following factors:⁸

- political leadership and sound administration;
- collaboration between government departments;
- strong technical guidance and effective use of demonstration models;
- effective mobilization of finance from central government, local government and villagers;
- building on tradition and actual living conditions, solving perceived problems;
- a comprehensive approach linking sanitation, health, agricultural production and domestic and economic improvement.



At the household level the actual construction costs for ecological sanitation are easy to calculate and can be remarkably low. In 2001 the total cost of materials for a typical eco-san toilet in Guangxi province was CNY 284 (= USD 35). This is only a third of the cost of a three-chamber septic tank or a biogas toilet.⁹ Private entrepreneurs in different parts of China now produce several models of urine-diverting squatting pans. The pans are made of plastic, fibreglass or porcelain and range in price from USD 5 to 10.

Figure 3.6 *The toilet rooms in the Guangxi province eco-san project have a high standard of finish: a prefabricated squatting pan and tiled floors and walls. (Design: Lin Jiang, Nanning, China, 1999).*

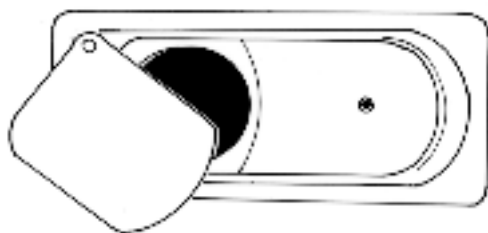


Figure 3.7 Squatting pan with urine diversion made of plastic. The lid can be pushed aside and closed with the foot. (Design: Lin Jiang, Nanning, China, 1999). This squatting pan is now mass-produced for use all over China and in neighbouring countries.

The development in Guangxi province in China is an example of the Vietnamese concept brought up to date. As the eco-toilets have a standard of finish equivalent to that of a modern urban bathroom and a ventpipe to reduce odours, most households in Guangxi prefer to place the eco-toilet inside the house. Following the success of the original pilot project more than 100,000 families in other parts of Guangxi province installed urine-diverting, ventilated, double-vault toilets inside their houses between 1998 and 2003.¹⁰ The total number of eco-toilets in China is estimated at 685,000 in 17 provinces (2003).¹¹

Central America and Mexico

The Lasf (Letrina Abonera Seca Familiar) is another modified version of the Vietnamese toilet. It was introduced into Guatemala in 1978¹² and over the past 25 years many thousands of units have been built in Central America and Mexico (see Figure 3.8).

Like the Vietnamese original, the Lasf toilet (in Mexico called Sanitario Ecologico Seco) consists of two chambers built above ground, each with a volume of about 0.6 cubic metres. A household of 5–6 persons will produce almost 0.5 cubic metres of dehydrated completely odourless material per year.

The experience of 25 years of use of the Vietnamese double-vault system in Central America and Mexico is positive. Properly managed, there is no smell and no fly breeding in these toilets. They seem to work particularly well in the dry climate of the Mexican highlands. Where the system has failed (wetness in the processing chamber, odours, fly breeding) it was usually due to non-existent, weak or bungled information, training and follow-up.

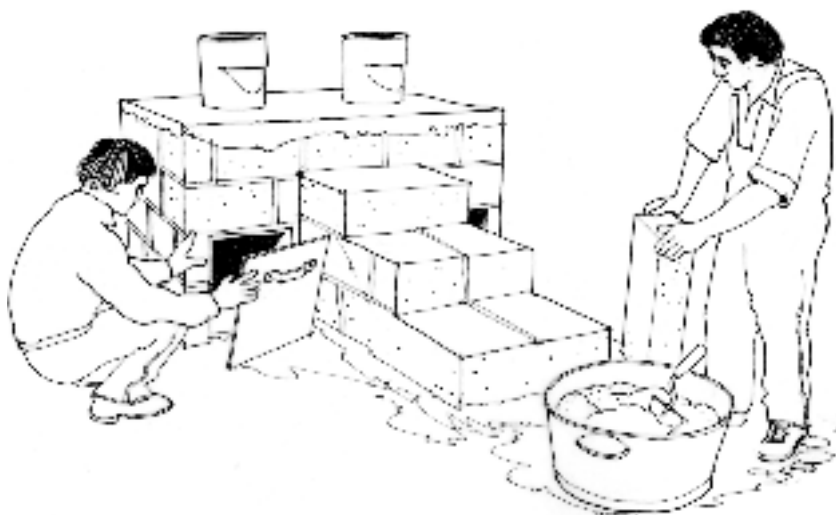


Figure 3.8 A Lasf toilet under construction in El Salvador. On top of each vault is a seat-riser with a urine collector. The seat-riser not in use is usually covered with a plastic bag.

3.1.2 Adaptations for ‘washers’

India and Sri Lanka

The Vietnamese double-vault toilet was developed for people who use paper, dry leaves etc. for anal cleaning (‘wipers’). In some cultures people use water instead (‘washers’) or a combination of solid material and water (‘wipe-washers’). In Kerala, India, a double-vault toilet similar to the Vietnamese one has been redesigned by Paul Calvert (EcoSolutions, Trivandrum, Kerala, India) to suit a population of washers. Not only urine, but also the water used for anal cleaning, is diverted, in this case into an evapo-transpiration bed next to the toilet.¹³

The vault is lined with straw before use. This provides a carbon-rich bed to receive the faeces and also absorbs moisture. A scoopful of ashes is sprinkled over the faeces after each use. Occasionally some straw, leafy material and paper scraps are also added, which means that there is a process of decomposition rather than dehydration. A reduction in volume of the vault contents confirms that decomposition is occurring. Each vault is in use for about a year. The toilet can be operated in both composting and desiccating modes, the choice de-

pending on local conditions and the type of residues available for covering the faeces.

The evapo-transpiration bed, depending on the space available, may also receive shower and kitchen greywater flows and requires little maintenance. This bed is often used for the production of flowers, fruits and vegetables, making beneficial use of the nutrients in urine.

A dry, above-ground toilet was chosen because this coastal part of Kerala has a high water-table and wells have been contaminated by seepage from pit and pour-flush toilets.¹⁴ The new system has been established in over 300 households in urban and rural areas in Kerala, many of them operating since 1995. The design has been replicated in other parts of India such as Madras, and success in India led to its introduction in Sri Lanka in 2000.¹⁵ Many of the toilets are built close to or attached to the house. There are also more refined examples inside urban homes which have been operating successfully since 2000 with the latest designs installed on the second floor of apartments. These toilets are built for the equivalent of between USD 80 and 150 depending on superstructure and standard of finish.^{16,17}

This example shows that a dry system of sanitation can work well in a humid climate where the users are washers. It also shows that the device (a double-vault toilet with urine diversion) that works in Vietnam by using dehydration can, with the addition of carbon-rich material work by using a decomposition process instead. The success to date is due to good mobilization of the local population, especially the women, and to effective hygiene education and regular follow-up.

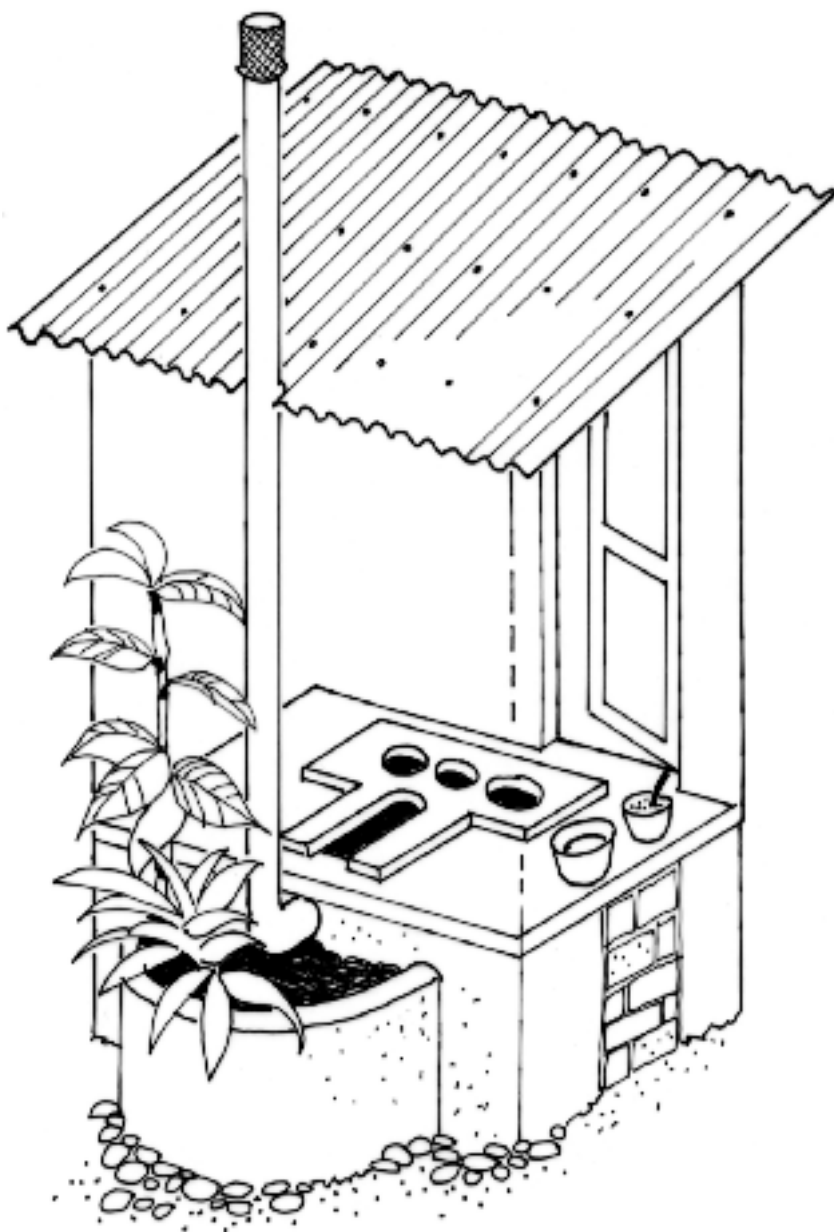


Figure 3.9 The Kerala double-vault toilet. Over each vault there is a drop hole for faeces and a funnel for urine. Between the two vaults is a trough over which anal cleaning is performed. (Design: Paul Calvert, EcoSolutions, Trivandrum, Kerala, India, 1994). The water used for anal cleaning and the urine flow into the evapo-transpiration bed planted with bitter melon, plantain or *Canna indica*.

Palestine

Another example of the Vietnamese double-vault toilet adapted to a washer culture (wipe-washers in this case) is from the Hebron area in Palestine. In this extremely hot-dry, water-starved area 28 households, many of them large (>10 family members) were provided with eco-toilets in a Sida-funded project managed by the Palestine Hydrology Group (PHG), Jerusalem, in 2001 and 2002.¹⁸

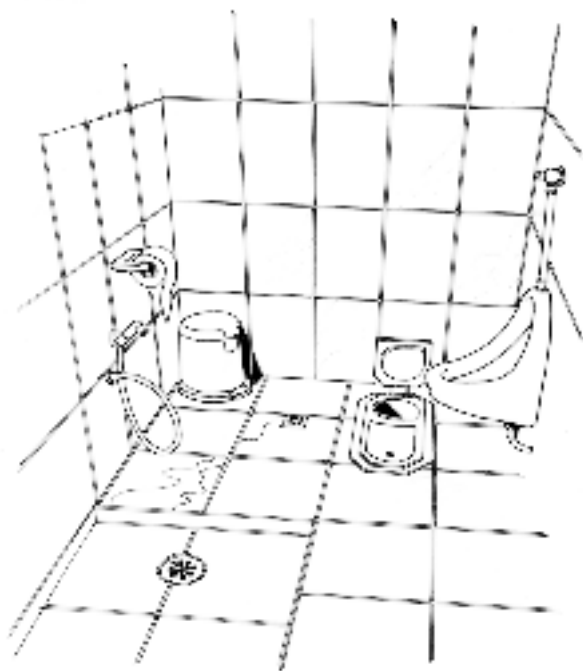


Figure 3.10 A typical toilet-bathroom in the PHG project, Beni Naim village, Hebron, Palestine. The lid of the squatting pan is open and the drop hole for faeces is visible. To the left of the urine diverting squatting pan is a drain for anal cleaning water. (Design: Yousef Subuh, Beni Naim, West Bank, Palestine, 2000). The low shower on the left is for anal cleaning. On the right is a urinal.

The eco-toilets in this project consist of a squatting pan for urine diversion, a drain for water from anal cleaning, a urinal, and below the floor a processing chamber with access door and ventpipe. The toilet is thus designed to handle three separate streams: faeces, anal cleaning water and urine.

Toilets on upper floors have a chute down to the single processing chamber. The faeces are collected in a wide, low plastic container. When one is full, an empty container is placed under the drophole

and the full container is stored in the processing chamber until the second container is full.

Operation and maintenance are facilitated by the extremely dry climate of the Hebron area, the good availability of lime as an additive, and the high standard of finishing of the toilet rooms. The total cost of each unit in 2002 was in the range USD 700–1000.

This small, well-conceived, high standard project shows that ecological sanitation could be a serious sanitation alternative for Palestine.

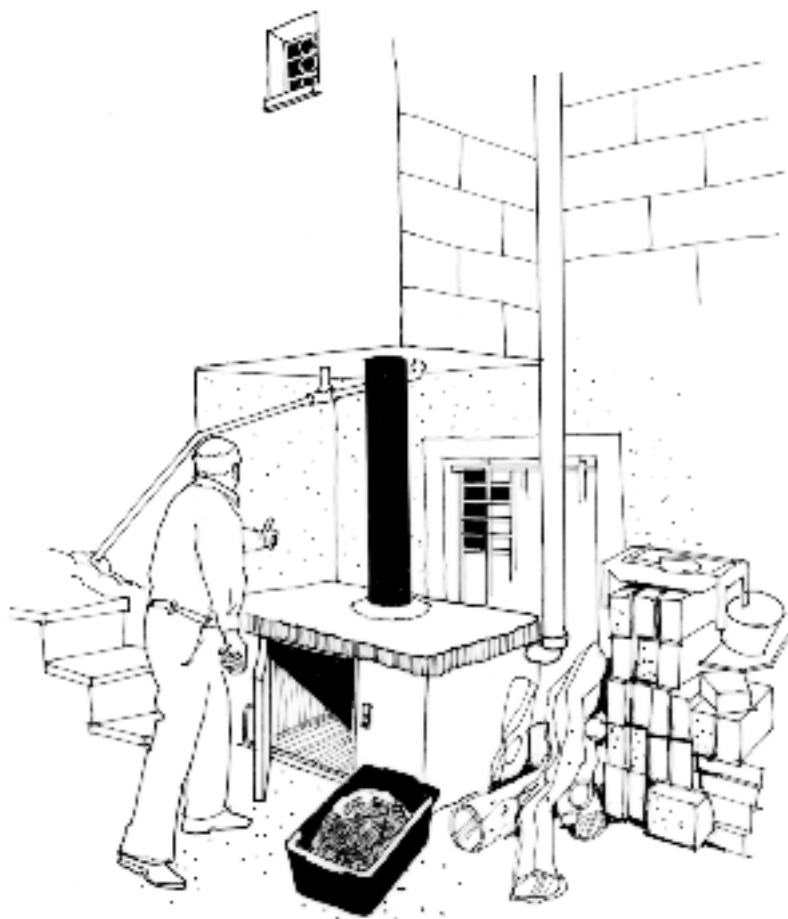


Figure 3.11 Processing chamber with PVC chute from first floor indoor toilet, West Bank, Palestine. Urine, water for anal cleaning and greywater are treated in a septic tank.

3.1.3 Composting toilets

Sweden

Composting toilets for use in weekend houses were introduced in Sweden more than 50 years ago. Since then a wide variety of models have come on the market and they are now used in different parts of the world, including North America and Australia. Commercially available composting toilets range from small units, about the size of a standard flush toilet fixture, to larger ones that utilize a simple toilet pedestal in the bathroom connected by a drop chute to a composting vault below the floor.

The example shown below is the classic model, 'Clivus', developed by Richard Lindström, Täby, Stockholm.¹⁹ It is a single-vault composting toilet with combined processing of urine, faeces and organic household residues. It consists of a composting vault with an inclined floor, air conduits and at the lower end a storage space. A tube connects the toilet seat-riser with the processing chamber and there is sometimes a special chute for kitchen refuse. There is a constant draught due to natural convection from an air intake in the composting vault, through the air conduits and out via a ventpipe.

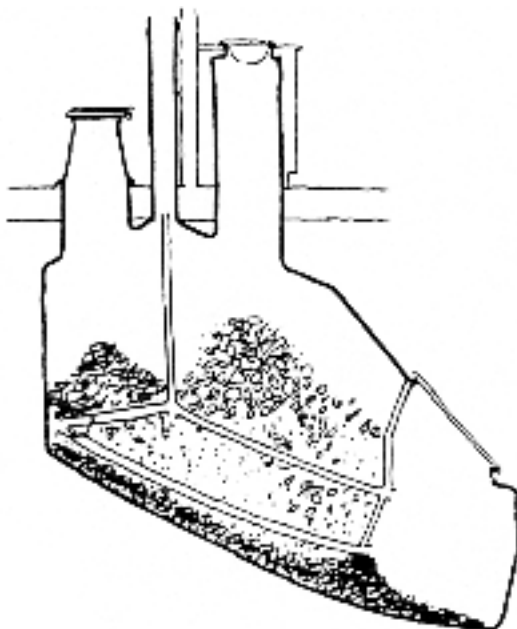


Figure 3.12 A composting toilet placed in the basement of a house. This model – 'Clivus', the classic model – has a separate chute from the kitchen for food left-overs etc. Perforated pipes bring air into the centre of the compost pile.²⁰ (Design: Ricard Lindstrom, Tyreso, Sweden, around 1940).

Into the processing chamber goes not only faeces, toilet paper and urine but all kinds of organic kitchen and household residues: vegetable and meat scraps, peelings, bones, eggshells, floor sweepings, sanitary napkins and grass clippings (but not cans, glass, plastic or large amounts of liquids of any kind).

Because the floor of the processing chamber slopes, the contents are supposed to slide slowly from the upper end down to the storage part of the vault. The process of decomposition reduces the heap to less than 10% of the original volume.

The heap gradually becomes humus: a black, lumpy substance similar to good garden compost. It may take several years until a household has to take out the humus for the first time. After that they may have to remove it once a year. The amount of humus produced varies from 10 to 30 litres per person per year. (The large part of the receptacle is never emptied. Only material that has passed under the partition separating the storage vault from the rest of the receptacle is removed.)

The maximum number of users depends on factors such as temperature, humidity, amount and type of refuse, proportion of urine to faeces, and volume of the receptacle. In most cases the maximum for one Clivus (the classic model in Figure 3.12) in regular, year-round use is 8–10 people.

If the classic model of the Clivus Multrum is properly built and well looked after it can be reasonably nuisance free. But frequently there are problems: liquids accumulate at the lower end of the composting vault, these liquids will carry pathogens from fresh faeces at the top of the pile and contaminate old, already decomposed material at the bottom. (This problem could be avoided if the Clivus was fitted with a urine diverting seat-riser.) Another problem is that the solids often get stuck halfway down the incline. This problem can be avoided if instead of one vault with an inclined floor there are several chambers, as in the following example.

Norway

The Norwegian ‘Carousel’ has long been one of that country’s most popular composting toilets, and about 60,000 units have been installed around the world since 1973. Similar types are also manufactured in other countries.²¹

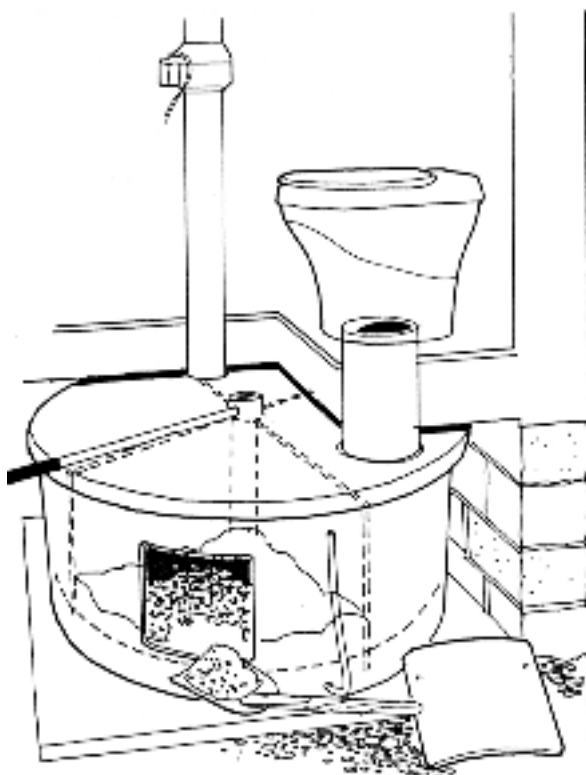


Figure 3.13 The 'Carousel' composting toilet from Norway.

The design of the Carousel features a below-the-floor processing vault consisting of a cylindrical outer tank in which a slightly smaller inner tank is able to rotate on a pivot. The inner tank is divided into four chambers (six on some models). The one in use is positioned directly below the drop chute from the toilet in the bathroom. When a chamber is filled, the inner tank is rotated so that the next chamber is positioned below the toilet. In this way each chamber is filled in sequence. The material in the oldest chamber is removed through an access door. Liquid drains through holes at the bottom of the inner tank into the outer one, where it may be collected in a separate container, discharged into an evapo-transpiration bed or evaporated.

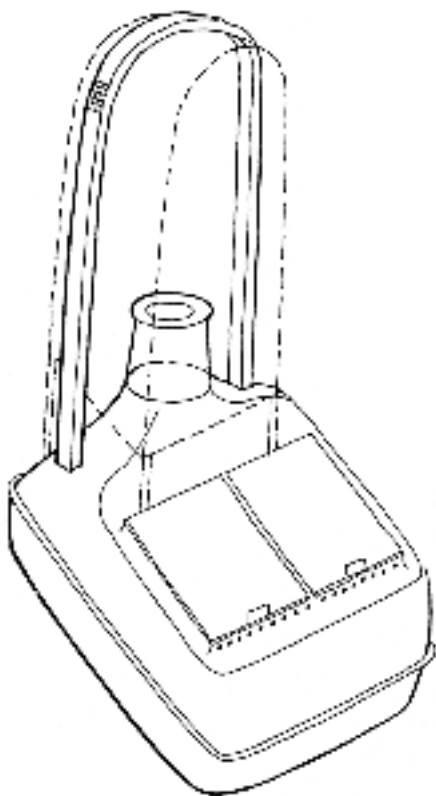
The Carousel can be equipped with either a urine diverting or with a non-diverting seat-riser. Several different size units of varying capacity are available at prices between NOK 14,000 and 20,000 (USD 2000–2800).

Mexico

A prototype double-vault, solar-heated composting toilet was originally developed by Uno Winblad in Tanzania in the mid-1970s and further developed in the early 1980s together with Josefina Mena and Grupo de Tecnología Alternativa in Mexico. Prefabricated fibreglass and polyethylene models (called ‘Sirdo Seco’) have been in production since 1987.

Like the Vietnamese toilet, this Mexican design has a receptacle divided into two chambers. Above the dividing wall there is a baffle directing the excreta into one of the chambers. When that chamber is full, the excreta are directed into the other chamber (see Figure 2.6). Single-vault models are also available.

The processing chambers extend outside the superstructure and have lids that are also simple solar heaters. If the lids face the sun the evaporation from the chamber and the temperature of the surface of the compost pile will increase.



The prices of a prefabricated seat-riser and solar-heated processing chambers range from MXN 2500 to 3100 (USD 227 to 282) depending on model and of a prefabricated superstructure from MXN 2072 to 2485 (USD 190–226).

Figure 3.14 The ‘Sirdo Seco’ double-vault, solar-heated composting toilet in Mexico. The whole toilet, including the superstructure, was originally made of fibreglass but since 1996 has been made of rotomolded polyethylene.²² (Design: Josefina A. Mena, Mexico City, 1987).

This solar heated composting toilet has been used with good results in Mexico for 20 years. One particular advantage with the lightweight, prefab model is that it is mobile. People living in squatter settlements can be evicted at short notice. If this happens they can arrange to have the toilet emptied and take it with them like a piece of furniture.

Box 3.2 *The Centre for Clean Development (CCD) toilet in Micronesia*

A prototype of the CCD design constructed out of concrete blocks in 1992 by Greenpeace and local participants on the island of Yap in the Federated States of Micronesia was used regularly by four adults and three children for one year. Four slightly modified units were then built by CCD in 1994 on the island of Pohnpei for use by individual families of from 6 to 12 people. Periodic visual inspection indicated that solids in the digestion vault had undergone biodegradation, and that all excess liquids had been evaporated. In all cases the users expressed satisfaction with the toilets and reported no foul odours. This is specially noteworthy given the humid climate of Pohnpei, where the average rainfall is nearly 5000 mm per year. As of May 1997 all four of the CCD toilets were reported to be functioning well based on visual inspection and interviews with the owners by a member of the project team. Remarkably all but one of the demonstration units had gone more than 2 years before switching over to the second digestion vault, indicating greater than expected capacity. The Federated States of Micronesia national government is currently building at least 40 more units in Pohnpei and the state's environmental agency has indicated its intention to require their use in environmentally sensitive areas.

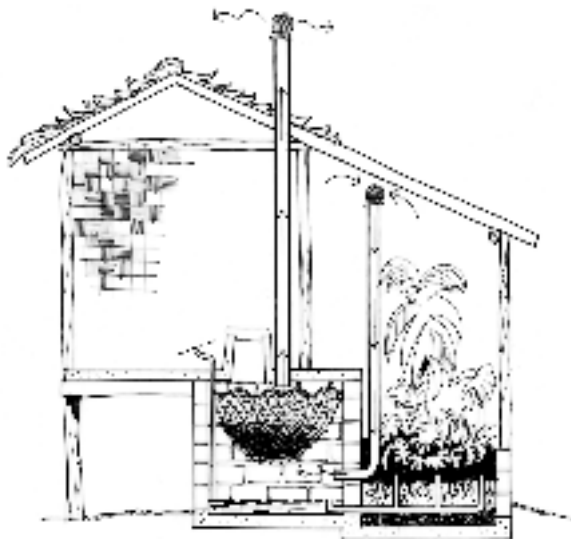


Figure 3.15 *The CCD composting toilet with attached greenhouse and evapo-transpiration bed (Design: David Del Porto, Concord, Mass., USA, 1992).*

3.1.4 Soil composting sanitation systems

Ladakh, India

Ladakh is a dry highland region in the western Himalayas at an altitude of 3500 metres. Most traditional houses have an indoor toilet on the upper floor (see Figure 3.16). Due to an extremely dry climate it is possible to process human excreta indoors without prior diversion of urine, by using a combination of soil composting and dehydration.

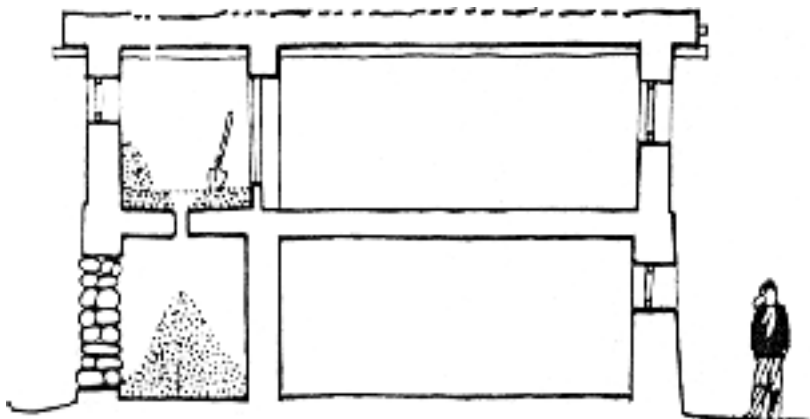


Figure 3.16 Indoor, traditional dehydrating toilet in Ladakh, India.

On the floor of a small room next to the kitchen/living room there is a thick layer of soil from the garden. In the floor a drop hole leads to a small ground-floor room. This room can only be reached from the outside. People excrete on the soil which is on the floor. Then they push soil and excreta together down the drop hole. Urine goes the same way. Ashes from the kitchen are added from time to time. The household members bring loads of soil into the room when necessary. For the long winter (September–May) a supply of soil is piled into one corner of the toilet room upstairs. A spade or shovel is also kept in the room. Normally there is no anal cleaning. The decomposed excreta are removed in spring and again at the end of summer and spread on the fields.

As long as the toilet is well maintained and enough soil is pushed down the drop hole every day, there are no odours. In some cases there might be a faint smell of ammonia from urine splashed on the soil-covered floor of the toilet room. There is no fly breeding due to the dryness of the soil/excreta pile. The system has worked well in rural areas for hundreds of years but in recent years there have been

some problems in the central part of the town of Leh where households have no easy access to soil.²³

Box 3.3 *Nineteenth century earth closets*

During the second half of the nineteenth century there was a fierce contest in Britain between those who favoured water closets and those who favoured earth closets. The first patent for an earth closet was taken out in 1838 by Thomas Swinburne but his device was not widely adopted. The breakthrough came quarter of a century later with the work of Henry Moule. He experimented by burying the contents of his own household bucket toilet in the garden. He discovered that in 3–4 weeks there was no trace of the buried material. Moule went on to design a toilet that deposited a controlled amount of earth on the fresh faeces from a hopper behind the seat-riser. He went on to establish the Moule Patent Earth-Closet Company Ltd and developed luxury models as well as ones designed for barracks, schools and hospitals. Various other inventors patented semi-automatic devices to flush the toilet with earth when the pressure on the seat was released or when a foot pedal was pressed.

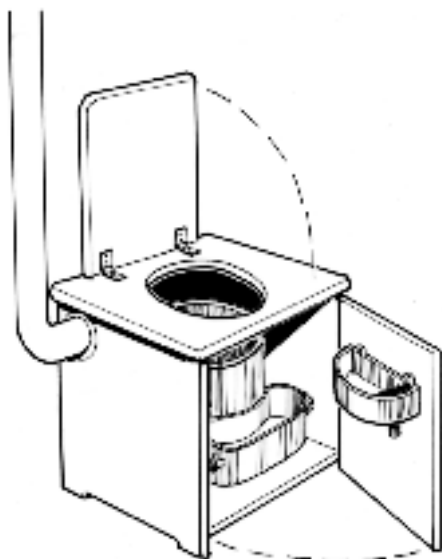


Figure 3.17 *Henry Moule's earth closet, around 1860.*

Henry Moule was an effective publicist and used pamphlets to promote the advantages of earth-based sanitation and the insanity of waterborne sanitation. In 1861 he published a pamphlet called 'National Health and Wealth' which generated widespread support. *The Lancet* of 1st August 1868 reported that 148 of his toilets were used by a military encampment in Wimbledon, London. Forty of them were used daily by 2000 men without any annoyance of odour. In 1860 a number of schools switched from water closets to earth-closets because they were considered more reliable and cheaper to maintain.²⁴

Zimbabwe

By applying the eco-san approach to traditional pit-toilets Peter Morgan in Zimbabwe has developed a series of low-cost eco-toilets based on soil-composting. He calls them the 'Arborloo', the 'Fossa Alterna' and the 'Skyloo'.²⁵ They are intended for use in warm climates.

The Arborloo consists of a shallow pit covered with a squatting pan (see Figure 2.3). Urine and faeces are deposited into the pit and covered with soil after each deposit. The composting process is improved if some wood ash and leaves are also added. The approximate mixture of ingredients is 50% excreta and 50% additions (soil, ash, leaves). When the pit is nearly full, the slab and structure are removed and the pit is topped up with additional soil.

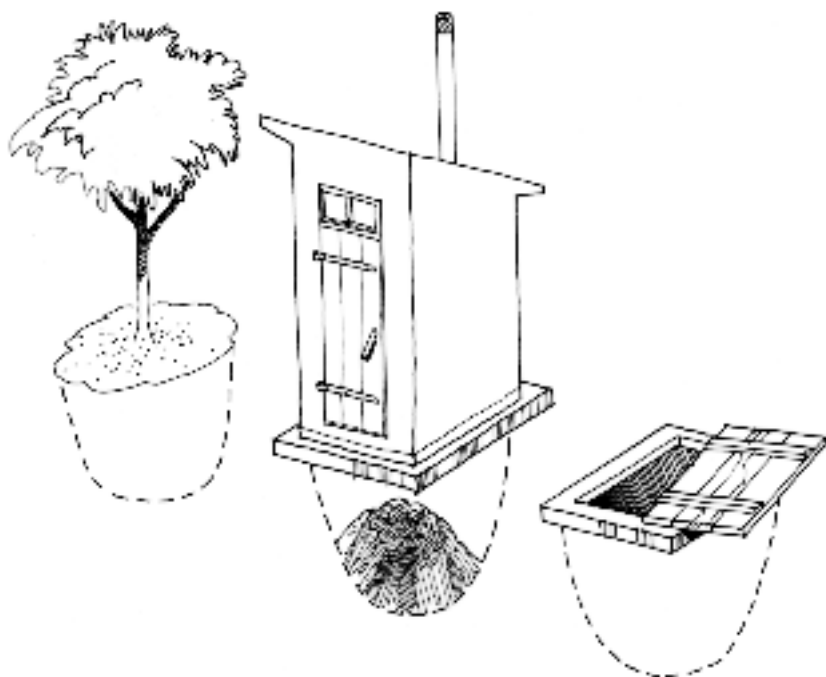


Figure 3.18 *The Arborloo in Zimbabwe. When the first pit is full a tree is planted in it. The superstructure is moved to a new pit and the process repeated.*

The soil is lightly watered and a tree is planted in the top soil that has been added to the pit. The roots of the young tree grow in the plain top soil at first, invading the mix below as it turns into humus. The idea is to use one shallow pit for between 6-12 months, plant a tree, and then move to the next site and repeat the cycle. Each 6-12 months a new pit is added and a new tree is planted, thereby gradually creating an orchard or woodlot.

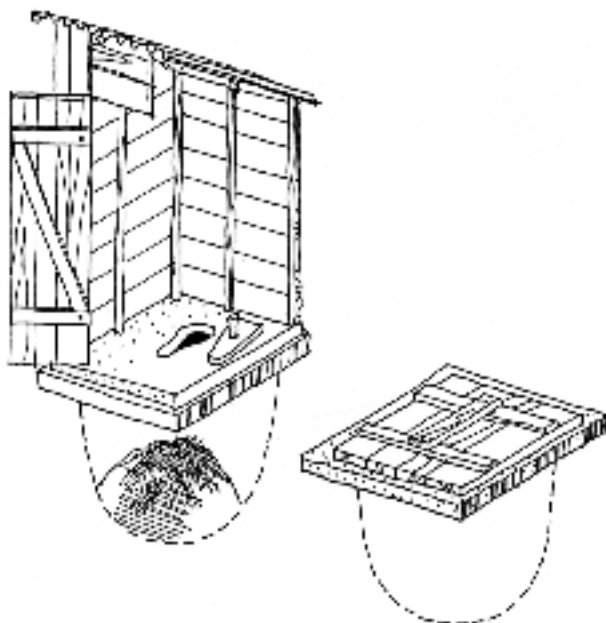


Figure 3.19 *The Fossa Alterna in Zimbabwe. Two shallow pits are dug. When one pit is full the other one is used. When the second is full the first pit is emptied and the contents used as fertilizer/soil-conditioner in the household garden.*

The Fossa Alterna works on a similar principle and consists of two shallow pits dug at the same time and close to one another. One is covered and the other is used for about a year as a shallow pit toilet. As with the Arborloo, urine and faeces are deposited into the pit and covered with soil after each deposit. The regular addition of wood ash and leaves into the pit is also recommended as this produces a better end product. When the used pit is nearly full, the slab and structure are removed and placed on the second pit and the first is topped up with additional soil. After a second year, both pits are full.

The older one is opened and the contents, which have changed into a soil rich in nutrients and soil micro-organisms, are removed. This soil

can be mixed with poor topsoils to considerably enhance their fertility (see also Chapter 5). The toilet slab and structure are then placed back on the original pit. Organisms in the soil break down the excreta and the toilet paper. Peter Morgan recommends that the pit soil is allowed to compost for at least a year before removal.

The Skyloo is a urine diverting system using a single shallow vault in which a removable container, such as a bucket, is placed to collect faeces, toilet paper and a mix of soil and wood ash, which is added after every defecation. Urine is diverted as in the Vietnamese-type toilets described earlier in this chapter. The contents of the bucket are removed at intervals and placed in a secondary composter – a jar or shallow pit where more soil is added and the mix kept damp. A nutrient-rich humus is formed in the secondary composter within months. The secondary composter linked to the Skyloo is normally designed for a retention time of 6–12 months.

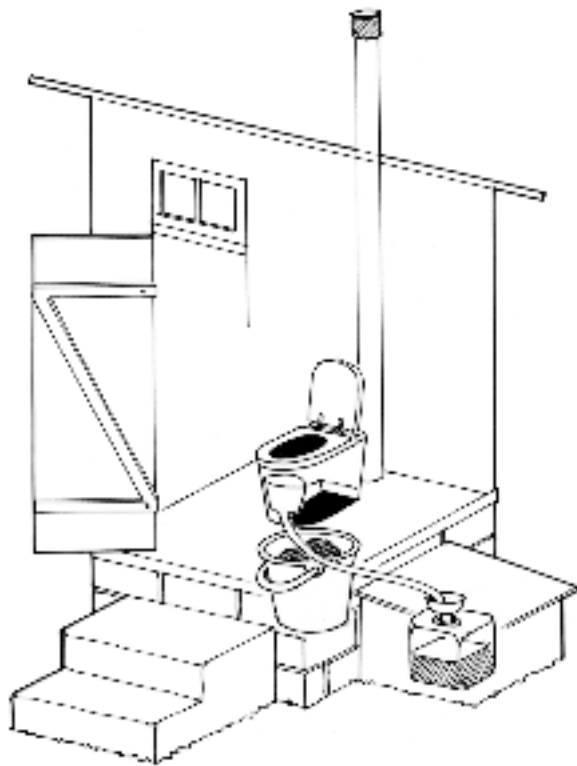


Figure 3.20 *The Skyloo in Zimbabwe. The urine-diverting pedestal directs urine into a pipe which is led to a urine storage container. The faeces drop directly into the bucket in the vault. The users add dry soil and wood ash after every visit.*

3.2 Municipal areas

3.2.1 Double-vault dehydrating eco-toilets

El Salvador

In Mexico and Central America there are many contemporary examples of the urban use of double-vault dehydrating toilets. One example is in El Salvador: Hermosa Provincia is the name of a small, densely built up low-income barrio in the centre of San Salvador. Water is scarce, plots are small and the subsoil is hard. Here all the 130 households built Lasf toilets in 1991. As there is little space between the houses and often no backyards, the Lasf toilet (see 3.1.1 – Central America and Mexico) is usually attached to the house, sometimes even placed inside the house.

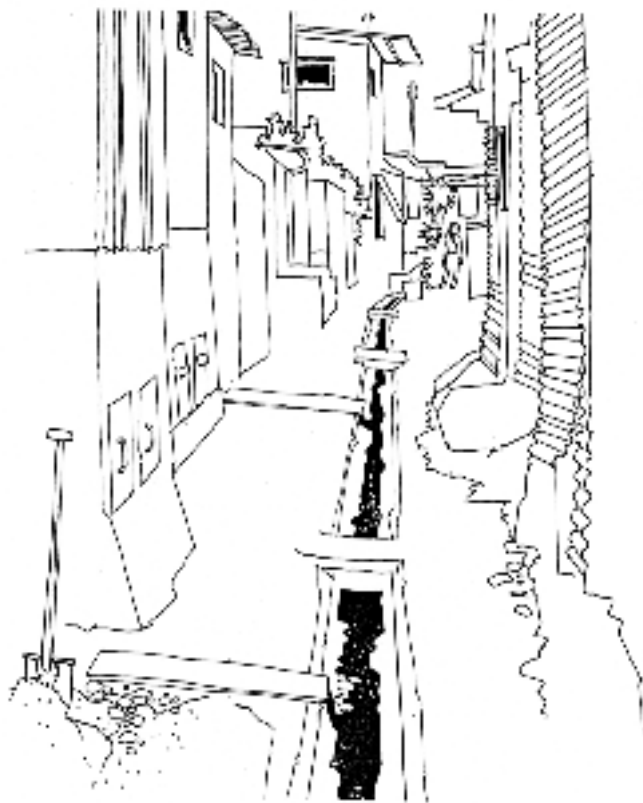


Figure 3.21 A street in Hermosa Provincia, a high-density squatter area in the centre of San Salvador. Each household has its own Lasf toilet, most are attached to, or placed inside, the house.

All the units in Hermosa Provincia were 6 years later still functioning extremely well thanks to a high level of community participation. There were no bad odours from the toilets and no fly-breeding in the processing chambers. The dry mixture from the toilets was used to reclaim wasteland or put in bags and sold.

UN-Habitat estimates that the global number of slum dwellers will increase to about 2 billion in the next 30 years, if no firm and concrete action is taken.²⁶ The Hermosa Provincia example shows that an eco-san system can be successfully used in a poor, high-density, inner-city squatter area ('slum').

Mexico

César Añorve in Mexico has spent the past 20 years promoting the Vietnamese sanitation system. His version of the Vietnamese toilet is a high-standard, in-house solution: a moveable, urine-diverting seat-riser made of fibreglass or concrete (see Figure 2.2).

The 2004 price of a seat-riser plus a urinal in polished concrete is the equivalent of MXN 506 (USD 46). The price of seat-riser and urinal in fibreglass is MXN 1150 (USD 105).

Sweden

A Swedish adaptation of the Vietnamese double-vault dehydrating toilet was developed by professor Mats Wolgast about 20 years ago. Urine is flushed to an underground storage tank with a small flush of water (about 0.1 litre). The volume of the tank is usually 0.5 cubic metres per person. The tank is periodically emptied and the urine transported to a farm for use as fertilizer. Faeces and toilet paper drop down into an insulated vault where they are collected in an 80 litre plastic container. There is a fan to draw air from the bathroom, down the toilet to the processing vault and out through a ventpipe.

When the container is full (after 2–3 months) it is put aside and an empty container is placed under the toilet. The full container is left in the vault for about 6 months. The dehydrated contents can then be further treated (secondary treatment) in a ventilated compost bin (see Figure 2.4), carbonized or incinerated.

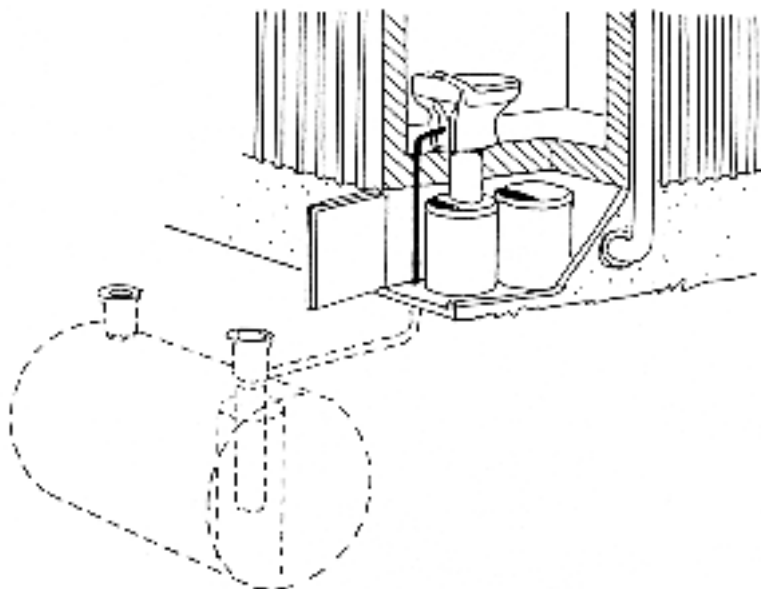


Figure 3.22 A dehydrating toilet installed inside a house in Sweden. Faeces and toilet paper are dropped in a large bucket. Urine is piped to an underground storage tank. (Design: Wost Man Ecology AB, Stockholm, Sweden, 1991).

The retail price of the porcelain toilet seat-riser with urine diversion was in 2004 about SEK 3000 (USD 450). The total on-site cost for a toilet like this (seat-riser, fan, processing vault, transport container and a 1000 litre urine tank) is in Sweden SEK 7000–10,000 (USD 1000–1400).

There are at present about 3000 units installed in Sweden: in week-end houses, permanent houses, apartments, industries and institutions.

3.2.2 Long-drop dehydrating

Yemen

In the old parts of the city of Sana'a, as in other Yemeni towns, the traditional houses are tall, rising five to nine stories from narrow streets. A house is usually occupied by one extended family. Each upper floor has one or two toilet-bathrooms next to a shaft (a long, narrow vertical passage). Figure 3.23 shows how this shaft runs from the top of the house to the level of the street.

Each bathroom has a toilet. The urine drains away from the squatting

slab to a groove in the stone floor. From there it goes through an opening in the wall of the house, down a vertical drainage surface on the outer face of the building. The urine evaporates on its way down the drainage surface. The faeces drop through the squatting-hole, down the shaft, to a vault at street level from where the dried faeces are periodically collected, further dried on the roof of the neighbourhood public bathhouse and finally used as fuel for heating water.

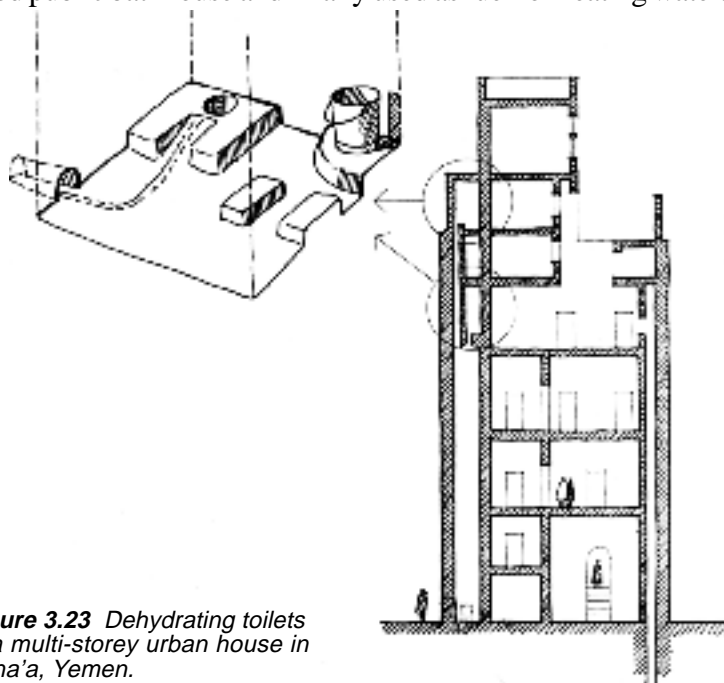


Figure 3.23 Dehydrating toilets in a multi-storey urban house in Sana'a, Yemen.

Anal cleaning takes place on a pair of square stones next to the squatting slab. The water used for anal cleaning as well as bath water is drained in the same way as the urine. No liquids are thus led into the long-drop shaft or the vault below. As Sana'a has a hot, dry climate, the faeces quickly dry out.²⁷

Next to the toilet there is, during morning hours, a charcoal fire in a bucket. After anal cleaning with water, the Yemenites dry themselves by squatting over the bucket.²⁸

This is an example of the eco-san approach to sanitation applied to an urban situation with multistorey housing and communal collection of dehydrated faeces by special staff. It is also an example of a dry sanitation system used in a culture where people are washers. It has been successfully used in the towns of Yemen for hundreds of years.

There is no smell and no fly-breeding. Urine and cleaning water are evaporated. Faeces are sterilized in three steps: first dehydrated on site, then further dehydrated and subject to direct solar radiation at the public bathhouse, and finally reused as fuel. In modern times this age-old system has been replaced by flush toilets. As a result of increased water consumption the water-table in Sana'a is falling by 6 metres a year. The World Bank expects Sana'a to exhaust its remaining water supply by 2010.²⁹

Sweden: Gebers, Stockholm

A modern version of the long-drop dehydrating system was built on the outskirts of Stockholm when in 1998 a housing cooperative rebuilt a vacated multi-storey nursing home, Gebers, and turned it into 32 apartments. One of the ambitions of the housing cooperative was to recycle all the nutrients of the human waste to agriculture. The system has now been in use over 6 years and is working well.³⁰

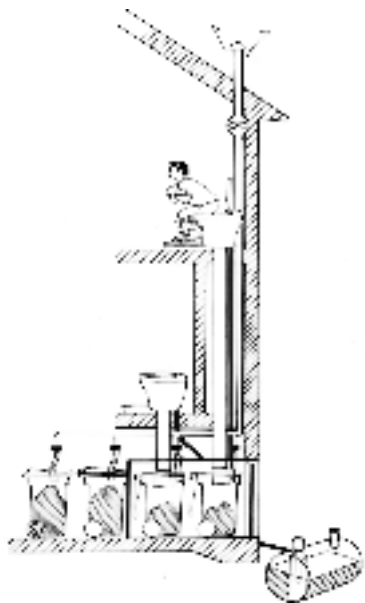


Figure 3.24 *Gebers housing cooperative in Stockholm – an example of adapting an eco-san system to an existing building. (Design: Anders Schonbeck, Lysekil, Sweden, 1996).*

China: Erdos, Inner Mongolia

A solution similar to the one used at Gebers in Stockholm is now being tested in a large pilot eco-san project in Erdos Municipality, Inner Mongolia, China (see 8.1.4). About 2000 apartments and houses under construction (2004–2006) are being provided with dehydrating, urine-diverting toilets and local greywater treatment based on a communal system of collection and management.

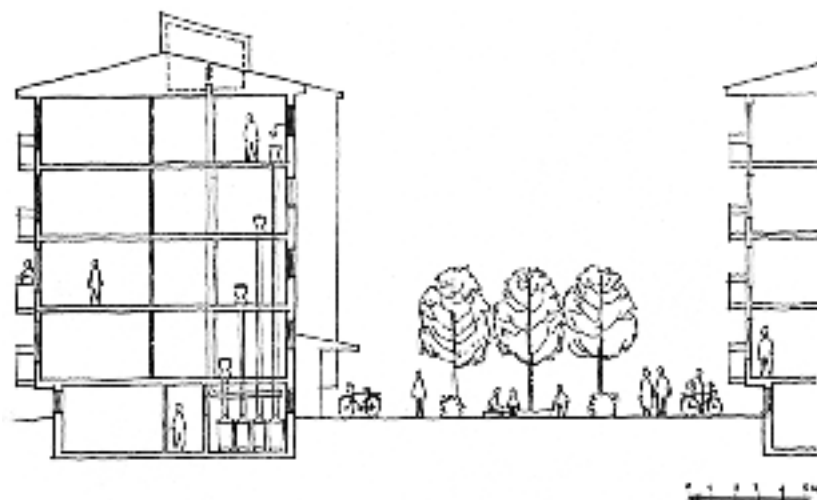


Figure 3.25 Urine diverting long-drop toilets in multi-storey blocks of flats, China-Sweden Erdos Eco-Town Project, Erdos Municipality, Inner Mongolia, China. The toilet, produced in China, is specially designed for multi-storey buildings. (Design: Uno Winblad and Karl Rydberg, Stockholm, Sweden, 2004).

Primary treatment of faeces (dehydration, pH increase, retention time) is in moveable processing chambers placed directly under the chute from each toilet. The processing chambers (bins on wheels) will periodically be collected by the municipal staff and transported to a neighbourhood eco-station for secondary treatment. Urine is piped from the toilet to a temporary storage tank in the basement of the building and greywater is treated on site in a vertical soil filter before it is percolated to the groundwater.

3.2.3 Small flush – composting/biogas

Sweden: Ekoporten, Norrköping

In 1996 the municipal housing company in the Swedish town of Norrköping renovated an existing apartment building. The objective was to test new technical solutions for resource-saving and recycling. The apartment building was originally constructed in 1967 and is fairly typical for this period. It has 18 apartments on three floors plus a top floor with communal rooms for study and recreation.



Figure 3.26 'Ekporten' in Norrköping, Sweden, as it looks today. This is a four-storey building with 18 modern, high-standard apartments, rebuilt and retrofitted with ecological sanitation systems for handling urine, faeces, organic kitchen left-overs and greywater. (Design: Krister Wiberg och Johan Morling, FFNS, Stockholm, Sweden, 1994).

The toilets are designed for urine diversion and with a small flush for faeces removal. Urine is piped into underground tanks and later used as fertilizer by local farmers.

Faeces are separated from flush water in an 'Aquatron' separator (see 4.3.2) and then composted in an automatic composting device together with paper-, kitchen- and garden-waste and wood pellets. The compost product is used by the tenants in vegetable and flower cultivation.

The flush water separated from the faeces in the Aquatron is treated with ultraviolet radiation for disinfection. The flush water is then, together with the greywater, collected in a three-chamber septic tank. From there it is channelled into a reedbed where the plants take nutrients from the water before it is discharged into a small stream.³¹

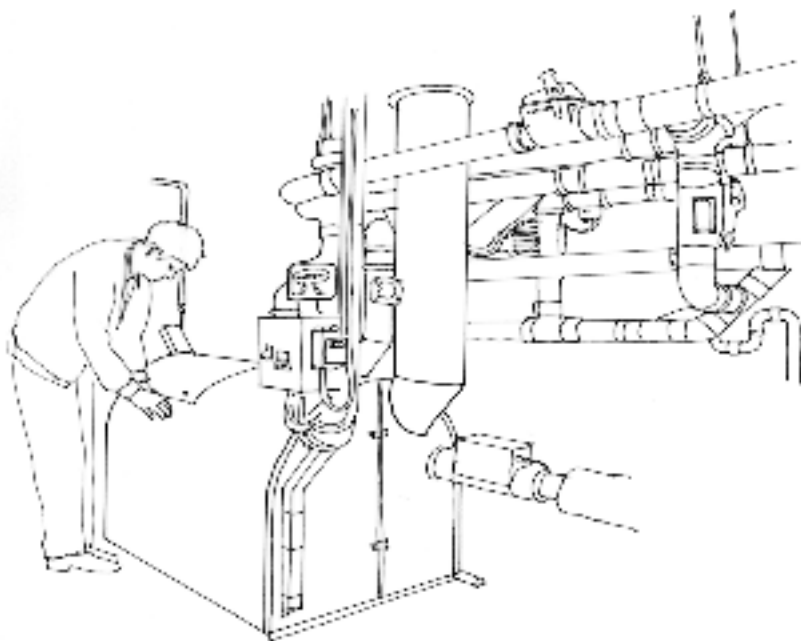


Figure 3.27 A composting machine serving the 18 apartments in 'Ekoporten'.

Germany: Flintenbreite, Lübeck

An integrated sanitation concept with vacuum toilets and a biogas plant for blackwater and kitchen refuse has been included in a housing project in the new suburb of Flintenbreite in Lübeck, Germany. The settlement has around 350 inhabitants on 3.5 ha and is a pilot project to demonstrate an example of sustainable sanitation in urban areas. It has been designed by Otterwasser GmbH in cooperation with the Lübeck city council.

The system in Lübeck consists of three water-treatment systems for: (a) blackwater and kitchen refuse, (b) greywater and (c) stormwater. The system involves vacuum toilets (0.7 litres/flush), vacuum blackwater transport, and anaerobic treatment with co-treatment of solid biowaste in a biogas-plant. The output is liquid fertilizer for use in agriculture and biogas for heat and power generation in combination with natural gas. Decentralized treatment of greywater takes place in artificial wetlands (bio-sandfilters). Stormwater is partly collected for reuse; svaes take care of retention and infiltration.

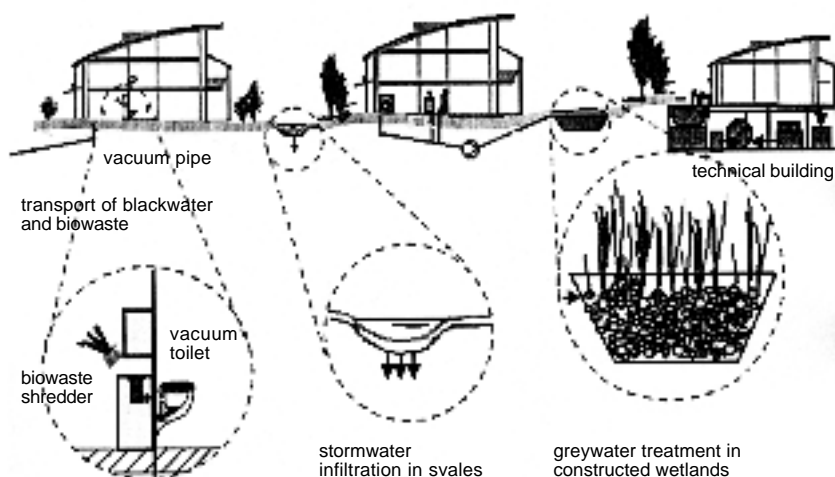


Figure 3.28 Schematic view of the vacuum-biogas system Lübeck-Flintenbreite. (Design: OtterWasser GmbH, Lübeck, Germany, 1994).

Costs are similar to those of conventional systems in the region. Money is saved by not needing a central sewerage system, by reduced freshwater consumption and by coordinated construction of all pipes and lines (vacuum sewers, local heat and power distribution, water supply, phone- and TV-lines).

The energy balance of this vacuum-biogas system is positive because of biogas utilization and the substitution for industrial fertilizer. Most of the nutrients can be returned to the land in the form of nitrogen, phosphorous and potassium. Returning carbon to the soil improves soil fertility and counteracts global warming by increasing carbon storage. This increase in soil organic matter reflects healthy farmland.³²

Chapter 4

DESIGN AND MANAGEMENT FEATURES

The ecological sanitation systems and eco-toilets described in the previous chapter are neither widely known nor well understood. They cannot be replicated without a clear understanding of how they function and how they can malfunction. They have several unfamiliar features, such as urine diverting toilet seats and squatting slabs and pans, which may raise questions about their cultural acceptability. In addition they require more promotion, support, education and training than ordinary pit, VIP, pour-flush or cistern-flush toilets, but the benefits to the environment and to human health are immensely worthwhile.

Much has been learned about ecological sanitation systems from the many units in use in the world today. In China and Vietnam hundreds of thousands of rural households have double-vault toilets and many recycle their products in agriculture. In Latin America there are many thousands of units of similar types. In North America and Scandinavia a large number of eco-toilets of various designs have been on the market for well over a generation (mainly used in vacation houses). In Ladakh and Yemen dry toilets have been used for hundreds of years. In India, and Africa there are growing numbers of eco-toilets in operation. Among these, there are successes and there are failures, and we can learn from both.

In this chapter we describe the design and management features of ecological sanitation toilet systems, so that mistakes can be avoided. The purpose of the chapter is first to provide an overview of the variables that influence the choice of an appropriate sanitation system, then to discuss the possibilities in dealing with liquids and in sanitizing solids, and finally to discuss a number of design options.

4.1 Factors influencing design and management

Many local variables influence the choice of an eco-san system:

Climate – temperature, humidity, precipitation and solar radiation. In dry areas it will be easiest to sanitize faeces through dehydration, whereas composting may be more successful in humid areas.

Population density and settlement pattern – the availability of space for on-site/off-site processing, storage and local recycling.

Social/cultural – the customs, beliefs, values and practices that influence the design of the social components of a sanitation system, its acceptability by a community. (It should be noted, however, that these things are not static, and that new practices are constantly evolving in most societies.)

Economic – the financial resources of both individuals and the community as a whole to support a sanitation system.

Technical capacity – the level of technology that can be supported and maintained by local skills and tools.

Agriculture – the characteristics of local agriculture and homestead gardening.

Institutional support – legal framework, extent of support for the eco-san concept in government, industry, financial institutions, universities and NGOs.

4.2 Dealing with faeces

The primary processing in an eco-san system is generally either through dehydration or decomposition, but a combination of both is also possible. The purpose of the primary processing is to destroy pathogenic organisms, to prevent nuisance and to facilitate subsequent transport, secondary processing and end use.

4.2.1 Dehydration

Dehydration means lowering the moisture content of the material in the processing vault or container to less than 25% through evaporation and addition of dry material (ash, sawdust, husks). No water, urine or moist plant material must be added to the processing chamber. There is little reduction in volume because of the added dry material, and minimal decomposition of organic material because of

the low moisture content. The crumbly pile that remains when faeces dry out is not compost but rather a kind of mulch which is rich in nutrients, carbon and fibrous material.

Dehydration is a way of destroying pathogenic organisms. It does this by depriving them of the moisture they need to survive (see 2.3). At this low moisture content there is little odour and no fly-breeding. As there is so little breakdown of organic material, toilet paper or other things placed in the processing vault will not disintegrate regardless of storage time. Toilet paper must therefore either be handled separately (commonly by burning it) or be composted in a secondary treatment process.

Urine diversion is essential in eco-toilets based on dehydration. Where water is used for anal cleaning, this water should be diverted and can either be treated separately or mixed and treated with the urine (see 4.3.3).

4.2.2 Decomposition

Decomposition ('composting') is a complex natural biological process in which organic substances are mineralized and turned into humus. The speed of decomposition is influenced by a number of environmental factors inside the pile such as the amount of oxygen (aeration), temperature, moisture, pH value, the ratio of carbon to nitrogen (C:N ratio), competition among micro-organisms for nutrients, and the toxic by-products of decomposing organisms.

The following text is based on Chapter 9 in *Sanitation without Water* (1985) by Uno Winblad and Wen Kilama, Macmillan, London.

Aeration

Some of the micro-organisms in the pile need oxygen in order to play their role in decomposition. Such organisms are called aerobic. Others that do not require oxygen are called anaerobic. Many organisms can survive conditions with and without oxygen. Air enters the processing chamber from the outside or is trapped inside the compost heap. Near the surface of the pile the process may be aerobic while in the interior it is often anaerobic. Under aerobic conditions, decomposition is rapid and odour-free. Under anaerobic conditions decomposition is slower and foul-smelling and the heat given off is only a fraction of that under aerobic conditions. Earthworms and insects play an important role in aeration by burrowing

holes through the pile.

Temperature

High-temperature aerobic composting (with temperatures reaching $>60^{\circ}\text{C}$) will effectively destroy most pathogenic organisms, but such process temperatures are in practice difficult to reach in a composting toilet. The volume of material is too small, it tends to be too compact and it is difficult and unpleasant to turn the pile to aerate the central part. Occasionally higher temperatures can be found in a small part of the pile. To raise the temperature for faster decomposition and faster die-off of pathogens, there should be a large input (four to five times the weight of faeces) of carbon rich material such as weeds, husks, wood shavings and kitchen waste, combined with occasional turning to ensure a good supply of oxygen to the inside of the pile.

It is important to remember that temperature is not solely important for destroying pathogens. Pathogen destruction is a function of both temperature and time, so that lower temperatures can achieve acceptable pathogen kill if the material is retained long enough. In many cases, this lower temperature/longer time strategy is preferable to more intensive management of the compost pile. Most composting toilets are designed for a retention time of 8–12 months.

Moisture

In a composting toilet we get the best results in terms of pathogen destruction with a moisture content of 50–60%. At a higher moisture content conditions in the material become soggy and compact, and the organisms are deprived of oxygen. A low moisture content, on the other hand, slows down the activity of the micro-organisms, as they are starved for water.

An extremely wet compost toilet may result from a combination of some of the following factors: humid climate, water used for anal cleaning, too much urine has gone in, too many users (too much urine in relation to capacity to handle liquids), no addition of organic refuse, unventilated processing chamber, entry of rainwater, surface water or groundwater. The most common reason for a high moisture content in the pile is too much urine going into the processing chamber. This can be corrected by installing a urine-diverting toilet seat or squatting plate which channels the urine away from the compost pile into a separate container. Another possibility is to have some type of false floor which allows the liquid to seep out, preferably into a place from where it can evaporate.

Ratio of carbon to nitrogen

Micro-organisms feed on organic matter containing, among other nutrients, carbon and nitrogen. Carbon is used for energy and nitrogen is for body building. The optimum carbon to nitrogen (C:N) ratio is within the range of 15:1 to 30:1 in the initial mixture.

Since faeces, and especially urine, are rich in nitrogen, it is best to start a processing chamber with materials rich in carbon such as green grass clippings, vegetable scraps, straw, husks, wood shavings or a combination of these. Addition of these materials to the compost increases the C:N ratio. Excluding urine from the compost has a similar effect, as it lowers the amount of nitrogen in relation to carbon. The addition of layers of finely chopped carbon-rich material also helps to provide oxygen to the pile and to achieve rapid and complete decomposition.

Life in the compost toilet

A rich variety of organisms live in the compost heap and contribute to the breakdown of the excreta. They range in size from viruses, bacteria, fungi and algae to ants, mites, spiders, sowbugs and earthworms. Their activities are responsible for rapid decomposition. Earthworms and insects mix and aerate the pile, tearing apart the contents. If the environment is favourable to them, they will multiply, burrow holes in the pile, eat odorous organic material and convert it all into humus.¹

4.3 Dealing with liquids

A basic question when designing an eco-san system is whether to divert urine or to mix urine and faeces in a single receptacle. If the latter approach is used, effective processing will, with few exceptions, require later separation of liquids and solids. Thus we start with two basic options: divert urine or mix urine and faeces.

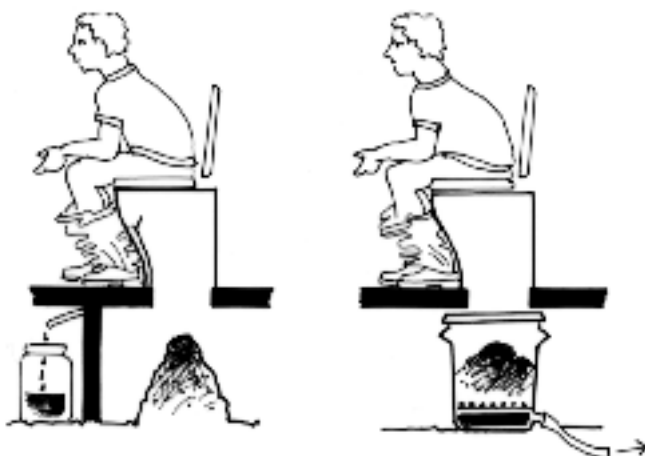


Figure 4.1 Eco-san systems have two basic options for dealing with liquids: divert urine (left) or mix urine and faeces (right).

4.3.1 Diverting urine

There are a number of good reasons for not mixing urine and faeces:

- it keeps the volume of potentially dangerous material small;
- the urine remains relatively free from pathogenic organisms;
- urine and faeces require different treatments;
- it simplifies pathogen destruction in faeces;
- it reduces odour;
- it prevents excess humidity in the processing vault; and
- the uncontaminated urine is an excellent fertilizer.

Urine diversion requires a specially designed seat-riser or squatting slab or pan that is functionally reliable and socially acceptable. The basic idea of how to avoid mixing urine and faeces is simple: the toilet user should sit or squat over some kind of dividing wall so that faeces drop behind the wall and urine passes in front of the wall.

The idea of not mixing urine and faeces is not new. In parts of China, in Japan and in other parts of the world simple toilets with urine diversion have been in use for centuries (see Figures 4.2 and 3.16).

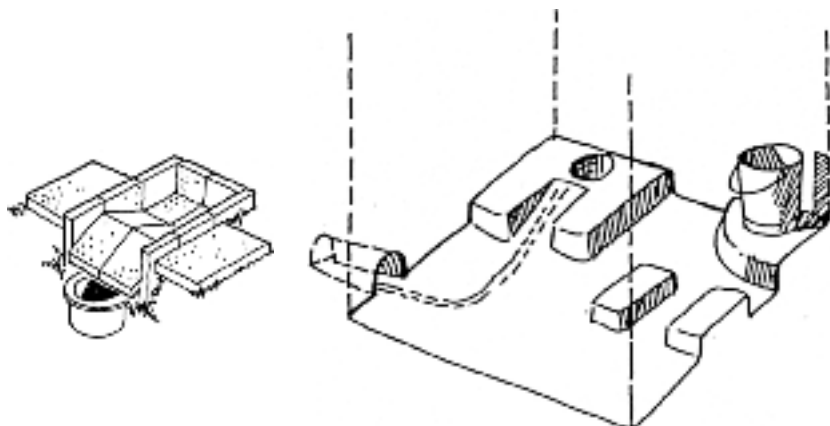


Figure 4.2 Historical examples of urine diversion. The one from China (left) is emptied every day: urine is used directly as liquid fertilizer and faeces placed in a compost pile together with animal manure.² In the example from Yemen (right) urine is evaporated and faeces dehydrated and reused as fuel (see 3.2.2).

In recent years several factories have started producing squatting pans as well as seat-risers with urine diversion. The faeces drop down into either a composting or a dehydrating chamber.

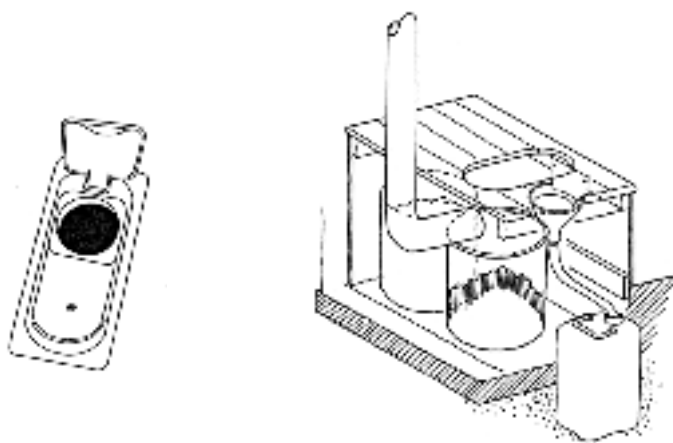


Figure 4.3 Urine diversion: to the left a prefabricated squatting pan from Yongning county, Guangxi province, China (Design: Lin Jiang 1999), to the right a bench-type seat riser from El Alto, Bolivia (Design: Uno Winblad 1997), built of wood and with a standard plastic funnel as urine collector.

Once collected the urine can either be used directly in the garden, infiltrated into an evapo-transpiration bed, or stored on site for later collection either as liquid fertilizer or further processed into a dry powder fertilizer.

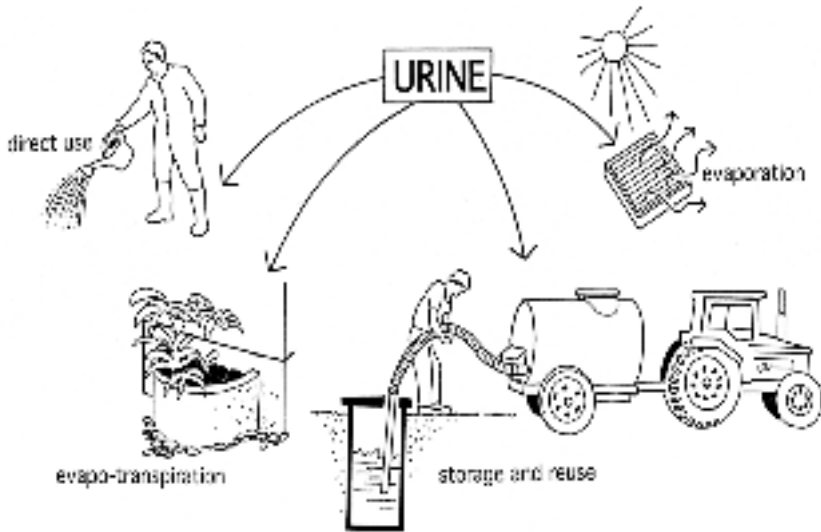


Figure 4.4 Alternative ways of handling urine diverted from faeces: used directly, disposed of in an evapo-transpiration bed, stored in a tank for later use or evaporated.

Although urine-diverting toilets have a long history the concept is, in most parts of the world, unfamiliar and many people find it hard to believe that they work properly. Sometimes newcomers to the systems remark that they do not believe they can be used by males. Others question whether they can be used by females.

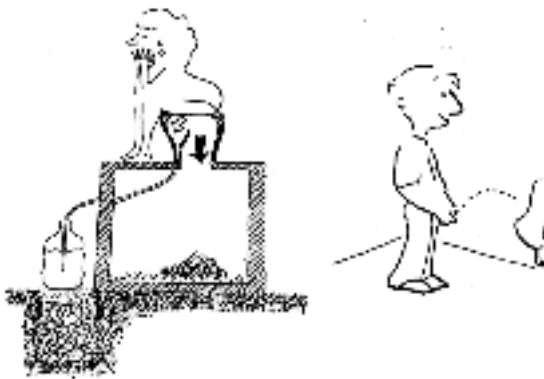


Figure 4.5 Urine diversion. (Drawings by César Añorve, Cuernavaca, Mexico).

Experience shows that these designs work equally well for both sexes, as long as they squat or sit. Some communities have designed their toilet units with separate urinals for men so that the main seat-riser or slab does not have to be used by those who prefer to stand when urinating.

The large size of seats and slabs, however, sometimes poses problems for small children, and some options are designed so that a smaller seat can be pulled down over the larger basic seat-riser.

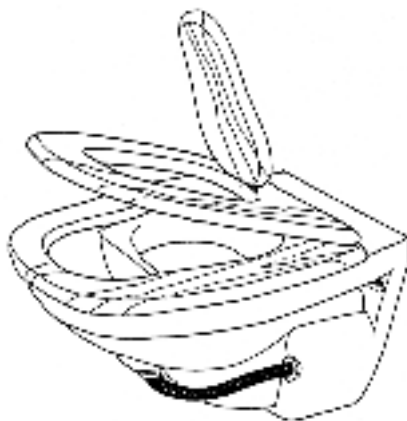
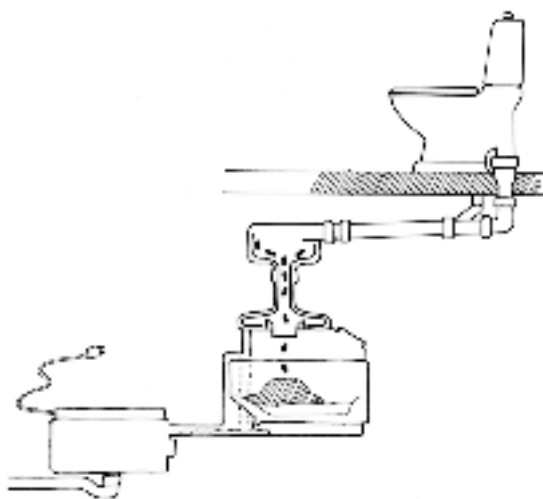


Figure 4.6 A Swedish toilet with urine diversion, 'Dubbletten', has a lid with a smaller hole for children to use.

4.3.2 Mixing urine and faeces

Systems based on liquid separation do not require a special design of the seat-riser or squatting plate. Urine, faeces, and in some systems a small amount of water, go down the same hole. Liquids and solids are then separated, for example in an 'Aquatron', fixed on top of the processing vault (see 3.2.3 – Sweden). This device, developed in Sweden, has no moving parts and simply uses the velocity of the flush to send the liquid around the inner wall of a doughnut-like contraption while the solids fall through a hole in the middle.

Figure 4.7 An Aquatron device for separation of liquids and solids from a minimum-flush toilet. The separator is placed on top of a processing (composting) chamber. The liquids are sanitized with ultraviolet radiation in a separate unit.



Another possibility is to drain the liquid from the processing chamber through a net or a perforated floor as in the example below.

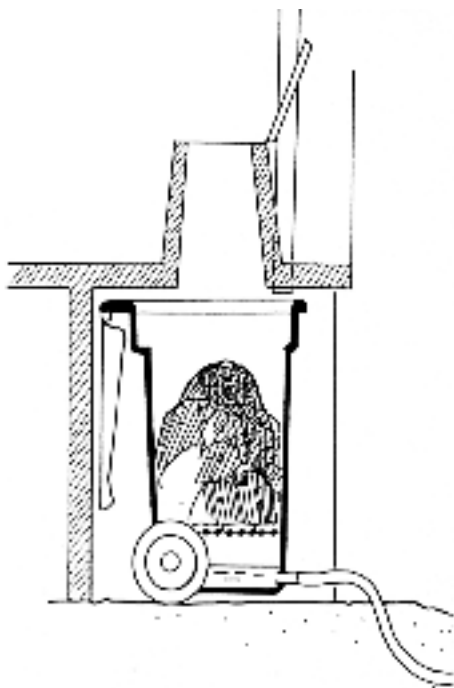


Figure 4.8 A composting toilet with liquid separation through a perforated floor.

One of the main points that must be considered in liquid separation systems is that, as the liquids have been in contact with faeces, they must be evaporated, sterilized or otherwise treated before they can be recycled as fertilizer. In rural, basic toilets in warm and dry climate it is possible to process liquids and solids together. Urine and faeces go down the same hole. Dry soil or a mixture of soil and ash are added to the urine-faeces mix in the pit. Biological activity in the combination of excreta and added soil results, over time, in a useful soil conditioner and fertilizer. Since some of the liquids percolate into the soil, these types are not suited to areas with a high water-table.

4.3.3 *Water for anal cleaning*

In some cultures, washing after defecation is mandated by tradition or religion (see 7.1.1). In some Islamic cultures, for example in Yemen, Zanzibar³ and in Kyrgyzstan⁴ people traditionally wash away from the toilet opening. Our examples from India and Palestine in Chapter 3 show that also where there is no such tradition the required modification of toilet behaviour is indeed possible.

The water used for anal cleaning can be treated in an evapotranspiration bed as in the Kerala example or in a septic tank as in Palestine (see 3.1.2).

4.4 Preventing odours and flies

Sceptics claim that eco-san is an inferior alternative: it will be smelly, fly-producing and incompatible with modern living. This is a valid concern as eco-san systems are sensitive to bad design and careless operation. If they are not designed, built and operated properly, taking into account natural environment, traditional beliefs and the chosen process (dehydration or decomposition), they may indeed smell and can even provide a habitat for flies.

Fly breeding in toilets is basically related to the wetness of the contents of the processing vault. In a properly functioning dehydration system there would be no fly breeding, but if something goes wrong and the contents turn wet, fly breeding might occur. The risk of fly breeding is greater in a composting system for two reasons: it works with a much higher process moisture content and fly eggs may be introduced into the processing vault with kitchen scraps. When a properly selected and well built eco-toilet fails, the most common fault is that the process has turned wet. In a system based on dehyd-

ration the moisture content of the contents of the processing vault should quickly be reduced to less than 25% through the addition of dry additives and ventilation – in some cases helped by the addition of a solar heating device. In a system based on decomposition the corresponding moisture content should ideally be between 50% and 60%. If this is achieved and fresh faeces are covered with an absorbent (see 4.6.4), there is no smell, no fly-breeding and rapid pathogen destruction.⁵

4.5 Household or communal removal and treatment

4.5.1 Household management

Probably the most unfamiliar aspect of ecological sanitation options is that they may require some handling of processed or partly processed human excreta at the household level. In most existing eco-san projects this has been necessary because the projects were small and scattered. Each household therefore had to manage the total system: daily care of the eco-toilet; weekly/monthly emptying of the storage tank for urine; recycling of urine in the garden; monitoring the primary processing chamber for faeces; half-yearly emptying of the processing chamber, secondary processing of chamber content; and the end use of the sanitized material. With proper motivation and instruction this management by the household can work well.

The advantage of this approach is that the user gets a direct feedback and can gradually improve his/her operation: take greater care in not allowing urine and water into the processing chamber, increase the amount of ash/lime, etc.

Problems tend to occur when new tenants/owners are taking over. As eco-toilets are still relatively unfamiliar the risk is that the newcomers do not understand how to use them. And without instruction they would not know why and how to empty urine tank and processing chamber, or about the need for secondary processing, etc.

4.5.2 Communal management

For larger projects, particularly in urban areas, the output from eco-san toilets can be monitored, collected, further processed and sold by a municipal or private service organization.

Secondary treatment can be carried out at neighbourhood or centralized collection centres, called eco-stations with trained personnel (see 8.1.3).

Communal management has two main advantages: it is more convenient for the user and safer for public health. The user only needs to operate and maintain the eco-toilet. Eco-san can therefore offer the same standard of convenience as a conventional WC connected to a centralized sewer. As all handling, processing, transport and sale of the urine and faeces is taken care of by the trained staff of the service organization, end products of a consistent quality can be assured.

4.6 Other technical options

4.6.1 Solar heaters

Solar heaters can be fitted to the processing chambers of the toilet to increase evaporation. This is more important in humid climates and where urine and water are mixed with the faeces. It is also more important in a system based on dehydration than in one based on decomposition.

The main purpose of the solar heater is to increase evaporation from the material in the processing chamber. It is also likely to slightly increase the temperature of the pile in the chamber and there are indications that pathogen destruction is faster in solar heated than in non-solar heated chambers.⁶ The increase in pile temperature is, however, unlikely to be high enough for high-temperature composting.⁷

The solar heaters used in some of the eco-toilets described in the previous chapter consist of a black-painted metal (aluminium) sheet covering the part of the processing chamber exposed to the sun. This metal sheet may also act as an access lid to the processing chamber (see Figures 3.14 and 4.9).

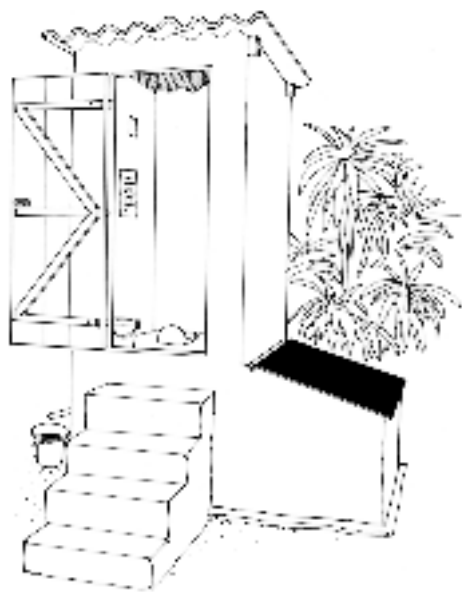


Figure 4.9 *An eco-toilet with solar-heated processing chamber, Nha Trang Pasteur Institute project in Cam Duc commune, Khanh Hoa province, Vietnam. (Design: Uno Winblad and Duong Trong Phi, 1996).*

The solar heater must be fitted so that it prevents water as well as flies from entering the processing chamber(s). It should be tight enough to prevent air leakage.

4.6.2 Single or double vault

Most eco-toilets built so far have two vaults, each with its own seat-riser or squatting slab or with a movable device. The advantage with the double-vault design is that each vault is used alternately for a certain period. When the first vault is full it is left dormant and the second vault is used. The contents of the dormant vault are emptied when the second vault is nearly full. The assumption is that after a specified period (6–12 months depending on climate) without new faecal material added, the contents of the dormant vault should be safe to handle. A single vault toilet with two or more moveable containers would offer the same advantage. For eco-san systems with communal management moveable containers probably offer a more rational solution than fixed vaults or processing chambers.

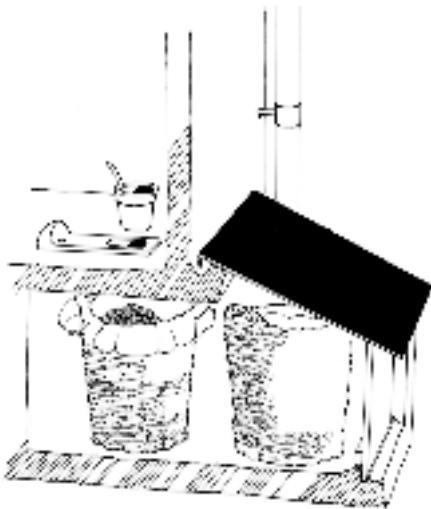


Figure 4.10 A single-vault, solar-heated eco-toilet with moveable containers, in this case two large baskets. When the first basket is full it is placed directly under the solar heater and remains there until the second basket is full.

4.6.3 Anal cleaning material

Cultures differ in their use of cleaning materials after defecation. Some use paper, some use vegetable material, mudballs or stones, and others, as mentioned above, use water. The inappropriate disposal of cleaning material in a toilet can cause problems. In some parts of the world the drainage system for WCs cannot cope with large amounts of toilet paper, so this has to be collected separately in a bin for later disposal by burning. Elsewhere WCs have rapidly been rendered useless by people trying to dispose of stones or maize cobs in the toilet.

Dry systems can take all kinds of paper and solid objects and still function well. As mentioned above a dry system can even be adapted to cope with the use of water for anal cleaning.

During the process in a composting toilet paper breaks down, but not in a dehydrating toilet – the paper does not decompose. This paper will, however, break down during secondary processing if the process used is either composting or carbonization/ incineration.

4.6.4 Absorbents and bulking agents

Absorbents such as ash, lime, sawdust, husks, crushed dry leaves, peat moss and dry soil are used to reduce smells, absorb excess moisture, and make the pile less compact as well as less unsightly for the next user. Absorbents should be added immediately after defeca-

tion in order to cover the fresh faeces. They are used in both dehydrating and in composting toilets.

Bulking agents such as dry grass, twigs, coconut fibre and wood shavings are used in composting toilets to make the pile less compact and allow air to enter and filter through the heap.

In the nineteenth century in Europe there were a number of designs for 'earth closets', with a lever-operated mechanical device to sprinkle earth and/or ash on to the faeces. A similar device is used in current eco-san projects in China.



Figure 4.11 A mechanical, pedal-operated, ash dispenser used for school toilets in the Yongning eco-village programme (see 3.1.1 – China). (Design: Lin Jiang, 1999).

4.6.5 Ventilation and aeration

Ventilation serves several purposes: it removes odours, it dries out the contents and, in composting toilets, provides oxygen for the decomposition process. A ventpipe is not always necessary: the Vietnamese double-vault toilet and its variations in Central America are usually built without a ventpipe. All indoor models in for example the Scandinavian countries, Mexico, Palestine and China are provided with vent pipe. The need for a vent pipe is determined by climate, wetness of the input into the processing chamber and standard desired. (With a well-functioning vent pipe from the processing chamber, the toilet/bathroom can be completely odour free, as air from the room is evacuated via the drop hole in the seat-riser/squatting-pan.) A vent pipe should have a diameter of 10 – 15 cm. In

extremely humid climates the diameter could be larger – up to 25 cm as in the example from Micronesia (see Figure 3.15). The pipe should be as straight as possible as bends reduce draft, and reach 50–90 cm above the roof. If necessary the ventpipe can be fitted with a small electric fan.

Composting is basically an aerobic process. Many of the micro-organisms responsible for the decomposition need oxygen. Air must therefore be brought into the pile. In some cases the processing chamber is provided with perforated pipes that bring air into the centre of the pile (see Figure 3.12). Aeration can also be accomplished with the addition of a bulking agent that creates air pockets inside the pile.

4.7 Materials and workmanship

Eco-san is, like any sanitation system, sensitive to poor workmanship and defective materials. But in some ways eco-san systems are less sensitive: the processes involved are dry and the volumes handled comparatively small. Common faults include seepage of water into the processing vault, leaking or blocked urine conduits and blocked ventpipes.

4.8 Maintenance

All sanitation technologies require maintenance to function properly. The amount of maintenance that users of eco-san systems need to do varies a great deal and is influenced as much by the organization of operation and maintenance as by the design of the eco-san devices.

Good system design can minimize the need for intensive maintenance, and the tasks required need not be onerous. For example, systems that rely on composting often require the regular addition of bulking agents and periodic checking to ensure that ventpipes are not blocked by debris, spider webs or nesting insects. Some systems may require the transfer of partially processed solids to a secondary processing area. Many systems require that the toilet seat-riser or squatting hole be in some way closed-off when not in use.

All systems require periodic inspection and removal of the end products. Particularly urine collectors, pipes and containers/tanks

need to be monitored. Urine pipes should be flushed periodically to avoid accumulation of deposits, which can block the flow and generate unpleasant odours.

The major common element in the maintenance of eco-san systems is that the user must ensure that the system is working properly. However, it is important to note that many operation and maintenance functions, such as emptying of toilet vaults, transport and secondary treatment, can be carried out by special service providers, either as a public service or through private enterprise. Service contracts will minimize the burden on households and also enable municipal administrations to guarantee a satisfactory standard of operation and maintenance.

Chapter 5

RECYCLING THE NUTRIENTS

Ecological sanitation regards human excreta as a resource to be recycled rather than as waste for disposal. The use of human excreta for crop fertilization has been widely practised in many regions of the world. The Chinese have been composting human and animal excreta for a few thousand years,¹ and Japan introduced the practice of recycling human faeces and urine for agriculture in the twelfth century and continued until the 1950s.² In Europe, until modern times, it was common for farmers to recycle human excreta with animal manure.³

The very idea that excreta are waste with no useful purpose is a modern misconception.⁴ It is at the root of the pollution problems that result from conventional approaches to sanitation, particularly flush-and-discharge. In nature there is no waste: all the excreta of living things are used as raw materials by others. Recycling sanitized or well composted human urine and faeces by returning them to the soil serves to restore the natural cycling of life-building substances that has been disrupted by our current sanitation practices.⁵

5.1 Why recycle nutrients?

5.1.1 *Food security and poverty alleviation*

In parts of the world, particularly in sub-Saharan Africa, rural people suffer from periodic famines due to drought, small plot size, soil erosion, poverty (inability to purchase sufficient food) and political factors. In urban areas around the world, poor people also suffer from undernutrition due to poverty, although urban agriculture is a growing phenomenon. However, growing food for the immediate family within confined spaces is a challenge. The products from eco-toilets with their nutrients can be used in rural and urban areas to increase food security for all households, particularly the poor. To ensure that the increased food security results in improved health, it is important that users follow the guidelines given in this chapter.

The products from eco-toilets can be used directly at the homestead level, in backyard gardens. As this chapter shows, about 1.5 litres of

undiluted urine can be used to fertilize 1 square metre of soil. 1.5 litres is the amount produced by one adult in one day. Even without an eco-toilet, people could collect their own urine and use it on backyard gardens to increase yields. However, the fertilizing effect of urine works best in soil with a high organic matter content and this can be increased by adding the humus from eco-toilets and garden composts.

In urban areas, the sanitized humus from eco-toilets can be used as a rich and nutritious soil for planting in pots, and the urine can be used to fertilize the soil before planting and for continued fertilization of plants during growth. This chapter shows that vegetable and fruit crops grown using urine fertilization produce 2–10 times the amount of crop by weight as those grown in unfertilized, poor soil. If people use urine to grow vegetables and fruits, the increased production results in greater food security at virtually no cost. Soil enriched with humus from eco-toilets holds water longer than soils not enriched with compost. Research has shown that plants grown in soils enriched with large amounts of humus require less watering and survive droughts better than plants grown in ordinary soils without this humus.⁶ In times of drought, when whole fields of grain may die, backyard crops grown on humus may well survive and produce enough vegetables to help a family through a difficult period. If, over time, families can collect enough humus from their eco-toilet, they may be able to enrich larger and larger areas, leading to increasing food security.

5.1.2 Cost savings to farmers

The formulation of nutrients in urine is similar but not exactly the same as that in commercial fertilizers. But urine and commercial fertilizers give similar result in boosting plant growth. Urine is high in nitrogen and lower in phosphorous and potassium. Some top-up of phosphorous and potassium is often needed to get the best possible use of nitrogen. As faeces and ash are high in phosphorous and potassium, farmers can replace commercial fertilizers with urine and top up with sanitized faeces from eco-toilets at little or no extra cost.

A study in China calculated the cost savings of using urine and dried faecal humus from eco-toilets as a fertilizer in a 3000 square metre greenhouse owned by one farmer in Jilin province of northern China. The farmer not only used the dried faeces and urine from his own household but also purchased additional dried faeces from other homes with eco-toilets and was given their urine free of charge. He

did not calculate the cost of transport of dried faeces (which was transported by tractor) or the cost of transporting urine, which was carried in buckets on shoulder poles. He used to buy 350–400 kg commercial fertilizer per year, but now this has been replaced by the free urine. The farmer calculated his cost savings per year to be the equivalent of CNY 740 (USD 90) per 1000 square metres.⁷

Such calculations could become even more important at the community level, especially where farmers are struggling to make a living. A city of 100,000 people would produce about 500,000 kg of elemental nitrogen, phosphorous and potassium (NPK) per year in excreta. While the cost of commercial fertilizer varies between countries, as does its content of elemental NPK, it is possible to make a rough cost comparison of buying commercial products or collecting and transporting locally produced urine and faeces.

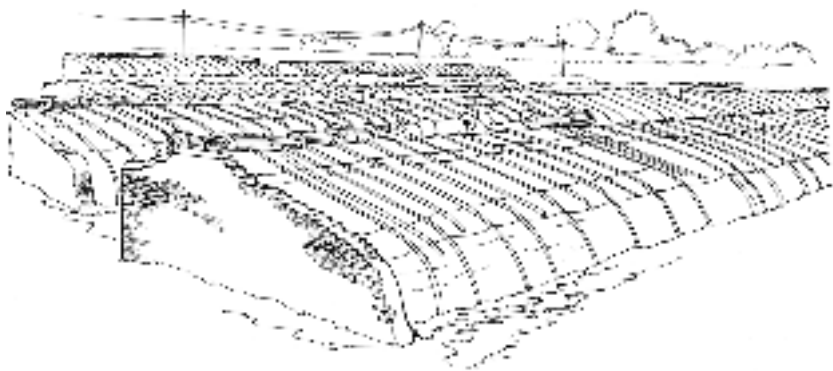


Figure 5.1 Greenhouse for vegetable production, Jilin province, northern China.

5.1.3 Preventing nitrogen pollution

Pit toilets as well as sewers are frequently a source of groundwater pollution,⁸ especially in areas where the water-table is high. Urine is rich in nitrogen and up to 50% of the nitrogen leaches out of the pit toilet, passes through the soil and reaches groundwater.⁹ Water with NO_3 concentration higher than 50 mg/litre is considered to be unfit for human consumption.¹⁰ It is not unusual to find such high concentrations of nitrogen in wells in communities with pit toilets. Recommendations that toilets be sited at least 30 metres from wells are meant to protect well water from pollution, but plenty of experience shows that soil conditions vary considerably and both pathogen and nitrogen pollution can still result.

5.1.4 Restoring lost topsoils

According to FAO, the Earth is losing 25 billion tonnes of topsoil per year because of erosion.¹¹ Chemical fertilizers, while boosting plant growth, cannot replace topsoil. Topsoil contains humus formed from decayed plant and animal matter and is rich in carbon compounds and micro-organisms necessary for healthy plant growth, which are not found in chemical fertilizers. The addition of humus is therefore necessary to maintain and renew the topsoil. With the loss of topsoil comes the loss of human food security. In many parts of the world people are experiencing reduced productivity on their lands due to loss of topsoils.

5.2 Nutrients in human excreta

5.2.1 Urine

Most of the plant nutrients in human excreta are found in the urine. Based on data from five countries (China, Haiti, India, South Africa and Uganda) we estimate that on average each person produces about 5 kg of elemental NPK in excreta per year, about 4 kg in the urine and 1 kg in the faeces.¹² Urine is therefore worth using as fertilizer, especially as its content of NPK is readily available to the plants.

In Sweden the total yearly production of human urine contains elemental nitrogen, phosphorous and potassium equivalent to approximately 20% of the amounts of these nutrients used as mineral fertilizers in 1999/2000.¹³ The concentrations of heavy metal in human urine are negligible – an important advantage over chemical fertilizer.¹⁴

When urine is collected for use as a fertilizer, it is important that the storage method prevents odours and the loss of nitrogen to the air. Swedish research indicates that most of the nitrogen in urine, which is initially in the form of urea, is quickly converted to ammonia within the collection and storage device (if this device has been used several times and is not more or less sterile). Ammonia loss to the air can be minimized by storage in a covered container with restricted ventilation.¹⁵

When urine is applied to open soil before planting it can be undiluted. If used on growing plants it can be applied without or with dilution,

typically one part urine to 2–5 parts of water. Care should always be taken to apply the urine to the soil and not on the plants.

Box 5.1 *Swedish research on the recycling of human urine*

A number of research institutions in Sweden studied urine diversion and reuse in two large projects between 1996 and 1999. In the projects, urine was collected from urine-diverting toilets at two housing estates in Stockholm. The urine was stored on-site in tanks at each housing estate before being transported by trucks to a farm south of Stockholm. There it was stored in air-tight containers before being spread on cereal crops as a fertilizer. The overall goal of the project was to evaluate urine diversion as a system for reusing the nutrients in agriculture. Risks of disease transmission, energy usage, potential environmental impact, agricultural value and various technical and social issues were all examined. Among other findings, research demonstrated that the nutrient loss from the urine was negligible during the collection and storage process if appropriate measures were taken. The nitrogen fertilizing effect of the urine was almost as good as that of corresponding amounts of chemical ammonium nitrate fertilizers.¹⁶

5.2.2 *Faeces*

Human faeces consist mainly of undigested organic matter such as fibres made up of carbon. Although faeces contain less nutrient than urine, the humus produced from faeces actually contains higher concentrations of phosphorus and potassium. After pathogen destruction through dehydration and/or decomposition the resulting inoffensive material may be applied to the soil to increase the amount of available nutrients, to increase the organic matter content and to improve the water-holding capacity.

The simplest form of recycling is when the individual household can use the product as fertilizer in its own garden or on its own farm land. In urban situations many householders will have neither the land nor the inclination to use the product themselves. Lack of land need not hinder food production as seen in the example from Mexico City in Box 5.3 and the ‘vertical garden’ in Botswana in Box 5.4.

5.2.3 *Nutrients in combined systems*

The humus formed in toilets where urine and faeces are combined, such as the Zimbabwean ‘Arborloo’ and the ‘Fossa Alterna’, is rich in nutrients. Studies undertaken in Zimbabwe compared major nutrient levels in samples of naturally occurring topsoil and in humus from pits where urine and faeces have been combined and

supplemented with soil and wood ash and allowed to decompose for one year, Table 5.1 below.¹⁷

Table 5.1 Comparison of nutrient levels in natural topsoil and humus from Fossa Alterna pits.¹⁸

Source of soil	N (mg/kg)	P (mg/kg)	K (mg/kg)
Natural dryland topsoil	38	44	192
Fossa Alterna soil	275	292	1763

5.3 Application of nutrients derived from excreta

Nutrients from human excreta may be applied as two separate products (urine and composted faeces), or as one combined product (composted urine and faeces). When they are applied separately, it is usually because they have been collected separately. When urine and faeces are applied in combination, it is because they have been collected together and composted as a mix, as in the Arborloo or Fossa Alterna.

The most efficient way to recover excretal nutrients, however, is to collect urine and faeces separately. Most toilets collecting urine and faeces mixed allow leaching of the liquid from the toilet, which means that some nitrogen will be lost.

5.3.1 Application of urine

Urine can be applied in a variety of ways:

- Undiluted before or at sowing/planting or to the young plant.
- Urine can be applied in one large dose or several smaller ones during the cropping season.
- As a liquid plant food mixed with water. Diluted urine can be added to the soil where vegetables (and plants like maize) are growing – once a week or even twice or three times a week, provided that the plants are also watered frequently at other times. This addition of urine makes a big difference to the growth of plants.
- Undiluted to soil beds before planting. Bacteria in the soil change the urea into nitrate which can be used by the plants.

- As an ‘activator’ for compost heaps. The transformed organic nitrogen will be available to plants when the compost has matured.
- Concentrated fermented urine can be applied to beds of dried leaf mold, as a medium for growing vegetables and ornamental plants (see Box 5.3).

A future possibility, when large amounts of diverted urine are available from urban areas, is to use human urine to produce a concentrated fertilizer in powder form.¹⁹

5.3.2 Application of faeces

Faeces are removed from the vault of dehydrating toilets as a dehydrated, sanitized powder or lumps. This dry material is usually given a secondary treatment (for example in the form of high temperature composting, see 2.4) before being dug into the ground or into flower beds where the material comes into contact with the living soil.

From composting toilets faeces are removed as humus, which is not dry but slightly moist. The same applies to its removal from secondary composting sites, if the partly decomposed faeces, in combination with soil and ash, have been moved from the toilet to be further processed elsewhere.

To make best use of this valuable asset, it can be applied in furrows or holes close to where the plants will later be growing.

5.3.3 Application of humus from urine and faeces combined

In the Fossa Alterna, a mix of urine and faeces, in combination with an almost equal volume of soil, and often combined with wood ash or leaves, is dug out of the shallow pit after 12 months of composting. This material is either bagged awaiting further use or mixed with local topsoil in equal proportions and applied to vegetable gardens, where it enhances plant growth.

5.4 Effects of nutrients on plant growth

Urine can be applied in one large dose for the growing season or once or twice a week in smaller doses to vegetables – with additional watering to keep the plants healthy. With the same total dose of urine during the vegetative part of the growing season, the yield is usually about the same, irrespective of the number of doses.²⁰

In a series of experiments carried out in Harare, Zimbabwe, during 2002, it was shown that by adding the 3:1 water:urine mix to vegetables planted in 10-litre containers three times per week, with all other irrigation carried out with water alone, spinach yield was increased up to 6 times, covo yield 1.5–4 times, lettuce yield was doubled and the weight of tomatoes increased up to 3.6 times, compared with similar plants growing in similar soil and similar containers, but irrigated with water only (Table 5.2). Maize production in fields was also increased by between 29–39% by the application of undiluted urine watered with natural rainfall.²¹

Table 5.2 *Plant trials with urine for various crops.*²²

Plant and growth period	Weight at cropping (water application only)	Weight at cropping (3:1 water:urine application 3 x week)
	<i>grams wet weight</i>	<i>grams wet weight</i>
Lettuce – 30 days	230	500
Lettuce – 33 days	120	345
Spinach – 30 days	52	350
Covo* – 8 weeks	135	545
Tomato – 4 months	1680	6084

**Covo is a type of spinach used as a salad green.*

Trials on the fertilizing effects of urine have been tried in a number of other countries. The box below summarizes some of the key findings from Sweden and Ethiopia.

Box 5.2 *Results of some agricultural trials using urine as a fertilizer*¹

Sweden

Tests on barley: 'Results showed that the nitrogen effect of urine corresponded to about 90% of that of equal amounts of ammonium nitrate mineral fertilizers.'

Tests on winter wheat: Three fertilizers were compared: human urine, dried chicken manure and dried meat + bone meal. 'The winter wheat yields were 18 kg grain per kg N for human urine, 14 kg for dried chicken manure and 10 kg for meat + bone meal. These data show that the plant availability of N in urine is higher than in chicken manure and meat + bone meal.'

Tests on leeks: 'Fertilizing with urine gave a three-fold crop yield increase. The nitrogen efficiency ..., when using human urine was high, ranging from 47% to 66%. This is on the same level as when mineral fertilizers are used. Nitrogen efficiency for most other organic fertilizers, e.g. compost, is normally between 5 and 30%.'

Ethiopia

Tests on Swiss chard: The crop yields of the fertilized plots were up to four times that of unfertilized.

Urine works better if the soil to which it is added contains humus. Such humus is rich in living material and beneficial soil bacteria, and these convert the urine nitrogen into a form that the plants can use.

With poor soils, the best way of enhancing plant growth using processed human excreta is in two stages. The first stage involves improving the texture and humus content of the soil by combining it with humus formed from processed faeces or faeces and urine. Leaf compost and garden compost can also be used at this stage. The second stage involves enhancing and sustaining the nutrient levels in the soil with urine. It should be noted that during their growth, all plants take up nutrients, and the nutrients removed from the field with the crop must be replaced if the soil is to remain a fertile medium for growing of healthy plants.

It is wise to irrigate the plants most of the time with plain water and to supplement this irrigation with the application of urine or urine and water mix, according to the chosen fertilizing plan. This appears to maintain a healthy soil over the growing period of plants tested. Urine does contain salt, and this must be kept in check (by regular plain watering) if the plants are to remain healthy.

Box 5.3 Growing vegetables in Mexico City

In response to rapid inflation, high unemployment and inadequate nutrition, CEDICAR (Center for Rural Development and Training), an NGO based in Mexico City, has perfected a method of growing vegetables in containers using human urine as a fertilizer. The project was launched in Mexico City in 1988 and more than 1200 urban households participated. Other organizations in Mexico have now adopted this approach.

The technology used was selected and adapted to fit the local circumstances, which include no land available for conventional kitchen gardens, participants unable to afford the required investment in containers and fertilizers, and the need for growing containers of light-weight materials to allow rooftop cultivation.

Vegetables are grown in containers (ideally 18–20-litre plastic buckets filled with deciduous tree leaves or grass clippings topped with a 15-centimetre layer of soil). This soil can be made from the bottom layer of plant material from the previous year's containers, which has composted into rich humus, and household organic waste, which has been composted with worms. A drainage hole is made in the side of the container, 5–10 centimetres from the bottom, depending on the type of plant to be grown, so that there will be a permanent reservoir of water and fertilizer. Urine, which has been stored in 2–5-litre containers for 3 weeks is applied to the containers after dilution with water on a 1:10 ratio.

- Plants fertilized with urine grew more rapidly, larger and healthier than those grown with conventional agricultural techniques – and less water was needed.
- Plants that produce edible leaves (for example spinach, Swiss chard, parsley, as well as nopal, a nutritious, widely available cactus) performed particularly well. Leaves were large and dark green in colour.
- Some fruit-bearing plants grew well and produced abundantly, particularly chillies, the hot peppers essential in the Mexican diet, although they were not as hot as those grown conventionally.
- All of the plants proved remarkably resistant to insect pests and disease.

5.4.1 Effect of urine and faeces combined

Humus derived from Fossa Alterna pits (where urine and faeces are mixed) contains about eight times the amount of N, P and K found in poor local topsoils in Zimbabwe.²⁴ These combined products, therefore, can make a valuable addition to poor soils and result in improved vegetable production. The improvement in vegetable yield depends on the state of the original soil. If the soil is poor, significant increases in vegetable growth are possible. In fact, the weight of vegetables grown on the mix of soils can be many times the weight of vegetables grown on the poor soil alone. The Fossa Alterna soil behaves like a good compost or fertilizer and improves soil texture.

In a series of informative experiments undertaken in Harare, Zimbabwe during 2002, vegetables like spinach, covo, lettuce, green pepper, tomato and onion were grown in 10-litre buckets or basins of very poor soil from Epworth or Ruwa, and their growth was compared with plants grown in similar containers filled with a 50:50 mix of Epworth (or Ruwa) soil and Fossa Alterna soil. In each case the growth of the vegetables was monitored and the crop weighed after growing for a certain number of days. Table 5.3 shows the results of these trials. The significant increases in vegetable production are due entirely to the nutrients available in the Fossa Alterna humus.²⁵

Table 5.3 *Plant trials with Fossa Alterna humus.*²⁶

Plant – Top soil type – Growth period	Weight at cropping (top soil only) <i>grams</i>	Weight at cropping (50:50 top soil:FA* soil) <i>grams</i>
Spinach – Epworth – 30 days	72	546
Covo – Epworth – 30 days	20	161
Covo 2 – Epworth – 30 days	81	357
Lettuce – Epworth – 30 days	122	912
Onion – Ruwa – 4 months	141	391
Green pepper – Ruwa – 4 months	19	89
Tomato – Ruwa – 3 months	73	735

*FA denotes soil taken from Fossa Alterna pits.

All these results clearly show a dramatic and meaningful increase in vegetable yield resulting from the enhancement of poor soil (*Epworth* and *Ruwa*) with the Fossa Alterna humus.

These are significant increases in vegetable production. However the volume of humus formed per year is relatively small, about 500–600 litres per family unit, so it will not go far on a big field. The humus has so far often been mixed with other soils in equal proportions (50:50 mix) and used on backyard vegetable gardens at a rate of 1 part humus to 2 parts topsoil (about 35 litres humus per square metre garden). The yield can be increased further by using diluted urine as a fertilizer (see above).

These trials were conducted in 10-litre cement containers. Fifty containers can be made from a single 50 kg bag of cement. Each container is, with the addition of urine and eco-toilet humus, capable of

yielding 14 kg of onions in 6 months. Approximately 300–350 grams of spinach per month can be produced per container. Some containers produce a crop of spinach of up to 700 grams per month. Where space is limited, this may be an economic way of using limited volumes of eco-humus. Once the crop has been harvested the soil is recycled and reconstituted by adding more humus, leaf compost and/or compost.

5.5 Conclusions and recommendations on use of urine and faeces in agriculture²⁷

Urine and faeces are each fertilizers of high quality and with low levels of contaminants such as heavy metals. The best fertilizing effect is achieved if they are used in combination with each other, but not necessarily used in the same year in the same area. Composted faeces are an important soil conditioner, improving the nutrient content and the water retention capacity of the soil and providing a substrate/food for beneficial soil organisms.

Urine is a quick-acting nitrogen-rich complete fertilizer. Its nutrients are best utilized if the urine is applied from before sowing and up until two-thirds the way through the growing period.

Urine can be applied diluted or undiluted. Nitrogen concentrations in urine can be estimated at 3–7 grams per litre. For estimating the amount needed per crop, one could follow the recommendations given for chemical nitrogen fertilizers. In the absence of other guidelines, the urine collected from one person in a year is sufficient to fertilize 300–400 square metres of crop. This can be applied undiluted or diluted, before planting or during plant growth.

For most crops and under most circumstances, the total yield of a crop is the same whether the urine is applied in one large dose or in several smaller ones. For crops with a small root system, it might be advantageous to divide the application, into smaller doses applied more frequently. Also for plants grown in small pots, i.e. with limited root volume, it might be wise to dilute the urine and apply it in smaller doses.

Faecal matter is especially rich in phosphorous, potassium and organic matter. Dehydrated or composted faeces should be applied and mixed into the soil before cultivation starts.

Both organic matter and ash, which are often added to composting or dehydrating faeces, improve the pH and nutrient content of the soil. Organic matter also improves the structure and the water-holding capacity of the soil.

Box 5.4 *Vertical gardens in Gaborone, Botswana*¹

A Swedish horticulturist, Dr Gus Nilsson, who has lived in Botswana since 1967, has developed a container gardening system for dry areas. It is based on walls with built-in growth boxes made of hollow concrete blocks.

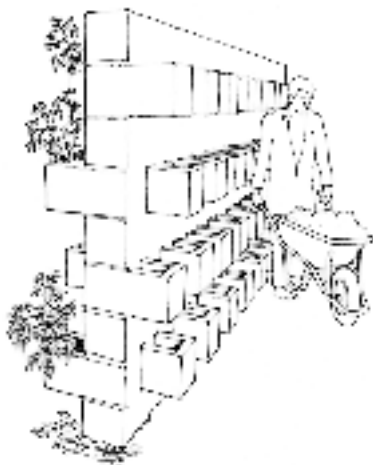


Figure 5.3 *In Botswana Gus Nilsson has developed a system of intensive horticulture for dry tropical areas, based on walls with built-in containers.*

When building the wall some of the blocks are turned through 90 degrees and the protruding hollow part is provided with a floor and a small hole for drainage. The core of the wall is filled with a weak concrete mixture. The protruding containers are filled with sand on top of a layer of fertilizer. The containers can be arranged in various patterns and the wall can be provided with containers on one or two sides. In the tropics the containers may face any direction and the walls can be quite closely spaced (1.2–1.5 metres).

On the walls surrounding the demonstration homestead in Gaborone, Botswana, there are 2000 containers. Also the tanks for storage of rainwater are made as container walls.

A variety of vegetables and ornamentals are grown in the containers. Dr Nilsson is able to produce 2 kg of tomatoes per container four times a year. The retail price of the tomatoes produced on 1 square metre during one year is roughly equivalent to the cost of building 1 square metre wall so cost is recouped quickly and profit can be made.

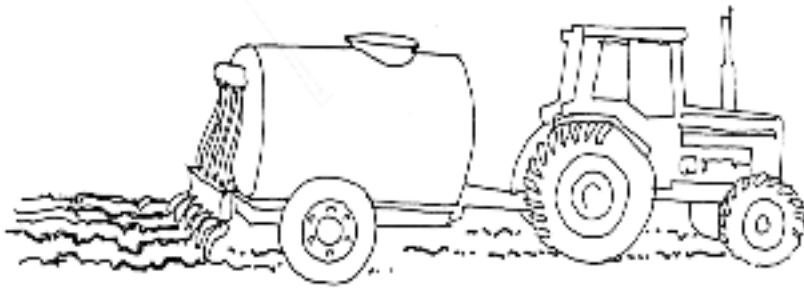


Figure 5.2 *In current R&D projects in Sweden human urine is stored in tanks on site, periodically collected by farmers and applied to their crop land with mechanized equipment.*

Chapter 6

GREYWATER

6.1 Introduction

The wastewater from kitchens, baths and laundries is known as greywater. In eco-san systems greywater is not mixed with toilet water containing human excreta. This significantly reduces the hygiene and environmental problems associated with wastewater management. But greywater still has to be managed in some kind of technical system where it can be returned to Nature in a responsible way.

The objectives of including greywater systems within the context of eco-san can be summarized as:

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

In rural areas the handling of greywater is seldom a major problem. Volumes are small and the content of hazardous or infectious substances is low. Greywater can be infiltrated into the ground or used for irrigation of trees.

In urban areas, the situation is different. Consumption of water and the use of household chemicals are greater than in rural areas. More buildings per unit of surface area limit the space for processing the greywater and increase the risks of environmental problems and human contact with polluted water. Urban areas require carefully designed and well-maintained systems for collection, treatment and discharge of greywater.

The design and operation of technical systems for greywater management depend on a number of factors: climate, land-use pattern, existing drainage systems and pollution load. The choice of treatment is also affected by how greywater is regarded by the community. The best system must therefore be found by considering local conditions and potential risks of alternative options.

The aim of this chapter is to give an overview of planning strategies and techniques for greywater management, with a focus on urban conditions. Our knowledge and experience of greywater treatment in urban areas and in different climates is still scant and mostly from cold regions. The current rapid development of urban eco-san will probably give us new insights in this field over the coming years.

6.2 Greywater characteristics

6.2.1 *Water amounts*

The amount of greywater produced varies between households. While the water consumption in poor areas may be as little as 20–30 litres per person a day, a person in a richer area may use several hundreds of litres a day. Water consumption can be reduced with the introduction of water-saving devices and a payment system based on the amount of water consumed.

Examples from Germany, Norway and Sweden show what can be achieved. In the ecovillage of Flintenbreite in Lübeck (see 3.2.3), where water-saving equipment has been installed, the mean greywater production is no more than about 60 litres per person a day.¹

6.2.2 *Biodegradable compounds*

The composition of greywater varies greatly and reflects the lifestyle of the residents and their choice of household chemicals for dish-washing, laundry, etc. A characteristic of greywater is that it often has high concentrations of easily degradable organic material like fat, oil and other substances from cooking, as well as soap and tensides (surfactants) from detergents.

6.2.3 Pathogens

The content of pathogens in greywater is low. The risk of infection is related to its faecal contamination. As source-separated greywater normally contains no faeces it is often regarded as harmless.² Still, many public authorities around the world regard greywater as a health hazard. One explanation for this is that there may be high numbers of indicator bacteria in greywater. Recent research has shown that enteric coliform bacteria tend to grow in greywater because it contains easily degradable organic compounds. The use of coliform bacteria as bacterial indicators therefore tends to overestimate the faecal load and the potential risk posed by greywater. The fact that greywater easily turns anaerobic and creates bad odours may contribute to the belief that it is a health hazard.

In recent years other methods have been developed to assess the hygiene quality of water. By measuring chemical biomarkers, such as faecal sterols, a more accurate estimate of the faecal contamination can be made. Studies of a local treatment system in Vibyåsen, north of Stockholm, concluded that conventional measurements using traditional bacteria indicators overestimated the faecal load by 100 – 1000 fold as compared with measurements using chemical biomarkers. Using new methods (with coprostanol as a biomarker) the faecal load in the greywater in Vibyåsen was estimated at 0.04 grams per person a day.³ (A normal faecal load in mixed toilet- and greywater from households is about 150 grams per person a day.)

The important conclusion is that untreated greywater is likely to contain far lower densities of pathogens than effluent water, even from an advanced wastewater treatment plant.

6.2.4 Nutrients

Greywater normally contains low levels of nutrients compared with ordinary wastewater from water-borne systems. The biochemical oxygen demand (BOD) of wastewater in Sweden is 60–70% of that in normal mixed wastewater. Nitrogen is 5–10% of that in normal mixed wastewater and phosphorous is 5–50%. Levels of nitrogen and other plant nutrients are always low but in some greywater high concentrations of phosphorous are found.⁴ This phosphorous comes from detergents, where it is used for softening the water. Phosphate-free detergents are available on the market. In general these are as cheap and as good as those containing phosphorous. If people were to use only phosphorous-free detergents, the phosphorous content in

greywater would be reduced to levels lower than that normally found in wastewater after advanced treatment. Some countries in Europe and some cities in East Asia have banned phosphorous-containing detergents to protect freshwater bodies. This explains why the levels of phosphorous in greywater in Norway are only 10–20% of those normally found in Sweden.

6.2.5 Heavy metals and other toxic pollutants

The content of heavy metals and organic pollutants in greywater is generally low but can increase as a result of addition of environmentally hazardous substances.

The levels of heavy metals in greywater are, for most substances, approximately the same as in mixed wastewater from a household. However for some metals such as zinc and mercury the levels are lower.⁵ Metals in greywater originate from the water itself, from corrosion of the pipe system and from dust, cutlery, dyes, and household chemicals.

Most organic pollutants in wastewater are in the greywater fraction, hence the levels are in the same concentration range as in mixed household wastewater. Organic pollutants are present in many of our ordinary household chemicals, e.g. shampoos, perfumes, preservatives, dyes and cleaners.⁶ They are also in fabrics, glue, detergents and floor coating.

By using environment friendly household chemicals, and by not pouring hazardous substances such as paints and solvents into the sink, the levels of metals and organic pollutants in greywater will be kept low.

6.3 Components in greywater management

Successful management of greywater involves proper design, and taking into account the size of the different technical components involved. Also the ‘soft’ aspects of the system, such as user participation in running and maintaining the system, are important.

Rural greywater can be managed using relatively simple household-based methods like soil infiltration and evapo-transpiration beds.

When planning greywater systems for urban, high density locations

the following collection and treatment components should be considered:

- control at source
- pipe systems
- pre-treatment
- treatment
- end uses

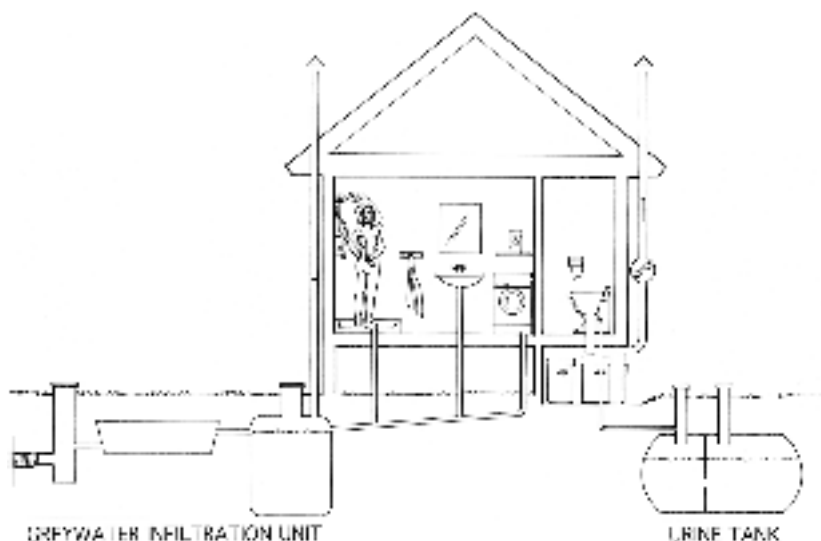


Figure 6.1 A house with on-site greywater management. On the right-hand side is a urine-diverting toilet and a urine tank.

6.3.1 Control at source

Any strategy for managing greywater will be made easier by water-saving measures as well as attention to reducing the use of household chemicals.

Technical components for a greywater system such as septic tanks, sand filters, soil infiltration systems and other treatment applications are designed in relation to the amount of water and BOD. Reducing these parameters at the point of origin gives us more options for cost-efficient and volume- and space-saving solutions. Source control makes the maintenance of the system more robust and efficient in terms of purification.

To reach and maintain a conservative use of water, experience shows

that water-saving equipment installed in households should be combined with economic incentives, i.e. a fee system based on water consumed. By combining technical and economic tools for water saving, greywater production can be reduced significantly without jeopardizing comfort and hygiene standards for the users.

Box 6.1 *Decrease in water consumption*

By using water-saving equipment such as mixer taps and water-saving shower nozzles, water consumption as well as energy for producing hot water is reduced. In Sweden the average water consumption has decreased from 220 litres per person per day in 1965 to 180 litres (150 litres in new houses per person per day mainly as a result of the development of washing machines and dishwashers that use less water.

The BOD load should be controlled at the household level. Such control includes information on proper behaviour and appropriate design of systems. In industrialized countries overdosing with household chemicals is common and is responsible for the increased levels of BOD often observed in wastewater during recent years. Correct use of such products is therefore an important part of greywater management. BOD levels in greywater are also a function of grease and oil used in food preparation.

Larger particles, fibres and grease should be removed at source to prevent clogging of the pipe system. Outlets from kitchen sinks, showers, bathtubs, washing machines and other fixtures and appliances should therefore be fitted with appropriate screens, filters or water traps. For greywater from restaurants and in households where large amounts of grease and oil are handled, special grease traps may be necessary to protect the pipe system from clogging.

As mentioned above, high levels of organics, phosphorous, organic pollutants and some of the heavy metals found in greywater come from household chemicals. Greywater management should therefore promote the use of environment-friendly household chemicals.

6.3.2 *Pipe systems*

A pipe system is needed to collect and transfer water to where it will be treated and used. Design and plumbing for greywater collection systems are similar to those for mixed wastewater. In eco-san, as there is no need to flush toilet waste, smaller pipes can be used

compared with mixed wastewater (flushing-and-discharge) systems. All pipe systems must have evacuation of air and odours. Normally a self-ventilating pipe arranged as a chimney above the roof is enough. Bad odours will sooner or later arise in the collecting systems. All pipe connections in the house must therefore be equipped with water traps. In extensive pipe systems, special consideration needs to be given to the problem of toxic and corrosive hydrogen sulphate produced from anoxic conditions.

Clogging from grease is a potential risk that must always be considered in greywater management, especially when the pipe system is extensive. Pipes must be laid straight with a gradient of at least 5 mm per meter. Pipe systems need to have flushing pipes and/or traps for use in case clogging occurs.

In smaller systems direct treatment and use is often the most appropriate option. In these systems, greywater is led directly to a mulch-bed where water is used for growing plants or trees. Such a system must be designed and sized so that also big particles can be digested by the soil ecosystem. The most appropriate solution is to connect each source of greywater to an individual mulch bed. Then the pipe system can be simple, and no flow splitter needs to be used. In countries with cold winters and water shortage, as in the Erdos project in China (see 8.1.4), a summer/winter system can be used. Such a system can be operated for direct use in summertime and for treatment and percolation in wintertime.

6.3.3 Pre-treatment

Pre-treatment is needed as soon as greywater is collected in larger pipe systems or stored for longer periods. Without such pre-treatment fats and other biodegradable organic compounds will clog the system or create bad odours. In pre-treatment suspended solids are removed mechanically by gravity, screens, seals or filters. The need for removal of suspended solids depends on how the water will be treated and used. The septic tank concept is an efficient and reliable technique that is useful in most treatment systems in rural as well as urban areas.

Septic tank

A septic tank is used for separation of particles and water. Floating particles are collected in the scum at the top of the tank and sinking particles are collected as sludge at the bottom. Transporting grey-

water in a pressurized system may have a negative effect on this separation.

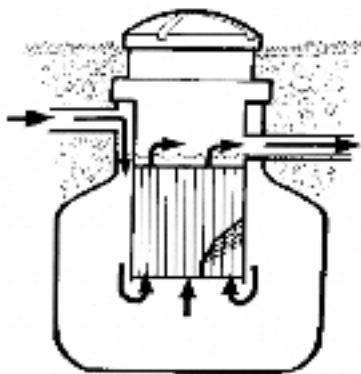


Figure 6.2 *Septic tank for greywater.*
(Design: WM-ekologen / P. Ridderstolpe).

Untreated greywater should never be stored in open ponds. Such ponds will create odours and nuisance for people and provide a perfect site for the increase of bacteria and other organisms that thrive on organic carbon.

Screens, seals and filters

Different pre-treatment devices based on screens, seals and filters are available commercially. Prefabricated devices are useful in large wastewater systems and in special applications such as drip-irrigation systems. For ordinary home-applications they will seldom be cost-efficient and reliable enough.

Homemade seals or filters based on gravel may be appropriate in small-scale systems. In rural areas in warm climates an open gravel filter combined with soil infiltration can provide full treatment.

6.3.4 Treatment

Section 6.2.3 above explains how, from environmental and hygiene points of view, greywater is relatively harmless compared with mixed wastewater. Besides, greywater problems tend to have only local impact. But if not managed properly, greywater may turn mal-odorous. We must therefore reduce the high levels of easily degradable compounds that are responsible for the bad smell. This should be done right away as anaerobic conditions and odours develop within hours if the weather is warm. Wherever greywater is exposed to the atmosphere, it should first be treated to ensure that BOD does not cause anaerobic conditions.

We also want to reduce levels of micro-organisms, organic pollutants and heavy metals. This is especially important when greywater is infiltrated to groundwater or used for irrigation.

The most appropriate method for achieving the above targets is to use *attached aerobic biofilm techniques*. In these techniques, the biological degradation of organics typically takes place in aerated conditions. The treatments range from extensive land applications to intensive applications, such as trickling filters and biorotors (see Figure 6.3).

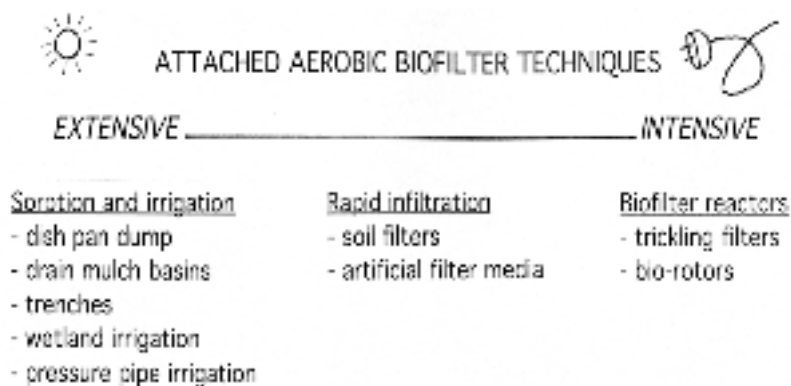


Figure 6.3 Examples of attached aerobic biofilm techniques. On the left are extensive applications that require little technical input, but often a large land area. On the right are intensive applications that require more input of technique and energy, but less land.

Where climatic conditions are favourable, aquatic systems, such as ponds and wetlands, can be used for greywater management. But such systems may not be appropriate for wastewater in cold climates and where water is scarce.

All aerobic attached biofilm techniques trap suspended solids in a filter medium, and then they are digested by micro-organisms well supplied with air. The most appropriate solution for greywater treatment is to filter it through soil.

Sorption and irrigation

Sorption and irrigation systems (slow-rate systems) use a soil filter to convert polluted water into a valuable plant asset. These systems should therefore be designed according to the water requirements of the plants. The amount of water that can be applied to an area varies typically from 2 to 15 litres per square metre per day depending on

the local evapo-transpiration rate.

Figure 6.4 illustrates direct application of greywater to a mulch bed. The bed is constructed by filling an excavated area beside a tree or a bush with gravel, bark or wood chips. The application device and the design of the bed must ensure that water is spread all over the area without clogging the inlet or water logging the soil used for plant growth. Water often flows to the mulch bed by gravity but pressurized systems can also be used.



Figure 6.4 An example of direct use. The water is piped to a bed where it is applied below a mulch surface and is available for plants or trees.⁷

Vertical soil filters

Soil filters can be used for greywater treatment. In the literature various terms are found for these systems: rapid infiltration, high-rate or vertical soil-filter systems.

Appropriately designed and operated, a soil filter has high removal efficiency for suspended solids and organic compounds. Removal efficiency for suspended solids and BOD is typically around 90–99%. Removal of bacteria and viruses is also high: 95–99% removal can be expected for most pathogens.^{8,9,10} The treated greywater from a vertical soil filter thus has low levels of pathogens compared with mixed wastewater.

In natural soil-filter systems, phosphorous and heavy metal removal is significant. Depending on soil properties, depth of unsaturated zone and wastewater load, removal efficiency of phosphorous in a soil filter has been estimated to be 30% to 95% over its lifetime (25–30 years). Also, nitrogen is reduced in a soil filter bed by nitrification and denitrification. Soil filters fed by mixed wastewater typically show a nitrogen removal efficiency of about 30%.

The design of vertical soil filters is based on wastewater load and

BOD load. Typical loads for soil infiltration filters are 40–80 litres per square metre per day, or 4–6 grams BOD per square metre per day. The soil in the filter must be neither too coarse nor too fine. If the natural soil is not appropriate for infiltration, its capacity can be improved by using filter sand as an infiltration layer. A soil filter with special filter sand, and a bottom drainage layer for collection and discharge of treated water, is called a sand filter.

Vertical soil filters can be constructed in many ways. The challenge is to find a practical way to treat as much water as possible without clogging and saturating the soil with water. To achieve this, water must be distributed evenly over the filter surface. In gravity systems, so-called ‘controlled clogging’ has proved to be a feasible method: water is distributed over clogged bottoms (e.g. a narrow trench) while infiltration takes place through the walls. Techniques for spreading water in pressurized systems can be divided into surface flooding techniques, application through perforated horizontal pipes, and spraying or sprinkling systems.

Trickling filters and biorotors

These systems purify water by using attached biofilm in filters with a high water load. In a trickling filter, the water is spread over the filter medium by rotating arms or nozzles. The filter is filled with a strong filter medium with a large surface area and large pores so that it is not clogged by biofilm. Earlier applications used brick towers filled with round stones but nowadays, prefabricated plastic materials are used.

By using a trickling filter or other more intensive applications (e.g. biorotors, or activated sludge) the space needed for treatment is reduced. Drawbacks of these systems are that they need electricity and that they produce sludge.

Semi-wet wetland systems

By semi-wet wetlands we mean artificial wetlands to which water is intermittently loaded and drained. The idea behind this concept is to promote efficient spreading of water over the surface where filtering of suspended solids and sorption mechanisms take place. During the periods of drainage biodegradation and chemical sorption mechanisms are promoted because of the air contact.

In overland flow systems, water is flooded over a gentle slope typically covered with grass. In many countries the technique is frequently used in rural areas for fertilizing pastureland or for irrigating meadows for hay production.

An overland flow system for wastewater treatment is typically constructed on soil with a low capacity to absorb water (loam or clay soils). The load of water may range between 50 and 200 mm/day. To prevent soil erosion, the slope should not be steeper than 8–10 degrees.

During the last 10 years the overland flow technique (as well as impounding wetlands, i.e. shallow dams that can be filled with water and drained) has been used as the biological step in municipal wastewater treatment plants in Sweden. These systems are easy to construct and operate and have a high capacity.

In the smallest on-site applications these systems can be constructed as shallow open ditches, but in larger applications they may need a more sophisticated construction, for example an artificial wetland.

Ponds and aquaculture

Ponds and wetlands differ from the techniques described above in that they use a medium continuously saturated with water. Such conditions are normally unfavourable for oxygen-consuming processes, as gas movement is slow in water. Also movement of air by dispersion is slow in water. This explains why anaerobic conditions occur easily in water but never on land. It also explains why aquatic media in conventional biological treatment have to be aerated to work.

In warm climates, use of oxygen produced by growing plants can save the cost of aeration. Such systems use the symbiotic relationship between heterotrophic bacteria that produce carbon dioxide and micro-algae that produce oxygen. To prevent secondary pollution from the micro-algae that are produced, or oxygen depletion and a release of sorbed phosphorous following plant die-off, the plant biomass has to be removed from the system. This can be done by harvesting plant biomass directly, or transforming it via the food chain into secondary or tertiary production that can be harvested later. Examples of pond systems using primary production directly are the so-called high-rate ponds where, typically, bluegreen algae are cultivated for single-cell protein production.^{11,12,13} Well-developed techniques for carp fish polyculture production are found in several countries in Asia. In other parts of the tropical world, a grass-eating fish, tilapia, is used as a biomass converter in wastewater aquaculture.^{14,15}

There are many examples in the world where manipulated pond ecosystems are used for wastewater treatment without producing any

valuable crops. Especially in urban areas in cold climates, these systems are seldom appropriate since large areas are needed and treatment results are uncertain. In arid climates, use of these systems should also be questioned, as a large amount of valuable water is lost by evapo-transpiration.

6.3.5 End uses

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

- discharge to surface water
- percolation to groundwater
- use in irrigation

Discharge to surface water

Discharge to surface water is often the easiest and most natural way to return treated greywater to the environment. If the water is treated in a soil filter or a trickling filter, it can normally be discharged in open ditches and drained away together with stormwater. Treated greywater can be used for landscaping, like the creation of wetlands and dams in parks. The water may, however, in spite of treatment, still contain oxygen-consuming substances or nutrients that are too high to produce attractive and stable aquatic ecosystems. In this case, the treated greywater would have to be given a second treatment, for example by letting water trickle through the root zone in a trench before it is discharged into a pond.

Percolation to groundwater

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

- Use only reliable methods that include the removal of suspended solids, BOD and bacteria.
- After treatment let the water percolate through the ground in an unsaturated zone of 1 metre depth or more. The subsoil should consist of sand.
- Leave a safety zone between percolation fields and wells. The extent of the safety zone must be determined according to local soil and groundwater conditions.

Use in irrigation

When greywater is used for irrigation special precautions are required. The following recommendations should always be followed:

- Method of application: Water should be applied to the soil or sub-surface rather than sprinkled.
- Choice of crop: Crops where leaves or stems are not eaten directly as well as fruit trees and bushes are most suitable for greywater irrigation.
- Waiting period: When irrigating edible crops, a certain waiting time between irrigation and harvest should be observed.

Chapter 7

PLANNING, PROMOTION AND SUPPORT

Eco-san systems may, for the user, seem more complex than conventional sanitation systems, and they do usually place more responsibility for appropriate functioning on individual families and local communities. Users must become aware that, despite potential health benefits, improper use of any toilet may turn it into a nuisance, threaten public health, and pollute the environment. These problems can best be avoided by adopting the appropriate behaviours from the outset. In addition, special care is required to take full advantage of the significant resource potential of the recycled plant nutrients.

At the household level individuals and families must understand how the eco-san system works, what can go wrong, and have the commitment and skills to manage it correctly. For large-scale application, it is also essential that a significant part of the local community shares this understanding and commitment.

In urban areas the fundamental issue of eco-san is how to establish a full-scale operation. It is one thing to operate scattered eco-san devices spread over a large rural area; it is a different matter to make thousands of eco-san devices work properly in a densely populated urban area.

This chapter will examine issues related to planning, promoting and supporting eco-san systems on a larger scale in urban and rural areas. Urban and rural planning, promotion and support will have fundamental differences, and thus this chapter is divided accordingly. We open this chapter, however, with the cultural factors affecting acceptance of eco-san and a paradigm shift in thinking that is often required at all levels for eco-san to be accepted and applied.

7.1 Cultural factors and facilitating change

7.1.1 *The faecophilia–faecophobia continuum*

One of the key obstacles that a new eco-san programme must overcome is the understandable and in some ways rational fear of human excrement, which we might refer to as ‘faecophobia’. Faecophobia is a personal or cultural response to the fact that human faeces are malodorous and potentially dangerous.

In some cultures this response has been codified into concepts of ‘clean’ and ‘unclean’. Hinduism is the prime example. A traditional upper caste Hindu would have nothing to do with human faeces, not even his own. This is not because they are malodorous but because they are perceived as unclean. Anyone touching them also becomes unclean. The only people supposed to handle human excreta and to clean toilets are the ‘untouchables’. Even today this is a reality in both traditional villages and major cities.

Faecophobic attitudes are also common in Africa south of the Sahara. Here many farmers have until recently been practising shifting agriculture. There was no need for them to recycle human excreta and as shifting agriculture often meant a semi-nomadic life there was no tradition of building permanent wells and toilets. Faeces were dropped on the ground and the smell of other people’s faeces was perceived as a warning signal.

In contrast, on the densely settled flood plains of China farmers have for a few thousand years had to fertilize their fields. Traditionally in China all human excreta was returned to the soil, fresh or composted. In China human excreta was therefore considered a valuable product.¹ Even today the rural Chinese have no problems talking about it, smelling it or handling it. Such a culture can be called ‘faecophilic’.

Faecophilia thus represents one extreme point of a continuum where the other extreme is faecophobia. This model can be used to describe and understand a complex and changing reality. Indeed, most cultures – or sub-cultures – are somewhere in-between the extremes.

It took the AIDS pandemic to convince society that sexual behaviour is a topic to be discussed in social gatherings, educational institutions and public places. Are the global water, environmental and agricultural crises enough to convince us that it is now time to talk about

human excreta and how we handle them?

7.1.2 Participatory methods to facilitate change

For many cultures and for many leaders and families, acceptance of eco-san with its new toilet designs and new behaviours will require a paradigm shift in the way they think about and talk about sanitation. To ensure that the eco-san users can integrate the system into their local culture, including the capacity to set up, operate and maintain an eco-san system, it is usually necessary to train facilitators. These facilitators are likely to be more effective when they are attached to existing programmes, such as water, health, agriculture or environment.

To equip the team of eco-san facilitators adequately, a balance of three complementary educational strategies should be considered: *participatory learning*, *sharing information* and *skills training*. The degree of emphasis towards one approach or another will depend on the specific culture. For example, the use of participatory learning methods will be essential where urine diversion and the concept of recycling are unfamiliar or unacceptable. On the other hand, highly motivated cultures, with few or no basic resistances or taboos may simply require information on the options available and specific skills training on how to construct the units and monitor their operation. Whatever the combination, it is especially important to maintain a holistic, interdisciplinary approach, which will permit the users to integrate eco-san into their local culture and lifestyle.

The effective use of participatory methods can be vitally important to the success of eco-san programmes, as well as to hygiene and sanitation programmes in general. These methods involve users in the overall identification of problems and needs, in planning and finding solutions, and in monitoring health and environmental impact. User participation is essential to make necessary adjustments to the system.

The various participatory learning methods useful for sanitation programmes include ‘Saras’ and ‘Phast’. Saras is a participatory non-formal education and training method, developed by Dr Lyra Srinivasan and associates in the 1970s.² It is a human growth-oriented approach for enabling individuals and groups to assess their situation, problem-solve, seize opportunities and plan creatively – realizing their full potential in the face of life’s challenges. Saras seeks to stimulate a process of dynamic transformation based on: personal

growth and confidence, group process and leadership skills, resourcefulness, creativity, planning for practical applications, action planning, commitment to sustainable improvement and responsibility for follow through.

In 1992 the World Bank Water and Sanitation Programme and WHO joined forces to produce better methods for hygiene education by adapting the Sarar method to stimulate sanitation and hygiene behaviour improvement. The result was the Participatory Hygiene and Sanitation Transformation initiative (Phast).³ Phast provides a simple step-by-step process and tools to map local resources, explore the linkages between health and sanitation, assess people's knowledge gaps, promote discussion around the problems they identify and begin to develop strategies to address these problems.

7.2 Eco-san in urban areas

7.2.1 Planning

Planning for urban eco-san systems takes place in much the same way as planning for conventional sanitation systems has taken place in the past. The town or city must consider the quantity and quality of its water resources, its existing sanitation systems, and its storm drainage. It must consider whether the city floods periodically in the rainy season, or has serious water shortages either during the dry periods or permanently. It also has to consider what kind of sanitation the city can afford and how it wants to move forward with regard to sanitation over time.

Like all other city development planning, decisions as to whether to incorporate eco-san options into the existing system, or to maintain and extend an aging sewerage system, are normally taken by the city council or other governing body of the city.

7.2.2 Promotion, education and training

Promotion of eco-san at the urban level usually begins with educating the city staff and developers on the benefits and costs of this new approach to urban sanitation. This may require visits to urban or rural communities that have adopted eco-san so that staff and leaders can see eco-san in operation for themselves. Once city staff and city leaders are convinced that eco-san would be good for their town or city, the next step is to make a preliminary plan for the city and then

bring that plan to the public.

Before any plan is finalized, there may be a period of further studies on different aspects of eco-san for the urban setting, such as the best ways to collect, store and utilize urine and how to transport it to farmers. Studies on alternative greywater systems may be required. The city would also need to look into setting up new types of urban services and training for its workers, and this might need a period of research or trials (see 8.1.5).

Promotion to the public in an urban setting might involve meeting with smaller political units within the city to seek their feedback on the proposal and to determine what further information campaigns will be required for the public in general. Urban ecological sanitation systems will be managed less by households and more by urban services. Households will need to know how their new system works, how to use the eco-san devices properly and how much they need to pay. They will probably not be involved in any aspect of collection of urine and sanitized faecal products from household toilets.

A public education campaign needs to be designed and implemented before construction begins. Demonstration units should be built within neighbourhoods so that households can see what is coming. All sorts of civil institutions could be targeted such as men's and women's organizations, schools and religious institutions. Radio, television, newspapers and magazines can be used extensively to publicize the message.

Large-scale urban eco-san systems require training at various levels:

- Key local authorities and field staff must be properly trained in the principles, technical solutions, comparative advantages and limitations of eco-san systems and may also need training in community empowerment methods.
- Builders need to understand the basic principles of eco-san in addition to practical training in eco-san specific construction and installation.
- The staff responsible for collection, transport and secondary treatment must have a good understanding of sanitation-related public health, eco-san principles and practical issues related to eco-san operation and maintenance.
- Household members must know how to operate and maintain the eco-san devices in their homes.

7.2.3 Institutions

An urban eco-san system may involve creating new institutional arrangements. Since the system will not be water-borne, the city may wish to create a new department separate from the water and sewerage authority. It may wish to create an institution that links the eco-san products with rural and urban end users.

7.2.4 Financial aspects

The financial arrangements for a large new urban eco-san system may be similar to those for urban sewerage systems. In developing countries the new eco-san system may require a loan from an international bank, in which case the bank might be involved in planning and decision making. Smaller urban and peri-urban projects might be financed from local resources and involve more community participation in planning and implementation.

The introduction of eco-san systems is bound to lower the total costs of urban sanitation. Conventional sewers, treatment plants and sludge disposal arrangements will cost several times as much as an eco-san system. This is particularly important for developing countries, where public institutions face stringent financial limits. Eco-san systems require much less investment as they need no water for flushing, no pipelines for the transport of sewage, and no treatment plants and arrangements for the disposal of toxic sludge.

However, urban eco-san systems will involve costs for information, training, monitoring and follow-up that are greater than corresponding costs for conventional sanitation systems. In principle and in most cases, during the early pilot project phase, the organization funding an eco-san project may need to pay the entire cost of holding workshops and courses, and building demonstration toilets, greywater systems and eco-stations. But once the project has been initiated and the local work teams have been set up along with national and international experts, the scale-up costs need to be covered by the local authorities and the users/beneficiaries. A good example is what is happening in China since Sida and Unicef in 1998 funded a small pilot project in one village in Guangxi province: 5 years later more than 100,000 households have installed eco-san toilets (see 3.1.1—China).

Successful urban sanitation relies on sound finances. In principle, households should fully repay investment and operational and main-

tenance costs to ensure the sustainability of the system. In practice, pilot peri-urban sanitation programmes involving free or highly subsidized demonstration models are likely to fail in the long run when false expectations have been raised regarding the cost of the system. Furthermore, an urban eco-san system will generate additional costs that are not usually present in small rural eco-san projects, such as the safe handling, transportation, storage of urine and dehydrated or composted material from many devices. On the other hand, the economic (and ecological) value of the fertilizers produced could be significant.

As in all other urban services such as water supply, sewerage and electricity, payment for services is an accepted fact. The city could continue and if necessary upgrade whatever payment system it now has in place for water and sanitation.

7.2.5 Codes and regulations

Ecological sanitation is so new that few cities and towns today have any regulations that refer to eco-san systems. Existing regulations pertaining to water-borne sanitation systems are not appropriate. New regulations will be required.

When eco-san is to be introduced on a large scale there is a need for specific regulation of the use of human excreta, and sometimes also greywater, as inputs for agriculture. Such recognition is important because it is the starting point for eco-san to become the object of plans and programmes, financial incentives, tax exemptions, specific grants etc.

It is important that new regulations in this area do not specify which techniques are to be used. Today regulations are often written so that they exclude systems that are not based on using water for transporting human excreta. The ideal is to have regulations based on technology-neutral functional criteria. These regulations should state in qualitative terms the required performance of the sanitation system to achieve societal goals.

Urban eco-san toilet systems have four main features: urine diversion, containment, sanitization and recycling. Regulations based on required performance criteria for each of these are necessary. Guidelines on the health aspects of eco-san systems and the environmental aspects for reuse of urine and faeces are outlined in Chapters 2 and 5. These are the foundations to performance criteria and the

development of codes of practice.

7.3 Eco-san in small towns and rural areas

7.3.1 *Planning*

Typically in the past, planning for sanitation and water supply systems in rural areas and small towns took place at higher levels of government, at state, provincial and municipal levels, and decisions were communicated to the administrative levels below. However, in recent years there has been recognition that, when planning begins at the local level and moves upwards, and when communities have more choice, there is a greater chance of achieving sustainable systems. This is because the systems are planned in accordance with local ecological conditions and local cultural practices.

Community management of rural and small town water supply systems is now common in many parts of the world. Water committees are formed at the start of new projects and they participate in the design of the new scheme. Experience shows that sustainability is more likely when users feel a sense of ownership of the systems because they selected the design, participated in construction and made key decisions along the way.

The same principle can be applied to eco-san systems. Local government authorities and local community groups should form partnerships to lead sanitation programmes. Sanitation committees can be formed in communities to lead in the planning and implementation and to develop a sense of ownership and responsibility for community sanitation.

7.3.2 *Promotion, education and training*

A sure recipe for failure of a rural ecological sanitation programme is to put it in place without the participation of the intended users and without proper instruction. This is clearly illustrated by the example in Box 7.1.

Box 7.1 *The FIS project in El Salvador*

In 1992–94, in a project financed by IDB, the government of El Salvador built 50,263 LASF toilets (see 3.1.1). The total investment at that time was USD 12.5 million. The toilets were built by contractors without community participation and little or no community training.

A sample survey of 6,380 families carried out in 1994 showed that 39% of the toilets were used adequately, 25% were used inadequately and 36% were not used at all.¹

These findings led to the development of a hygiene education strategy that focused on personalized education for all family members through home visits, participation of organized women in the implementation of the whole educational process, education materials and user-friendly monitoring and evaluation. After the completion of the first education module, the percentage of proper use increased to 72%, and the toilets that were being used improperly or were not being used at all decreased to 18% and 10%, respectively.²

The lesson learnt from this whole process was that the problems of non-use or improper use are not because of the technology itself but because of the interaction between technology and user. Promotion should therefore be on a personal and family basis, in order to provide advice on the spot. The need for behavioural changes, proper use and maintenance should be stressed.

Women

It is particularly important that women are included in the empowerment and promotion process right from the beginning. Women are the ones normally responsible for the household water supply, sanitation, hygiene and food preparation. They generally also play a major role in the education of the children in regard to health and hygiene issues. Their views and concerns must be expressed and integrated into the programme design as well as in detailed design decisions. Special effort should be made to assure that the toilet designs take into account women's special privacy and security requirements and are ergonomically appropriate for women, men and children.

Key or 'model' families

No matter how effective the eco-san system may seem, its long-term success will depend on the credibility it enjoys with potential users. For the system to become an integral part of local culture, it must first be shown to work and it must be acceptable to respected local leaders and opinion makers. A visit to a well-functioning eco-san toilet in a neighbour's home is one of the best ways to convert non-believers.

Local grassroots organizations

It is generally best to work through local organizations that are successful and well known within the community. Such organizations might include community water committees or health committees.

Local government

In the long run the support of local government will be essential for designing and installing the necessary infrastructure for supporting eco-san systems on a meaningful scale. Indeed, enlightened political commitment has been perhaps the principal common critical element in the start-up of key urban eco-san pilot programmes, such as that in China. It can be well worth the investment to take community leaders on study tours to other communities and countries so that they can see for themselves and be convinced that eco-san systems do work.

Pilot projects

The history of technology transfer has many examples of programmes that went wrong when planners or politicians tried to go too fast without adequate attention to user participation and understanding. Eco-san is no exception.

It is advisable to begin with experimental small-scale pilot projects through which different eco-san devices may be assessed. During this phase the social aspects of the approach can be refined while demonstrating to a broader audience that the technology works. Broad dissemination requires in addition that hardware, if any, should be available in the market. In the pilot phase, regular follow-up at the household level is required.

7.3.3 Institutions

Institutional arrangements for sanitation vary from country to country. Very often rural sanitation is the responsibility of health authorities. What seems to be universally true is that sanitation lags behind all other sectors in development and often gets the poorest budget and has the weakest strategy.

Eco-san offers an opportunity to strengthen the sanitation sector in rural development by forming an alliance with rural agriculture, rural development and, in some countries, food security bureaus, and by offering more toilet choices to rural households.

Rural eco-san programmes are much more focused around the

household, and thus within one rural community households may choose different eco-san systems for themselves depending upon their preferences. Households with plenty of space may choose the Arborloo (see 3.1.4, Zimbabwe) in order to gradually establish a small orchard. Households lacking spacing and wanting indoor toilets may choose double-vault desiccating toilets with urine diversion. Other households may want to stick with a pit latrine but collect their urine for fertilizer. Whatever the choice, the institutional arrangement should provide back-up and support for families in implementing their choices. At least one local institution should have a field agent capable of visiting households, speaking at schools and rural organizations, such as farmer's associations or women's clubs, and providing information and answering questions. There should also be arrangements for continuous monitoring and evaluation of the eco-san systems in operation for safety and to record benefits.

7.3.4 Financial aspects

Eco-san systems need not be expensive to build because:

For dehydrating and composting types:

- The entire device is built above ground – there is thus no need for digging and lining of pits.
- As urine is diverted and no water is used for flushing the volume of the processing chambers is small.
- The contents of the processing chambers are dry, which means that there is no need for expensive water-tight constructions.

For the soil-composting types:

- The pits are only 1.0–1.5 m deep since they need only hold excreta for about a year;
- The shallow pits are generally not lined and often only require a ring beam at the top;
- Special pans or seat-risers are not required.

Eco-san systems are usually cheaper than flush toilet systems built to the same standards of quality, as the example from Kosovo in Box 7.2 illustrates.

Box 7.2 *The cost of eco-san and flush toilets in Kosovo Schools*

In 2000 and 2001 Unicef helped to rebuild schools in Kosovo that had been destroyed during the 1999 war. At the start of the project most rural and some urban schools had only pit toilets that were full and unusable and with superstructures in a bad state of repair. As the Unicef programme offered only flush toilets, schools without water supply received no upgrades. In order to test the viability of the eco-san concept for schools in Kosovo a block of four eco-toilets was built at one school. The school well was upgraded to supply water for hand washing.

The cost of the new eco-san toilet block and the upgraded well was compared with similar facilities built for similar-sized schools that received flush toilets. The eco-san toilets cost 26% less than flush toilets, even taking into account the upgraded well and not considering the cost of obtaining new water supplies in the other schools (a cost that varied tremendously from school to school). These savings were due to pipes, toilet flushing tanks, a septic tank and labour not needed in the school with eco-san toilets. The school would realize other savings in years to come on maintenance and repairs of pipes and fittings and on not having to empty a septic tank regularly. The most appealing cost savings to the school was the fact that, unlike their pit toilets that lasted less than 10 years, this new toilet block was permanent!

Experience from rural sanitation programmes around the world indicates that subsidies are often an impediment to progress in getting sanitation coverage. Either all households should be subsidized or none should be. Subsidies frequently indicate that households cannot afford to build the type of toilet that has been selected (without community involvement) by authorities from outside the community.

Eco-san offers a variety of options costing different amounts of money. Families should be able to select an option that they can afford. Costs can be influenced by the type of toilet system, choice of building materials, financing arrangements, as well as whether paid labour or self-help owner constructed.

7.3.5 Codes and regulations

Although rural areas of developing countries may have codes and regulations for sanitation from colonial times, they are rarely enforced. In many developing countries sanitation coverage is so poor that governments are still working on getting any hygiene improvements no matter how simple.

Some countries may have regulations against the recycling of human excreta in agriculture. This might be the one and only regulation that would need to be addressed in a new rural eco-san programme.

7.4 Hygiene education and behaviour change

Every responsible sanitation programme has a hygiene education and behaviour change component. Previous sections describe the great importance of community participation in planning for services, and during this planning phase users will learn a great deal about disease transmission and how to block transmission. However, this is unlikely to be enough to bring about and sustain behavioural changes that are required to break the cycles of disease from faecal–oral contamination.

The key hygiene behaviours for breaking the cycle of faecal–oral diseases are:⁶

- Consistent use of toilets to keep faeces out of the environment;
- Hand washing after using the toilet, after cleaning up the faeces of children or helping children to use the toilet, and before food preparation or feeding children;
- Measures to keep drinking water clean;
- Hygienic food preparation and storage and reheating.

All of these behaviours need to be promoted in eco-san programmes.

Eco-toilets often also require new behaviours that people need to adopt. In urine-diverting toilets for example, people must be instructed to use these new toilets so that no urine enters the processing chamber and no faeces get into the urine collector. In cultures where water is used for anal cleaning people must be instructed to wash only over the drain designed for that purpose and not so that water gets into the processing chamber. In double-vault toilets people must be instructed to let the contents of the processing chamber not in use rest for 6–12 months before they are removed. These examples show that an eco-san hygiene education programme needs to be tailored around key hygiene behaviours as well as the behaviours particular to the new eco-san system chosen by the users.

A good communication programme begins with a study of current practices and the main local channels of communication within the community.

In any programme where the population is highly mobile, new families will be moving in who need to learn how to use existing eco-

san toilets. A system needs to be in place to instruct these new families in the proper use of their eco-toilet.

7.5 Monitoring and evaluation

Every eco-san project, whether urban or rural, should include a mechanism for monitoring and evaluation. Some indicators for monitoring and evaluation can be determined by a local community group (such as a water and sanitation committee or health committee) that has participated in planning the new sanitation system. Government authorities and/or NGOs involved in the project should carry out further monitoring and evaluation, using their own indicators.

The WaterAid-supported programme in northern Mozambique, described in Box 7.3, has been especially effective in demonstrating the value of ongoing community-based monitoring.

Box 7.3 *The WaterAid monitoring and evaluation system in Mozambique*⁷

The WaterAid monitoring and evaluation system is designed to assess whether the eco-toilets in the programme are being used effectively and hygienically, and whether they in fact are creating the necessary conditions for improved health. In other words, they recognize that the number of toilets built will have little long-term impact unless they are also able to demonstrate that the toilets are 'used by all and in a hygienic manner'. The monitoring and evaluation system is focusing on:

- Signs of faeces and urine around the drop hole;
- Presence of handwashing facilities (water, soap etc) and evidence that they are used;
- Presence of flies and odour (as indicators of excess humidity and/or insufficient ash/soil application); and
- Family perception of the toilet.

The primary conclusion for the monitoring exercise was that the programme had been overemphasizing sanitation at the expense of the hygiene programme. A better strategy might be to strengthen the hygiene effort, in order for the community to drive the sanitation solution. Monitoring activities had also shown that greater attention should be placed on gender and control issues, since it was discovered that the other members of the household were unwilling to move the slab to the alternate pit (an essential maintenance activity) in the absence of the male head of household.

By placing monitoring and evaluation at the centre of its programme, WaterAid/Mozambique has learned to ask hard questions, stimulate learning, improve programme support and guarantee greater, sustainable acceptance of eco-san.

Chapter 8

A VISION FOR THE FUTURE

8.1 A vision

This book sums up state-of-the-art ecological sanitation at the beginning of this century. We have outlined the global sanitation challenge; explained how human excreta can be sanitized for use as a fertilizer; described a variety of eco-toilets and eco-san systems; discussed the key design and management features that designers need to consider when adapting the concept to different environments and cultures; discussed the main concerns these systems raise in the minds of policy-makers; and provided cautions against failure. We have described how the plant nutrients in human urine and faeces can be safely recycled to agriculture and the great benefits these nutrients have for plants and food production. We have offered options for urban greywater management, as the eco-san concept implies that traditional, centralized sewerage systems will no longer be required. We have outlined our experience on working with urban and rural local governments and communities and what we consider to be the ‘recipes for success’. Now it is time to look ahead into the future. Have these efforts in eco-san over the decade been a fad, soon to disappear? Or can we turn eco-san into a force able to transform our increasingly urban future?

8.1.1 *The next 50 years*

Ecological sanitation today is at the same developmental stage that aeroplanes were at when Louis Bleriot in 1909, a few years after Wilbur and Orville Wright’s pioneering first flight, flew his monoplane across the English Channel from Calais to Dover.¹

Today, everyday, we have thousands of aeroplanes flying the skies of the world, on every continent, each carrying hundreds of passengers. Air travel, so primitive a hundred years ago, in 50 years has become a major form of transport. A key reason for its success was that governments and industry saw its potential benefits to society and invested large sums of money for its development and infrastructure. The same story could be told about the development of the auto-

mobile and telephones in the last century. Both were primitive inventions in 1900, but by 1950 they had been turned into transport and communication systems that transformed our lives. Both benefited from substantial public subsidies for research, development and infrastructure. People a hundred years ago could not imagine that we would fly across continents in one day, make a phone call from Africa to North America in a matter of seconds, and that in many countries most families would own a personal car that they could freely drive anywhere within their own country and beyond without worries about where to get fuel, repairs, or suitable road surfaces.

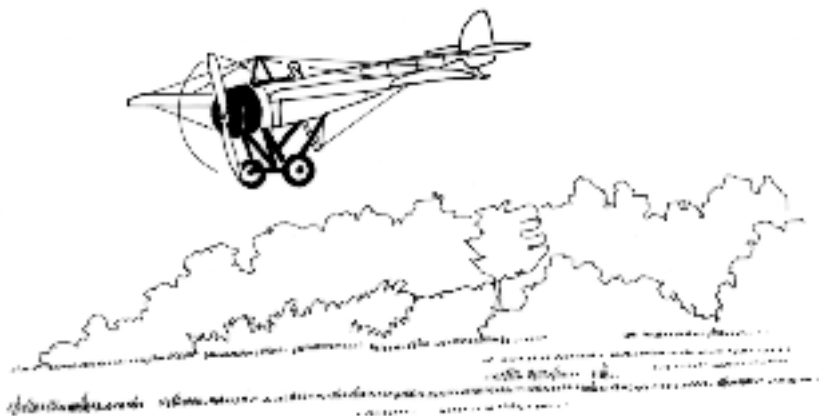


Figure 8.1 *Louis Bleriot's monoplane.*

The future of ecological sanitation, therefore, lies in seeing its potential and investing further in its research, development and infrastructure. We cannot easily imagine the eco-san systems that may exist 50 or 100 years from now. They will no doubt be much more sophisticated than those we have described in this book. However, even in the future, the eco-san principles of containment, pathogen destruction and recycling of nutrients may remain much the same, as these are biological principles.

We envisage eco-san of the future being applied to various ecological, cultural and population-density conditions using technologies not yet invented or not yet applied to sanitation. We see planners of new towns basing their master plans and building designs on ecological principles, including ecological sanitation. And we see existing cities served by old and decaying sewerage systems being retrofitted with ecological sanitation systems. We see government agencies and non-governmental organizations offering eco-san options to rural communities and small towns as alternatives to today's conventional

approaches based on drop-and-store or flush-and-discharge.

Within the next 50 years the world will rebuild or build new urban sanitation infrastructure for an expected 6 billion urban dwellers. Much of that could be ecological sanitation.

8.1.2 Eco-cities and eco-towns

Gradually, since at least 1950, planners and ordinary citizens have been awakening to the fact that we must live in an ecologically sustainable way. We must take into consideration our local and planetary eco-systems when we modify nature to improve our lives. If we continue on our current path of development resulting in increasing air and water pollution and destruction of natural habitats for varieties of species, we will seal our own doom, for a healthy eco-system is fundamental for all life on the planet.

Today that awareness is slowly being transformed into action. Pioneers of eco-living concepts are considering how to reduce our dependence upon automobiles, with all their impact on air quality and urban design and living. They are involved in 'green building', creating buildings that require less energy to heat, cool and light. They are trying to build communities on a human scale where we can walk to school, work and play. They are encouraging more green spaces, trees and other plants in urban areas and more forests in agricultural areas to enhance the chances for biodiversity. They are advocating locally-grown food to reduce dependence on food transported by highly polluting fossil fuels. Eco-san fits well into this overall framework for future ecological living.

The most demanding eco-san challenge in the coming years is to develop and implement systems for urban areas. Urban populations are expected to grow from 3 billion today to 5 billion in about 20 years time, 40% of them living in slums.² Can eco-san systems be used to serve some of these urban populations? – We think so but have yet to prove it.

Around the world there are already examples of eco-san applied to urban areas and densely built-up villages, but the projects are small and scattered. The first major effort to implement a fairly large, comprehensive pilot urban eco-san project in a new town is under way in Erdos municipality in Inner Mongolia, China (see 8.1.4). Another project, emphasizing retrofitting rather than new construction, is under preparation in Tepoztlán municipality in the state of Morelos,

Mexico (see 8.1.5).

Urban or rural – the basic eco-san approach, sanitize-and-ecycle, remains the same. The differences are in the technical solutions required for multi-storey buildings, difficulties of reaching large, fluctuating populations with information, the challenges of communal collection systems, and the need to store, transport and treat large volumes of urine, faeces and greywater on-site or within the neighbourhood. Some solutions do exist and have been tested in smaller projects in Sweden, Germany and China. Other solutions are being developed and tested in the current China-Sweden Erdos Eco-Town Project.³

8.1.3 Eco-stations

An evolving concept in ecological sanitation is the ‘eco-station’. This is a place within an urban area for recycling of solid wastes and secondary processing of human excreta from eco-san toilets. There might be smaller, intermediate eco-stations for groups of houses or apartments and a larger one serving the neighbourhood or town.

In an eco-station the three types of source-separated outputs from the households: the yellow (urine), the brown (faeces), and the grey (greywater), plus source-separated domestic solid waste, are collected from homes and neighbourhoods and transferred to a place (an eco-station) for further processing. At the eco-station the partly sanitized faeces, together with household organic waste, will go through secondary treatment consisting of high temperature composting.

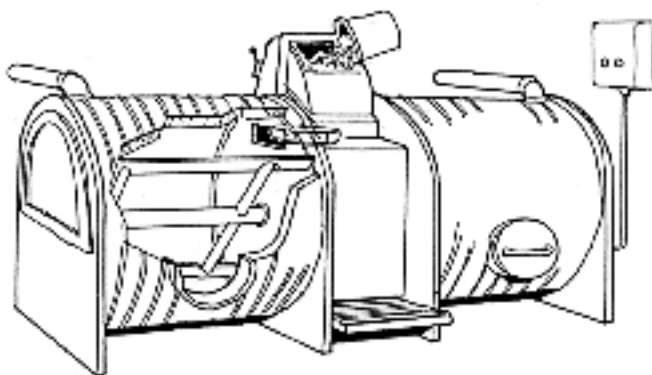


Figure 8.2 A mechanical composter serving 50–80 households. This example is from Sweden ('Jora Kompost 1400') and can handle 450 litre compostable refuse per week.⁴

The purpose of secondary treatment is to further break down the organic material (including toilet paper), further reduce volume and weight and reach an acceptable level of pathogen destruction. If the end-product must be totally sterile, the material could be carbonized or incinerated rather than composted. The urine can be used for the household's own garden or rooftop container garden, but excess urine, and urine from households that do not want it or have no garden, is stored in tanks until sanitized and then sold as a liquid fertilizer to market gardeners and farmers in and around the city. During the cold season there is still a demand for urine fertilizer from farmers who produce vegetables in greenhouses. (Another possibility is to turn the urine into a powder fertilizer.⁵)

Urine can be sold as a fertilizer and sanitized faeces as a fertilizer and soil conditioner. The price paid by farmers and urban horticulturalists will meet part of the staff costs of the eco-station, so that households may have to pay less for collection. The sorted non-biodegradable solid waste is recycled to industry. Each eco-station thus creates a number of jobs for local residents.

The introduction of the eco-station concept must be supported by an education and training programme. Collection workers are trained in instructing and following up households. If at the time of collection they see a problem in the household's sanitation unit, it is their job to discuss the problem with the owner and try to correct it on the spot. In addition, the municipal government has instituted regular monitoring of the neighbourhood eco-stations and the fertilizers being produced. There is periodic testing of both urine and sanitized faeces for public health safety. A bonus of the new sanitation system's educational programme is that a range of hygiene behaviours are addressed as never before. Hand washing, food hygiene and the care of infants and toddlers to prevent diarrhoeal diseases receive greater attention.

Municipal solid waste

Municipal solid waste is a huge and growing problem in cities around the world. In industrialized countries, the production of municipal wastes has increased by several factors as their economies have grown. Developing countries are now following this pattern which is resulting in 'mountains' of garbage piling up on the outskirts of large cities and much waste going uncollected, clogging streets and water courses.

Municipal governments normally need a comprehensive plan for waste reduction and recycling before the problem is properly

managed. Many of these wastes are in chemical forms that do not easily allow for recycling, such as most plastics and discarded electronic components which contain harmful heavy metals that require complex and expensive processes to extract and contain. Most cities of the world collect municipal solid waste and dump it in landfills or on top of the land in open fields. These mountains of mixed waste produce large amounts of methane gas, and release pollutants into the soil and groundwater. It is clear that continuing in this way is unsustainable. A more sustainable approach is a system whereby wastes are reduced, re-used, recycled and raw materials and energy are recovered.

One of the main problems with the way municipal solid wastes are handled today in most cities and towns of the world is that they are mixed. Solid wastes are usually a mixture of wet biomass, combustibles (paper, plastics, wood and textiles), minerals and metals. The proportions vary with the society and its consumption habits, but the result is much the same around the world. Putting all of these mixed materials into landfills or garbage mountains results in an ‘uncontrolled bio-chemical reactor’ and its effect on the local environment is unpredictable.⁶ What is known is that the amount of chemicals released by landfills into the atmosphere and groundwater and surface water is huge and has both local and global effects. Thus, an immediate objective of the solid waste management of an eco-town is to stop the mixing of solid wastes. Biomass can be composted and used to enrich soil, combustibles can be incinerated for energy, and metals need to be recovered.

Municipal solid wastes fall into 12 main categories: reusable items, paper, plant debris, putrescibles, wood, ceramics, soils, metals, glass, polymers, textiles and chemicals.⁷ In addition to these we may add a 13th category: dried human faeces from ecological toilets. For the human excreta products of eco-toilets, professional house-to-house collection will probably be the preferred method and offer the most public health safety advantages.

All eco-stations would have safe working conditions for employees, including facemasks, protective clothing, and sturdy gloves. The transport of the human urine and dried faeces would become a municipal responsibility and they would be collected on a regular schedule using modern equipment for the protection of workers.

Planning and costs

Waste issues should be addressed in a more sustainable way, and

points to be considered when establishing eco-stations include: the cost-benefit analysis; the household behaviours that need to be adopted or changed, such as household separation of refuse into categories; community education; and the need for community compliance. The cost-benefit analysis needs to take into consideration the cost of continuing with the present waste-handling systems ('business as usual'), whatever they may be, including potential existing harm to the environment, and environmental clean-up. Municipal officials and citizens may object to the eco-station concept on the grounds of cost, but until a complete cost-benefit comparison is undertaken, the true cost remains unknown.

As for community education, the programme needs to include education on harm to the environment. Another important message to be conveyed is for consumers to reduce the amount of waste they generate by avoiding excessive packaging, buying products that are easily recycled, and buying products that they can first reuse in their own homes.

Eco-stations can provide new employment opportunities to local communities. In many cities of the world, solid waste is collected and sold for recycling by scavengers, usually the poorest of the poor who have few opportunities for other employment. Their work conditions are usually unsafe and unhealthy. The World Bank estimates that globally there are over 800 million people unemployed or under-employed and perhaps 200 million 'on the move' looking for work. Therefore, there should be no shortage of potential workers for eco-stations.

8.1.4 Erdos: planning a new town

The China-Sweden Erdos Eco-Town Project (EETP) is an ambitious attempt to generate the data, technologies and policies required to bring about a major change in the way human settlements relate to the environment. The project is in Dongsheng town of Erdos municipality in the Yellow River basin, in the southwestern part of Inner Mongolia, northern China (latitude 40° north, altitude 1500 m). This part of China is semi-arid with an annual rainfall of 300–400 mm. The spring season is dry and often windy (sand storm days average 19 in the city area), summers are warm and often wet, autumns cool and winters long and cold. Cold air masses frequently invade from the north and winter lasts for 6 months. The record low air temperature is 32.6°C below zero. The number of frost-free days is on average 135.

Dongsheng is a rapidly growing town with a population of 300,000. Out of the 60,000 households only one-third have flush toilets. The remaining 40,000 households share 370 public toilets. (This sanitation situation is typical for China.) The main source of drinking water in Dongsheng is from underground aquifers. In some parts of the town water is available only three times per day for periods of 30–90 minutes.

The new eco-san neighbourhood is under construction (beginning in June 2004, to be completed by December 2006) on the outskirts of the present city. The project area will accommodate 2000 households on a 50-ha site, most of them in apartments in 4- and 5-storey buildings and the rest in 1- and 2-storey houses. There is already a large primary school on the site. Nursery schools and cultural and commercial facilities will be added.⁸

The major ongoing research/design issues in the EETP are:

Providing eco-san solutions for multi-storey buildings and 1–2 storey houses

Toilet systems with **urine-diversion are the chosen alternative.** A urine-diverting toilet for use in multi-storey buildings has been developed and is now in production.

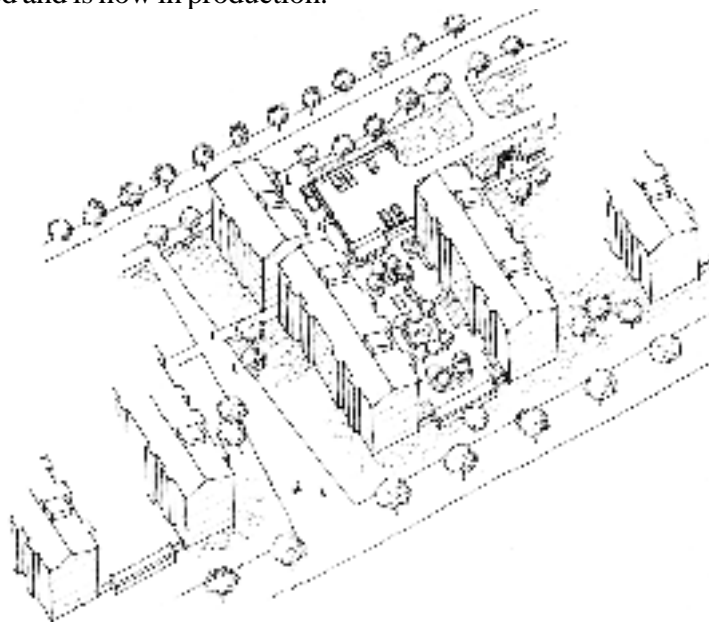


Figure 8.3 Group of apartment buildings with 'mini eco-station', EETP, China.

Providing eco-san solutions for greywater management

A variety of solutions have been designed and are now (2004) under construction. They are to be tested both under laboratory conditions and in real-life situations: small, family-size evapo-transpiration beds, larger units serving clusters of buildings, and constructed wetlands serving whole neighbourhoods. (A complicating factor in Erdos is the winter conditions and freezing of the surface soil drainage down to 1.5–2 m depth.)



Figure 8.4 Greywater treatment for a group of apartment buildings, EETP, China.

Providing eco-san solutions for solid and organic household waste management

Source-separation models used in some Swedish municipalities have been adapted to Chinese conditions and will be tested in the project. These solutions include the design of hardware for household use and the development of hygienic, cost-effective collection systems as well as a major and sustained education programme to promote source separation in all households and places of work.



Figure 8.5 Household source separation of solid waste.

Establishing eco-stations

Eco-stations for composting of household organic wastes and secondary treatment of faeces are to be developed together with test procedures for handling the different flows of these outputs and turning them into recyclable, marketable substances (see 8.1.3). The project's hypothesis is that this can be accomplished in a cost-effective way by source separation at the household and workplace level and bringing the residual products to the eco-stations serving a group of households or an entire neighbourhood.

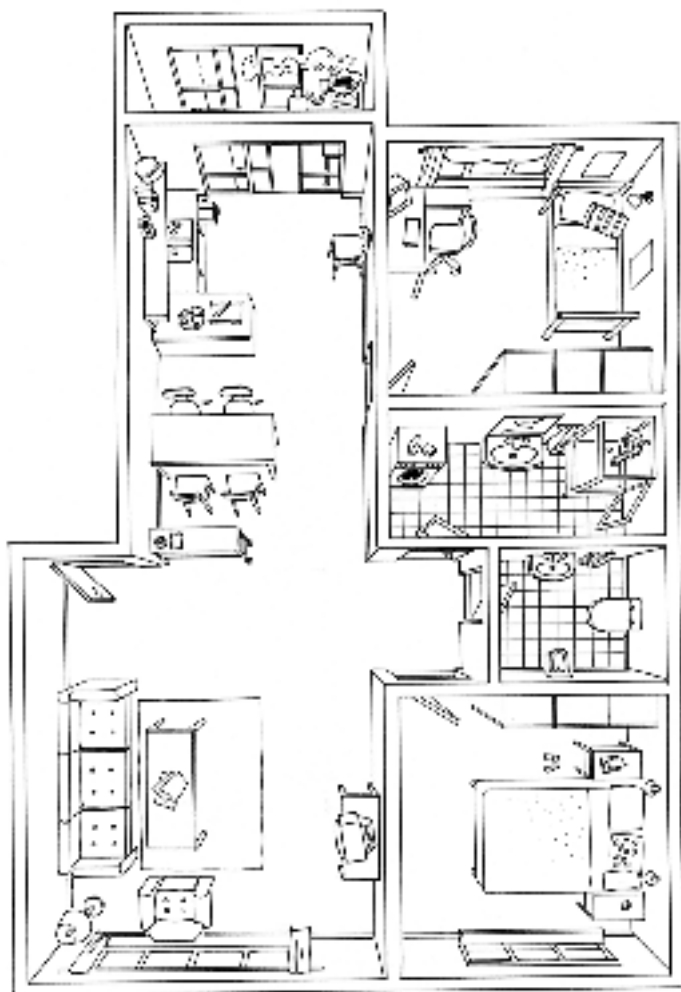


Figure 8.6 2-bedroom apartment, EETP, China. The toilet rooms in all apartments have a separate urinal next to the urine-diverting toilet.

Cost-effective design, production and operation

The houses and apartments are built according to good Chinese standards and will be sold to the public. Financial aspects are of central concern and the alternative systems developed in the project will be costed and compared with conventional systems.

8.1.5 Tepoztlán: planning for sanitation expansion in a small town

Tepoztlán is a small town about an hour from Mexico City. It has a population of about 34,000 and is similar to thousands of district or municipal small towns in Latin America. Since 2002 the local government in partnership with a private management firm has been planning an ecological sanitation pilot programme aiming at expanding and improving sanitation coverage within the town and surrounding peri-urban areas. Because of the new focus on ecological sanitation many of the conventional practices of centralized urban planning do not apply. Any expansion based on ecological sanitation principles must take into account the existing sewerage system serving the central business district and try to make it more eco-friendly. Experience to date has shown that a combination of political advocacy, multistakeholder bio-regional planning, decentralized community-based consultation, educational programmes, and social marketing has the best possibility of integrating the needs and expectations of both urban and peri-urban populations.

The ‘TepozEco Eco-san Pilot Project’ in Tepoztlán is one of the few examples of a holistic approach to eco-san covering both urban and peri-urban settings, poor and better off areas, and different eco-san technologies. A key strategy of the programme is to focus on creating the conditions that will guarantee the acceptance of sustainable water management and ecological sanitation approaches among a socio-economically diverse population, as well as the longer-term sustainability of the systems.

The project to date has focused on applied research and development activities that will be critical to the ultimate success and sustainability of the programme. These are:

Designing a range of eco-san toilet options

Eco-toilets must be sufficiently attractive, comfortable and nuisance free to compete with conventional WCs. The project is therefore designing urine-diverting toilets that will function well for men as well as women and for children as well as adults. There will be double- and

single-chamber options, models with moveable containers to facilitate handling and passive solar design for improved drying. Costs and effects of different dehydrating mixtures will be studied as well as the use of alternative building materials. Low-cost options will be considered for the more marginal peri-urban communities.

Developing urine-harvesting systems

Tepoztlán experiences peak demands on its water and sanitation systems due to weekend and public holidays tourism. To save water, the project is developing public waterless urinals for both men and women. This offers a special opportunity for harvesting significant volumes of urine to meet the fertilizer needs of local farmers. The programme is also testing improved low-cost, low-maintenance odour traps for public urinals. As for household urine collection, research is underway on combined urine and greywater drainage.

The urban agriculture component of TepozEco has worked closely with local producers to demonstrate the potential of urine as a substitute for conventional chemical fertilizers. Special emphasis has been given to use of urine on local food products like *nopal* cactus, avocado, maize and tomato and on nonfood cash crops such as flowers. Studies are also being conducted to compare the use and effects of fermented and non-fermented urine, especially for home garden uses.

Establishing eco-stations

Since mid-2003 a municipal composting center receives and processes the organic fraction from municipal and private solid waste. The project includes ongoing research on urine application to compost and secondary processing of fecal output from dry toilets.

Addressing the greywater challenge

As part of a household-centered approach the project is encouraging horizontal reed-bed bio-filters at household level and interconnected systems for groups of households with constructed wetlands for collective greywater discharges. Regulatory reforms are underway so that responsibilities are clearly spelled out for each level: household, neighborhood and municipality.

Advocating sustainable wastewater management

Tepoztlán, like many municipalities in Latin America, has begun to install a sewer system for the town center to deal with the high volume of wastewater. The eco-san project has used this to raise ecological awareness in the town and to gain support for the creation of a comprehensive municipal water and sanitation programme with a sustainable end-of-pipe alternative wastewater treatment for the town center, including a constructed wetland.

Developing municipal environmental & sanitation regulations

A major thrust of the programme has been to work with local and regional authorities to develop realistic and enforceable municipal environmental sanitation regulations based on a thorough analysis of a recent study carried out by the EcoSanRes programme.⁹

Conducting environmental communication and education

A variety of communication tools and media have been used to promote eco-san in Tepoztlán: participatory stakeholder workshops; an environmental sanitation diploma course to recruit community eco-san advocates and community promoters; participatory approaches and tools (primarily Sarar) for work with local communities; and information dissemination and promotion through public and electronic media.

8.2 Advantages of ecological sanitation

If this vision of ecological sanitation could be realized, then it would confer a great many advantages to the environment, households and families and to municipalities. To close our book we summarize these advantages below.

8.2.1 Advantages to the environment and agriculture

If ecological sanitation could be adopted on a large scale, it would protect our groundwater, streams, lakes and the sea from faecal contamination. Less water would be consumed. Farmers would require less expensive commercial fertilizer, much of which today washes out of the soil into water, thereby contributing to environmental degradation. Eco-san allows us to make use of the high fertilizer value of urine and the soil-enriching properties of dried or composted faeces.

Urine is rich in nitrogen, phosphorous and potassium. Urine can be diluted with water and put directly on vegetable gardens and agricultural fields or saved in underground tanks for later use.

Human faeces can be turned into a valuable soil conditioner rich in carbon, providing both good soil structure and a good medium for essential soil micro-organisms. With eco-san we can replenish the world's soils, both for agricultural use and to restore wasteland, and continue to enrich those soils more and more over time. Returning

human urine and sanitized faeces to soils on a regular basis has the potential to replenish soil nutrients to levels at which productivity will become sustainable.

Recycling human excreta would reduce the greenhouse effect if practised on a large scale as part of a comprehensive programme to increase the carbon content of soils. Most efforts to address the atmospheric build-up of carbon dioxide (CO₂), which is believed to be causing climate change, have focused on reducing the CO₂ emissions from fossil fuel burning and the clearing of rain forests. However, scientists have recently begun to focus on the ability of soils to serve as a sink for excess atmospheric carbon. (In soils carbon is stored in the form of humus and decaying organic matter.) A number of factors influence the accumulation of carbon in soils. Returning sanitized human excreta to degraded lands would play a significant role in this process by increasing the amount of carbon in the soil, enhancing soil fertility, increasing plant growth and hence the amount of CO₂ fixed from the atmosphere through photosynthesis. A modest doubling of the amount of carbon in non-forest soils, from the current low level of 1% (as a result of erosion) to 2% over the course of 100 years would balance the net annual increase of atmospheric carbon over that time.¹⁰

8.2.2 Advantages to households and neighbourhoods

No matter how unpleasant the immediate environment may be, individual households can improve their conditions considerably by adopting an eco-san system. Many of the options available are relatively inexpensive and not difficult to build. Households can immediately have the privacy, convenience and aesthetic advantages of an odourless and flyless toilet, attached to or even built right into their homes, however small. This is of course particularly important for women. Groups of households with access only to public toilets and open defecation can improve their neighbourhood dramatically.

The health benefits of toilets are usually not an important selling point for consumer acceptance. However, some consumers may find it attractive to know that if a large area of their community can be made more sanitary, the likelihood of diarrhoea and worm infections will decrease, leading to overall better health and better study results for school children.¹¹

The nutrition of families would also improve if urine and faeces were

recycled to grow additional vegetables in garden plots, on rooftops and balconies or even on walls (see Boxes 5.2 and 5.3). The fertilizer value of recycled urine and the soil-improving properties of decomposed faeces produce excellent crops even from poor soil or soil-less horticulture.¹²

Some designs of eco-san toilets are lightweight and movable. The urban poor usually do not own the land on which they live and do not wish to invest money in structures they cannot take with them. With the eco-san approach it is possible for them to have a prefabricated toilet unit that can be moved. This has proved to be an important selling point for the prefabricated toilets produced by Tecnología Alternativa SA in Mexico City (see 3.1.3 – Mexico).

The emptying of ordinary pit toilets and the sludge removal from septic tanks is messy, expensive and technically difficult. In many informal settlements, the vacuum trucks needed for the process cannot negotiate the narrow streets and the steep slopes. If contents are removed by hand, the sludge is smelly, wet and dangerous to the workers. Eco-san systems based on dehydration or decomposition reduce the volume of material to be handled and transported and result in a dry, soil-like, completely inoffensive and easy-to-handle product. As the toilet is built completely above ground there is easy access to the sanitized faeces for recycling and easier management of contents for pathogen destruction.

A great problem of building toilets in some areas is the subsoil and groundwater conditions. In some areas the ground is too hard for digging. In other areas the water-table is close to the surface. Both conditions prevent or make difficult the construction of pit toilets, VIP toilets or pour-flush toilets. As eco-san toilets can be built entirely above ground, they allow construction anywhere a house can be built, they do not collapse, they do not destabilize the foundations of nearby buildings and they do not pollute the groundwater.

The majority of eco-san toilets described in this book do not require expensive or high-tech equipment. Jobs can be created for builders and for collectors of urine and sanitized faeces. These products can be sold to farmers or households could use them to grow food. An entire mini-economy could potentially develop around eco-san systems, especially in urban areas.

8.2.3 *Advantages to municipalities*

More than half the world's population live in urban areas, a number projected to reach 5.1 billion by 2030; about 98% of the increase will occur in developing countries.¹³

Municipalities all over the world are experiencing greater and greater difficulty in supplying water to households and neighbourhoods. In many cities water is rationed and supplied only a few hours a day. Wealthier households collect this water in large tanks while the poor queue up at public taps to receive their daily ration. Eco-san systems reduce the use of these scarce water resources and may result therefore in a more equitable allocation of water to rich and poor households.

A major advantage of eco-san systems is that they have the potential to increase sustainable sanitation coverage of the unserved more quickly than any other method. Municipal governments are under increasing pressure to provide sanitation coverage for the entire urban population. Even if there is political will, the options available are severely limited owing to lack of water and/or money (for flush-and-discharge systems) and lack of space and/or difficult ground or groundwater conditions (for drop-and-store systems). The Millennium Development Goals will spur on the building of millions of toilets in the developing world over the next few decades. But the tendency will be to fall back onto conventional practices such as deep pit toilets and pour-flush cess pits if eco-san is not promoted. Modifying these installations so that they do not contaminate the subsoil and groundwater requires capacity building that remains to be developed. The eco-san options, outlined in Chapter 3, are in general affordable to the poor and have almost no recurrent costs for operation and maintenance. In most cases eco-toilets require no excavation; do not depend on water and pipe networks; can be used even in congested areas; and, as the units have no odour when properly looked after, can be placed anywhere (even inside a house and on upper floors). Eco-san is an inexpensive and attractive alternative to expansion of sewerage systems.

Finally, eco-san systems allow, even favour, decentralized urban waste-to-resource management. The burden for guaranteeing a well-functioning urban sanitation system is taken from the municipal government and transferred to the neighbourhood level where citizens can monitor conditions and take direct action when necessary. The role of municipal government then becomes regulatory with

the goal of safeguarding public health.



Figure 8.7 *A neighbourhood with an ecological sanitation system. Each household has its own dehydrating or composting toilet attached to the house. There is urine diversion and the processing chamber is solar heated. Municipal workers collect urine, primary processed faeces and kitchen wastes and take them to the neighbourhood's own eco-station.*

REFERENCES

Chapter 1: INTRODUCTION

- ¹ UN-Habitat, United Nations Human Settlements Programme (2003) *The challenge of slums – Global report on human settlements 2003*. Earthscan Publications Ltd, London, UK.
- ² United Nations (2002) *Report of the world summit on sustainable development, 26 Aug - 4 Sept 2002, Johannesburg, South Africa*. United Nations Publication, New York, USA.
- ³ WEHAB Working Group (2002) *A framework for action on water and sanitation*. (United Nations World Summit on Sustainable Development)
- ⁴ WHO (2003) *WHO Report 2003 – Shaping the future*. WHO, Geneva, Switzerland.
- ⁵ United Nations (2002) *ibid*.
- ⁶ Matsui, S., Henze, M., Ho, G. and Otterpohl, R. (2001) Emerging paradigms in water supply and sanitation. In: Maksimovic, C. and Tejada-Guibert, J.A. (eds.) (2001) *Frontiers in urban water management: Deadlock or hope*. IWA Publishing, London, UK.
- ⁷ Barret, M. (2001) Groundwater and sanitation: Nutrient recycling and waterborne disease cycles. *First International Conference on Ecological Sanitation*, 5–8 November, Nanning, China. Available from: www.ecosanres.org
- ⁸ UN-Habitat (2003) *ibid*.
- ⁹ Simpson-Hébert, M. (2001) Ecological sanitation and urban sustainability. *First International Conference on Ecological Sanitation*, 5–8 November, Nanning, China. Available from: www.ecosanres.org

Chapter 2: SANITIZING HUMAN EXCRETA

- ¹ Schönning, C. and Stenström, T-A. (2004) *Guidelines for the safe use of urine and faeces in ecological sanitation systems*. EcoSanRes, SEI, Stockholm, Sweden.
- ² Vinnerås, B. (2002) *Possibilities for sustainable nutrient recycling by faecal separation combined with urine diversion*. (PhD thesis) Swedish University of Agricultural Sciences, Uppsala, Sweden.
- ³ Schönning, C. and Stenström, T-A. (2004) *ibid*.
- ⁴ *ibid*.
- ⁵ *ibid*.
- ⁶ Winblad, U. and Kilama, W. (1985) *Sanitation without water*. Macmillan, London, UK.
- ⁷ Morgan, P. (1999) *Ecological sanitation in Zimbabwe: A compilation of manuals and experiences*. Conlon Printers, Harare, Zimbabwe.
- ⁸ Schönning, C. and Stenström, T-A. (2004) *ibid*.

Chapter 3: ECO-SAN EXAMPLES

- ¹ Winblad, U. and Kilama, W. (1985) *Sanitation without water*. Macmillan, London, UK.
- ² Kodama, T., Harada, F., Muto, N., Morikubo, S. and Okamoto, H. (1955) The studies about parasite control in rural areas in Japan – the new type of pit privy to separate urine and stool. *Yokohama Medical Bulletin*, 6(2), April. Yokohama University School of Medicine, Japan.
- ³ Duong Trong Phi, Bui Chi Chung, Le Thi Hong Hanh and Harada, H. (2004) *Report on Results of Ascaris suum tests to evaluate pathogen die-off in fecal material inside the ecosan toilets built in Dan Phuong-Lam Ha-Lam Dong-Vietnam*. Report to Ministry of Health, Hanoi, Vietnam, and JICA, Tokyo, Japan.
- ⁴ Winblad, U. (2002) *Final report SanRes 1992–2001*. (Report to Sida) Winblad Konsult AB, Stockholm, Sweden
- ⁵ Lin Jiang. (2001) EcoSan development in Guanxi, China. *Abstract volume, First International Conference on Ecological Sanitation*, 5–8 November, Nanning, China. Available from: <www.ecosanres.org/Nanning>
- ⁶ Luo Daguang. (2001) Theory and practice behind the development of the ecological model villages. *First International Conference on Ecological Sanitation*, 5–8 November, Nanning, China. Available from: <www.ecosanres.org>
- ⁷ Black, M. (2001) *Conference report – First International Conference on Ecological Sanitation*, 5–8 November 2001, Nanning, China. Available from: <www.ecosanres.org>
- ⁸ *ibid.*
- ⁹ *ibid.*
- ¹⁰ Lin Jiang (2004) Personal communication.
- ¹¹ NPHCC (2004) NPHCCO News Bulletin, No.3, 9 June 2004, Beijing, China. (in Chinese)
- ¹² Van Buren, A., McMichael, J.K., Caceres, A. and Caceres, R. (1984) Composting latrines in Guatemala. *Ambio*, 13(4), 274–277.
- ¹³ Calvert, P. (1994) Environmental hygiene and sanitation. *Socio Economic Units Foundation and International Union for Health Promotion & Education: Strategies and approaches for community-based initiatives, The 6th national conference of South East Asia Regional Bureau*, December 1994.
- ¹⁴ Calvert, P. (1997) Seeing (but not smelling) is believing – Kerala's compost toilet. *Waterlines* 15(3), 30–32.
- ¹⁵ Calvert, P., Seneviratne, A., Premakumara, D.G.J. and Mendis, U.A. (2002) Ecological sanitation a success in Sri Lanka. *Waterlines* 21(1), July.
- ¹⁶ *ibid.*
- ¹⁷ Calvert, P. (1998) A positive experience with composting toilets in India – Kerala case study. Paper presented at the *Center for Science and Environment Conference on Health and Environment*, July, New Delhi, India, 1998.
- ¹⁸ Winblad, U. (2002) *Ecological sanitation pilot project in Palestine – a project appraisal*. Report to Department for Natural Resources and the Environment, Sida, Stockholm, Sweden.
- ¹⁹ Hills, L.D. (1972) The Clivus toilet - sanitation without pollution. *Compost Science*, Vol 13, No 3, Rodale Press, Emmaus, Pa, USA.
- ²⁰ Winblad, U. and Kilama, W. (1985) *ibid.*
- ²¹ af Petersens, E. (2004) Personal communication.

- 22 Mena, J. (2004) Personal communication.
- 23 Winblad, U. and Kilama, W. (1985) *ibid*.
- 24 Moule, H. (1875) *National health and wealth*. W. Macintosh, London, UK. See also Poore, G.V. (1894) *Essays on rural hygiene*. London, UK.
- 25 Morgan, P. (2002) *Ecological sanitation in Zimbabwe: a compilation of manuals and experiences, vol I-IV*. Aquamor Pvt Ltd, Harare, Zimbabwe. See also <<http://aquamore.tripod.com>>.
- 26 UN-Habitat, United Nations Human Settlements Programme (2003) *The challenge of slums – Global report on human settlements, 2003*. Earthscan Publications Ltd, London, UK.
- 27 Winblad, U. and Kilama, W. (1985) *ibid*.
- 28 De Cal, I. (1984) Personal communication.
- 29 Brown, L.R. (2002) *Water deficits growing in many countries*. Earth Policy Institute. August, 6, 2002. Available from: <<http://earth-policy.org>>
- 30 Nilsson, S-I. (2001) *Nutrient Recycling in Gebers Housing Project, Sweden*, (Case study No. 4). Eco-Eng-Online. Available from: <http://www.iees.ch/cs/cs_4.html>
- 31 Svane, O., and Wijkmark, J. (2002) *Nar ekobyn kom till stan - lardomar fran Ekoporten och Understenshojden* (in Swedish). Formas, Stockholm, Sweden.
- 32 Further information available from: <www.flintenbreite.de> and <www.lambertsmuehle-burscheid.de>

Chapter 4: DESIGN AND MANAGEMENT FEATURES

- 1 Winblad, U. and Kilama, W. (1985) *Sanitation without water*. Macmillan, London, UK.
- 2 *ibid*.
- 3 *ibid*.
- 4 Sawyer, R. and Winblad, U. (2003) *EcoSan Workshop in Osh, Kyrgyzstan, April 2003*. Final report to UNDP.
- 5 Schönning, C. and Stenström, T-A. (2004) *Guidelines for the safe use of urine and faeces in ecological sanitation systems*. EcoSanRes, Stockholm, Sweden.
- 6 Moe, C. and Izurieta, R. (2003) Longitudinal study of double vault urine diverting toilets and solar toilets in El Salvador. *Proceedings from the 2nd International Symposium on Ecological Sanitation*, Lübeck, Germany, 7–11 April 2003.
- 7 Winblad, U. and Kilama, W. (1985) *ibid*.

Chapter 5: RECYCLING THE NUTRIENTS

- 1 King, F.H. (1973) *Farmers of forty centuries: permanent agriculture in China, Korea and Japan*. Rodale Press, Emmaus, PA, USA. (Originally published in 1909.) See also Winblad, U. and Kilama, W. (1985) *Sanitation without water*. Macmillan, London, UK.
- 2 Matsui, S. (1997) Nightsoil collection and treatment in Japan. *Publications on Water Resources No 9. Ecological alternatives in sanitation*. Sida, Stockholm, Sweden.
- 3 Slicher van Bath, B.H. (1963) *The agrarian history of western Europe*. Edward Arnold, London, UK.
- 4 Tarr, J.A. (1996) *The search for the ultimate sink: urban pollution in historical perspective*. University of Akron Press, Akron, Ohio, USA.

- ⁵ Schönning, C. and Stenström, T-A. (2004) *Guidelines for the safe use of urine and faeces in ecological sanitation systems*. EcoSanRes, SEI, Stockholm, Sweden.
- ⁶ Morgan, P. (1999) *Ecological Sanitation in Zimbabwe: A compilation of manuals and experiences Vol. I*. Conlon Printers, Harare, Zimbabwe.
- ⁷ Wang, Rusong and Tang, Hongshou (2001) Appraisal of the pilot eco-san project in China. Unpublished report to the SanRes project, June 2001. See Winblad, U. (2002) *Final Report SanRes 1992–2001*. (Report to Sida), Winblad Konsult AB, Stockholm, Sweden.
- ⁸ Barrett, M. (2001) Groundwater and sanitation; nutrient recycling and waterborne disease cycles. *First International Conference on Ecological Sanitation*, 5–8 November 2001, Nanning, China.
- ⁹ Jacks, G., Sefer, F., Carling, M., Hammar, M. and Letsamao, P. (1999) Tentative nitrogen budget for pit-latrines – eastern Botswana. *Environmental Geology* 38(3), 199–203.
- ¹⁰ Environmental Protection Agency (1991) *Drinking Water Regulations and Health Advisories*. Office of Water, Washington, USA.
- ¹¹ Food and Agriculture Organization of the United Nations (1995) *Dimensions of need – An atlas of food and agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available from: <<http://www.fao.org/docrep/U8480E/U8480E0D.HTM>>.
- ¹² Jönsson, H., Richert Stintzing, A., Vinnerås, B. and Salomon, E. (2004) *Guidelines on use of urine and faeces in crop production*. EcoSanRes, SEI, Stockholm, Sweden.
- ¹³ Jönsson, H., Eklind, Y., Albihn, A., Jarvis, Å., Kylin, H., Nilsson, M-L., Nordberg, Å., Pell, M., Schnürer, A., Schönning, C., Sundh, I. and Sundqvist, J-O. (2003) Samhällets organiska avfall – en resurs i kretsloppet (In Swedish). *Fakta Jordbruk* No. 1-2, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden.
- ¹⁴ Palmquist, H. and Jönsson, H. (2004) Urine, faeces, greywater and biodegradable solid waste as potential fertilisers. In: *Ecosan – closing the loop. Proceedings of the 2nd International Symposium on Ecological Sanitation, Incorporating the 1st IWA Specialist Group Conference on Sustainable Sanitation*, 7th–11th April, Lübeck, Germany.
- ¹⁵ Jönsson, H., Stenström, T-A., Svensson, J. and Sundin, A. (1997) Source separated urine – nutrient and heavy metal content, water saving and faecal contamination. *Water Science and Technology*, 35(9), 145–152. – Other researchers have found that the addition of acid inhibits the initiation of the decomposition of urea. The acid should be added before the decomposition starts, see Hanaeus, A. *et al.* (1996) Conversion of urea during storage of human urine. *Vatten* 52, 263–270, Lund, Sweden. A Vietnamese researcher recommends the addition of superphosphate to prevent the evaporation of ammonia, see Polprasert, C. (ed.) (1981) *Human faeces, urine and their utilization*. ENSIC, Bangkok, Thailand.
- ¹⁶ Johansson, M. (ed) (2000) *Urine separation – closing the nutrient circle. Final report on the R&D project: Source separated human urine - a future source of fertilizer for agriculture in the Stockholm region?* S-M Ewert AB, Stockholm, Sweden. Available from: <http://www.stockholmavatten.se/pdf_arkiv/english/Urinese_eng.pdf>
- ¹⁷ Morgan, P. (2002) *Ecological Sanitation in Zimbabwe: A compilation of manuals and experiences Vol. IV*. Aquamor Pvt Ltd, Harare, Zimbabwe.
- ¹⁸ Morgan, P. (2003) Experiments using urine and humus derived from

ecological toilets as a source of nutrients for growing crops. *Paper presented at 3rd World Water Forum, 16–23 March 2003, Kyoto, Japan. Available from: <<http://aquamor.tripod.com/KYOTO.htm>>*

- 19 Ongoing research under professor Saburo Matsui, Graduate School of Global Environmental Studies, Department of Technology and Ecology, Kyoto University, Japan.
- 20 Båth, B. (2004) Personal communication.
- 21 Morgan, P. (2003) *ibid.* See also: Steinfeld, C. (2004) *Liquid gold - the lore and logic of using urine to grow plants*. Green Frigate Books, Sheffield, Vermont, USA.
- 22 Jönsson, H. *et al.* (2004) *ibid.*
- 23 *ibid.*
- 24 Morgan, P. (2002) *ibid.*
- 25 Morgan, P. (2003) *ibid.*
- 26 Morgan, P. (2002) *ibid.*
- 27 Jönsson, H. *et al.* (2004) *ibid.*
- 28 Winblad, U. (1992) *The productive homestead*. Report to Sida. Winblad Konsult AB, Stockholm, Sweden.

Chapter 6: GREYWATER

- 1 Oldenburg, M. (2003) Personal communication.
- 2 Stenström, T-A. (1996) *Sjukdomsframkallande mikroorganismer i avloppssystem*. (Rapport No. SNV 4683). (In Swedish) Naturvårdsverket, Socialstyrelsen och Smittskyddsinstitutet. Stockholm, Sweden.
- 3 Ottosson, J. (2003) *Hygiene aspects of greywater and greywater reuse*. Royal Institute of Technology/SMI, Stockholm, Sweden.
- 4 Swedish Environment Protection Agency (1995) *Vad innehåller avlopp från hushåll?* (Report No. 4425) (In Swedish) Swedish EPA, Stockholm, Sweden. (In Swedish)
- 5 Vinnerås, B. (2001) *Faecal separation and urine diversion for nutrient management of household biodegradable waste and wastewater*. (Report No. 244) Swedish University of Agricultural Sciences, SLU, Uppsala, Sweden.
- 6 Eriksson, H. (2002) *Potential and problems related to reuse of water in households*. (PhD Thesis) Technical University of Denmark, Lyngby, Denmark.
- 7 Adapted from Ludwig, A: <<http://www.oasisdesign.net>>.
- 8 Ziebel, W.A., Anderson, J.L., Bouma J. and McCoy E. (1975) *Faecal Bacteria: Removal from Sewage by Soils*. (ASAE Paper No.75-2579). American Society of Agricultural Engineers, St. Joseph, USA.
- 9 Swedish EPA (1987) *Små avloppsanläggningar*. Allmänna råd 87:6. (In Swedish)
- 10 Stevik, T.K., Ausland, G., Jenssen, P.D. and Siegrist, R.L. (1999) Removal of *E. coli* during intermittent filtration of wastewater effluent as affected by dosing rate and media type. *Water Research* 33(9).
- 11 Dilov, C., *et al* (1985) Cultivation and application of microalgae in the People's Republic of Bulgaria, production and use of micro-algae. *Conference Proceedings*. Trujillo, Peru.
- 12 Kindvall, I. and Ridderstolpe, P. (1989) *Vattenbruk, vattenrening och resursåtervinning – en litteratursammanställning*. Royal Institute of Technology, Stockholm, Sweden. (In Swedish)

- ¹³ Feachem, R., McGarry, M. and Mara, D. (1980) *Water waste and health in hot climates*. J Wiley, London, UK.
- ¹⁴ Zweig, R.O. (1985) Freshwater aquaculture in China: ecosystem management for survival. *Ambio* 14(2).
- ¹⁵ Feachem, R. *et al.* (1980) *ibid.*

Chapter 7: PLANNING, PROMOTION AND SUPPORT

- ¹ Winblad, U. and Kilama, W. (1985) *Sanitation without water*. Macmillan, London, UK.
- ² Srinivasan, L. (1990) *Tools for community participation: A manual for training trainers in participatory techniques*. PROWESS / UNDP, New York, USA.
- ³ Sawyer, R., Simpson-Hébert, M. and Wood, S. (1998) *PHAST step-by-step guide: a participatory approach for the control of diarrhoeal disease*. (WHO/EOS/98.3), Participatory Hygiene and Sanitation Transformation Series, WHO, Geneva, Switzerland.
- ⁴ Fondo de Inversion Social (1994) *Diagnostico y recomendaciones proyecto letrinas aboneras, operaciones BID I y II*, San Salvador, El Salvador.
- ⁵ Fondo de Inversion Social, Unicef and Ministry of Health (1995) Unpublished evaluation of the pilot project on the hygiene education module, San Salvador, El Salvador.
- ⁶ WHO (Martinez, J. and Simpson-Hébert, M.) (1992) *Improving water and sanitation hygiene behaviours for the reduction of diarrhoeal disease*. (WHO/CWS/93.10), Geneva, Switzerland.
- ⁷ Van der Meulen, R.J., Moe, C.L. and Breslin, E.D. (2002) *Ecological sanitation in Mozambique: baseline data on use, perceptions and performance*. Department of International Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA.

Chapter 8: A VISION FOR THE FUTURE

- ¹ Further information available from: <www.bleriot.org>.
- ² UN-Habitat, United Nations Human Settlements Programme (2003) *The challenge of slums – Global report on human settlements 2003*. Earthscan Publications Ltd, London, UK.
- ³ For up-to-date information on the China-Sweden Erdos Eco-town Project see: <www.ecosanres.org>.
- ⁴ Mårtensson, H. (1996) *Biologiska toaletter och komposter*. (In Swedish). AB Svensk Byggtjänst, Stockholm, Sweden.
- ⁵ Matsui, S. (1997) Nightsoil collection and treatment in Japan. Publications on Water Resources No 9, *Ecological alternatives in sanitation*. Sida, Stockholm, Sweden.
- ⁶ Ludwig, C., Hellweg, S. and Stucki, S. (eds) (2003) *Municipal solid waste, strategies and technologies for sustainable solutions*. Springer, Berlin, Germany.
- ⁷ Anthony, R. (2003) Reduce, reuse, recycle: The zero waste approach. In: Ludwig, C., Hellweg, S. and Stucki, S. (eds) (2003) *Municipal solid waste, strategies and technologies for sustainable solutions*. Springer, Berlin, Germany
- ⁸ See endnote 3.

- ⁹ Ramos Bustillos, L.E., Cordova, A. and Sawyer, R. (2003) *Legal constraints and possibilities for ecological sanitation in Mexico - constructing a regulation for the Municipality of Tepoztlán*. VERNA Ekologi AB, Stockholm, Sweden.
- ¹⁰ Strong, M. and Arrhenius, E. (1993) Closing linear flows of carbon through a sectoral society – diagnosis and implementation. *Ambio*, 22(7).
- ¹¹ WHO (1997) *Strengthening interventions to reduce helminth infections*. WHO, Geneva, Switzerland.
- ¹² Brown, L. R. (1998) *State of the world 1998*. Earthscan Publications Ltd, London, UK.
- ¹³ The World Bank (2000) *World Development Report 2000/2001 - Attacking poverty*. The World Bank, Oxford University Press, Oxford, UK.

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