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DESIGN AND OPERATION CRITERIA FOR URINE-DIVERSION ECOLOGICAL SANITATION SYSTEMS WITH PARTICULAR REFERENCE TO PUBLIC HEALTH

by

LORIMER MARK AUSTIN

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SUMMARY

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Department:	**Civil Engineering**
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SANITATION, PUBLIC HEALTH AND THE ENVIRONMENT

The approach to sanitation worldwide should be ecologically sustainable, i.e. concerned with protection of the environment. This means that sanitation systems should neither pollute ecosystems nor deplete scarce resources. It further implies that sanitation systems should not lead to degrading water or land and should, where possible, ameliorate existing problems caused by pollution. More research and better designs are needed. Human excreta can be rendered harmless, and toilet designs that do this in harmony with agricultural and social customs hold promise for the future.

Problems with conventional sanitation systems have been shown to include inadequate institutional capacity to deal with the sanitation process, a fixation with providing either a full waterborne system or a VIP toilet, the social acceptability of various systems, and the perception that dry, on-site sanitation systems are inherently inferior. The basic purpose of any sanitation system is to contain human excreta (chiefly faeces) and prevent the spread of infectious diseases, while avoiding damage to the environment. An alternative sanitation technology known as urine-diversion (UD) performs these functions with fewer operational and maintenance problems than those associated with conventional VIP toilets, (for example, it is a major and expensive operation to desludge full pits, which is not the case with UD toilets as the vaults can be quickly and easily emptied using hand tools) and also provides a free, easily accessible and valuable agricultural resource for those who wish to use it. This technology represents one aspect of an approach, or philosophy, termed “ecological sanitation” or “ecosan.” Key features of ecosan are prevention of pollution and disease caused by human excreta, treatment of human excreta as a resource rather than as waste, and recovery and recycling of the nutrients. In nature, excreta from humans and 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 break this cycle.

UD systems have been successfully implemented in many countries, including South Africa where more than 60 000 of these toilets have been built since 1997. However, despite much research having been carried out internationally and locally, various questions still remain, particularly on the health aspects of operation, maintenance, and excreta use or disposal. Not enough is known about the dehydrating processes taking place inside the faeces vault, and there is still disagreement on safe retention periods and microbiological stability of the final product. The roles of dryness, pH, temperature and time in pathogen destruction also need to be further clarified. In addition, it is critically important that toilet users are able to operate and maintain their systems easily and safely, particularly while emptying the vaults and recycling or otherwise dealing with the contents. Engineers need to understand and take all these issues into consideration before they can properly design and implement sustainable UD sanitation systems.

It is therefore important to develop guidelines for sanitation practitioners that set out best practices for construction and operation of UD toilets. Construction recommendations are important because good construction facilitates easy operation, and also promotes rapid pathogen destruction. Easy operation in turn

directly influences the health risks associated with removing faecal material from the vaults.

Handling of faecal material is an aspect inherent in the operation of UD ecological sanitation systems, because emptying of the vault is usually done using hand tools. If the faecal material is also used for agricultural purposes then further handling must of necessity take place. As such, there is a health concern, both for the person(s) handling the material and for the wider public who may be consumers of the fertilised crops. It is therefore necessary that these health concerns be quantified, in order that proper regulation may take place.

CONCLUSIONS FROM THE LITERATURE REVIEW

The primary aim of sanitation is to prevent the transmission of excreta-related diseases. However, with all sanitation systems there is a risk of disease transmission related to the handling or use of the end product. Therefore, even a well functioning system could enhance pathogen survival and lead to an increased risk of disease transmission for those handling the end products or consuming crops fertilised with them. A greater understanding of pathogen die-off in dry sanitation systems is required where handling and/or use of excreta are expected.

Pathogen destruction in dry sanitation systems, particularly in the vaults of urine-diversion (UD) toilets, is mainly dependent on storage time, pH, temperature, humidity, moisture content, organic content of the faecal material, and type of bulking agent added. It is of utmost importance to ensure that the material is safe to handle. This implies that the primary treatment in the vault should, as far as possible, ensure the required level of safety.

While much research has been carried out internationally into pathogen destruction in the vaults of UD toilets, the same cannot be said of South Africa. There is also a wide range of results and conclusions, with recommended storage times varying from six months to two years. Construction and operational guidelines are required in order to assist practitioners in these and other respects.

Sound management practices could play an important role in reducing the health risks involved in emptying the vaults of UD toilets and the disposal or further use of faecal material. From the public health viewpoint, it is necessary to reduce, as far as possible, the risk of handling faecal material. To do this, a better understanding of the factors influencing pathogen die-off in the vaults is required.

FOCUS OF THIS THESIS

The primary aim of this thesis is to investigate the efficacy of various methods aimed at enhancing pathogen destruction in the vaults of UD toilets, with the aim of (a) establishing the best combination of factors/methods, in particular the vault storage period required, and (b) producing guidelines for the construction, operation and regulation of these systems. The overall purpose of the research is to establish safety criteria for handling of faecal material from UD toilets.

FIELD TRIALS: MICROBIOLOGICAL EFFECTS ON FOOD CROPS FERTILISED WITH FAECAL MATERIAL FROM URINE-DIVERSION TOILETS

Recycling excreta to soils reduces the need for chemical fertilisers; however, pathogens are recycled to humans if improper agricultural practices are followed. Concerns about using faecal material include higher pathogenic content in developing countries compared to that in developed countries. This material, as well as that from other sanitation alternatives in small-scale systems, demands more personal involvement from the users (including handling), which constitutes a higher human exposure level compared to that from conventional piped systems. Nevertheless, it is considered that where the material can improve agricultural productivity, it can contribute to improving the nutritional status of the population, thus improving public health.

Although ecosan technology is spreading all over the world, and with it the recycling of excreta to soils, only a few researchers have addressed the problems associated with the revalorization practice or documented the pathogen die-off. Moreover, little data about the microbial quality of ecosan faecal material from developing countries (where the health risks are the highest) are available. The objective of this research was thus to investigate the potential health risks of using faecal material in agriculture by determining the pathogen uptake on the surfaces of the edible portions of the crops.

Faecal material of between one and three months old was extracted from a number of UD toilets in the eThekwini (Durban) municipal area. This was used primarily for the experimental work described in the next section, but for the purposes of this particular experiment it was first left in a heap in the open air for a further four months. Thereafter it was used as a soil amendment in the cultivation of spinach and carrots. Detailed microbiological tests were conducted on this material as well as on the in situ soil before sowing and after harvesting, on the irrigation water, and on the harvested crops.

Applying different rates of material to spinach and carrots, two common edible crops, it was found that the bacteria and fungi content were only noticeable for the higher application rates (>35t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied. Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil.

It was thus illustrated that there is a health implication involved in growing edible crops in soils amended with ecosan biosolids. Even if in this case the spinach and carrots were cooked before consumption, normal handling of the crops during harvesting and preparation could have caused infection if personal hygiene was unsatisfactory. It is therefore important that crop growers and consumers, as well as proponents of biosolids use, are aware of the storage and treatment requirements for ecosan biosolids before these are applied to soils where crops are grown.

DETAILED INVESTIGATION INTO VAULT PROCESSES

It is hypothesised that the most advantageous approach to pathogen destruction in a UD toilet vault is to maximise the effects of various environmental factors, e.g. high

pH, high temperature, low moisture, type of bulking agent and storage time. In order to quantify these effects a field experiment was set up consisting of 12 UD toilet vaults, each with a different combination of faeces and bulking agent (soil, ash, wood shavings, NaOH or straw), ventilation (ventpipe / no ventpipe) and vault lid material (concrete, metal or perspex). Faecal material was obtained from UD toilets in the eThekwini area, as described above. Temperature probes, which were connected to a data logger, were inserted in the heaps and the logger monitored over a period of nearly 10 months. This enabled a number of graphs to be drawn illustrating the effect of the above parameters on heap temperature over the experimental period. During the coldest week in winter the mean heap temperatures averaged 16,8°C, while the minimum and maximum averaged 14,8°C and 18,8°C respectively. During the warmest week in summer mean heap temperatures averaged 27,6°C, while the minimum and maximum averaged 25,6°C and 29,3°C respectively.

In addition, samples were taken at various intervals from each vault as well as from the main heap of faecal material that was left exposed to the elements. The samples were subjected to microbiological testing in order to quantify the pathogen die-off over time for each vault as well as for the main heap. In the vaults, total coliform reduced by 3 $\log_{10}$ (99,9%) at between 130 and 250 days, faecal coliform between 100 and 250 days, and faecal streptococci from 125 days and longer. In the main heap, these times varied from 115 days for both total and faecal coliform to 140 days for faecal streptococci. Viable *Ascaris* ova were reduced to zero between 44 and 174 days in the vaults and by 44 days in the main heap.

The conclusions drawn from the experimentation were the following:

- *Influence of ventpipe*
  Ventilation of the vault by means of a ventpipe does not result in any meaningful difference in either the vault temperature or rate of pathogen die-off.

- *Influence of vault lid material*
  The lid material, and by inference also the material of the vault walls, has no significant effect on the temperature of the heap or the associated pathogen die-off.

- *Type of bulking agent*
  While the type of bulking agent used does not significantly influence the temperature of the faecal material, it does have an effect on the rate of pathogen die-off. The ordinary soil mix was seen to give the best results, and this was ascribed to the effect of competing microorganisms in the soil itself.

- *Influence of sunshine and rain*
  The main heap of material (faeces/soil mix) that was exposed to the elements performed among the best in terms of pathogen die-off. Apart from the influence of competing microorganisms in the soil on the pathogens as described above, this good performance was also ascribed to the effect of UV radiation and alternate wetting/drying and heating/cooling cycles, which suggests that open-air exposure is likely to provide the best treatment.

Comparing the results of this research with other local and international research, it appears that there is a great deal of convergence in the results. It is concluded that vaults of UD toilets should be sized for a storage period of 12 months from last use.

RECOMMENDATIONS FOR CONSTRUCTION, OPERATION AND REGULATION OF URINE-DIVERSION TOILETS

The standard of UD toilets in South Africa varies greatly. While there are many good examples of the technology, there are also many that have been ill-conceived and are badly built and poorly operated. Project implementers are responsible for the quality of sanitation schemes and should be equipped with the necessary information to oversee the process.

The guidelines are aimed at providing implementers with, firstly, the necessary technical information to build good quality UD toilets and, secondly, the basic operation and maintenance tasks that should be conveyed to the toilet owners. Basic regulatory guidelines for the responsible authorities are also given. The guidelines are intended to be a stand-alone document and some repetition of information from earlier chapters is thus unavoidable.

The technology of urine diversion is introduced, followed by basic design and construction guidelines, including drawings, for the superstructure and vault of a UD toilet. Both single- and double-vault toilets are discussed. A number of photographs are also provided, illustrating good and bad building practices. Further aspects discussed are requirements for urine pipes and ventilation.

Operation and maintenance of UD toilets are subsequently covered. Topics discussed are dehydration, odour, fly control, cleaning of the pedestal, disposal of anal cleansing material, urine collection and disposal, clearing of blockages in urine pipes, and faeces management.

The above guidelines are aimed at designers, builders and toilet users. However, organisations responsible for administering public and environmental health, such as Departments of Health, Environmental Affairs, etc, as well as the local and regional authorities that actually implement the sanitation schemes, should become actively involved in regulating the operation of UD toilets, particularly the removal and disposal of faecal material. Some regulatory guidelines are therefore also included to assist these organisations to set uniform (high) standards in their respective jurisdictions.

RECOMMENDATIONS FOR FURTHER RESEARCH RELATED TO THIS THESIS

It is deemed important that the field trials conducted in the various vaults as described earlier are repeated in other climatic areas, for example a hot and dry area, as it is likely that different results regarding recommended minimum storage periods will be obtained. This should be supplemented by trials involving co-composting of the faeces mix with other organic material, in order to compare the efficacy of this method with the dehydration process. Further, vault lids made of PVC should be tested for enhancing heat gain in the vaults. Finally, long-tem measurements of heap pH should be made in order to ascertain if high pH amendments (wood ash, lime, etc) do in fact maintain their initial pH level.

Additional field trials, similar to those described earlier for spinach and carrots, should be undertaken with a view to making recommendations regarding maximum application rates of faecal material. These should consist of food crops where the edible portions are either in or near to the soil, such as beetroot, onion, potatoes, tomatoes, etc. Trials involving urine should also be considered in order to determine the most advantageous application rate for the various crops.

Another important topic is recommended for further research on the subject of UD toilets. At present, virtually all the UD toilets built in the country have been for communities on the lower end of the income scale and who previously had no formal sanitation facility at all or, at best, an unimproved pit toilet. Research carried out by CSIR in a number of communities has revealed people's resistance to handling their faecal material, while in others it has not been a problem. There is often a general viewpoint in a village that "the municipality must take the faeces away."

However, willingness has also been expressed in some villages to pay for a faeces removal service. For instance, this has borne fruit in an area of Kimberley with UD toilets where householders pay a local resident to remove the faecal material on a regular basis. This is done by means of a wheelbarrow, and the material is stockpiled at a nearby approved facility from where it is destined for co-composting with other municipal waste.

However, this has not yet been attempted on a large scale in an area with hundreds, or even thousands, of UD toilets. While a theoretical desktop study has been carried out on the feasibility of setting up a large-scale faeces collection concern, such an enterprise does not yet exist in the country. It is suggested that one be set up utilising a horse- or donkey-drawn cart in a village, or group of villages, with sufficient UD toilets available to ensure that a viable business can be conducted. The cooperation of the particular local authority will be required.

If successful faeces collection/disposal services could be established in areas with UD toilets it would greatly enhance the social acceptability, and therefore the viability, of this sanitation technology.

KEY WORDS

Bulking agent
Dehydration
Ecological sanitation
Ecosan
Faecal material
Fertiliser
Guidelines
Health risk
Human excreta
Pathogens
Sanitation
Storage period
Toilets
UD
Urine diversion

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SOLI DEO GLORIA

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“Science and technology are neither hostile nor friendly towards human development. They provide tools, and it is the way in which these tools are used by decision-makers, politicians and others that determine whether they are destructive or constructive. The mistake made by scientists, technologists and engineers is that they have not educated people on how to use the tools they have created and the implications of the various uses.”

UNCHS, Habitat II: City Summit, Istanbul, June 1996

CHAPTER 1
INTRODUCTION AND BACKGROUND

1.1 SANITATION IN SOUTH AFRICA: POLICY AND PRACTICE

Flushing toilets are generally the most sought-after sanitation technology. However, inadequately maintained sewer reticulation systems in urban areas have caused adverse environmental impacts, most often as a result of leaking or blocked sewers, but sometimes also as a result of overloaded or inadequately maintained treatment works and failed pumping stations. In poor areas, especially, most of the operational difficulties are concentrated at the user end of the systems, where personal cleaning materials other than toilet tissue paper are used, and also because of a lack of education on the correct use of cistern flush toilets (Palmer Development Group 1993).

On the other hand, while many dry sanitation schemes have been successfully implemented utilising ventilated improved pit (VIP) toilets, it has been the author's experience (based on visits to numerous projects in South Africa) that others have been problematic, often because of poor design and construction practices. Furthermore, sufficient attention has not always been given to factors such as environmental impact, social issues or institutional capacity. The latter aspect, in particular the problem of desludging full pits, has prompted various local authorities to search for alternative dry sanitation technologies.

The sanitation policy of the South African government stresses that sanitation is not simply a matter of providing toilets, but rather an integrated approach that encompasses institutional and organisational frameworks as well as financial, technical, environmental, social and educational considerations (DWAF 2001). It is recognised that the country cannot afford to provide waterborne sanitation for all its citizens – nor, for that matter, should it necessarily aspire to do so. It is also acknowledged that, at all levels, the sanitation problem is related to socio-cultural, educational and institutional issues, with the lack of appropriate facilities and inadequate guidelines being contributory factors.

VIP toilets are generally considered to be the basic level of sanitation in South Africa, although the Department of Water Affairs and Forestry recognises various other systems. These include urine-diversion systems, septic tanks with soakpits, settled sewage systems, etc, and where appropriate, full waterborne systems. Urine-diversion toilets of various kinds have, in the last few years, become the systems of choice for a number of municipalities. However, due to some poor implementation practices, as well as some examples of poor design and construction, these have not always been successful. In some communities, operation and maintenance aspects are a matter of concern, particularly the need to periodically empty the vaults.

1.2 SANITATION, PUBLIC HEALTH AND THE ENVIRONMENT: THE CASE FOR URINE-DIVERSION ECOLOGICAL SANITATION SYSTEMS

Vast amounts of faecally contaminated material pollute the living environment of people, soils and bodies of water worldwide. Existing systems and available resources are often inadequate to deal with the associated social and behavioural factors. This has contributed much to the escalation in ecological problems. With rapid population growth, especially in urban areas, the situation will not improve unless there is a significant change in the manner in which sanitation systems are chosen, designed and implemented (Simpson-Hébert 1997). With uncontrolled urbanisation, as is seen in many areas today, sanitation problems result from poor, non-existent or reactive planning. There is an urgent need for pro-active sanitation planning, especially in urban areas.

It is predicted that, by early this century, more than half of the world's population will be living in urban areas. By 2025 this urban population could rise to 60%, comprising some five billion people. The rapid urban population growth is putting severe strain on the water supply and sanitation services in most major conurbations, especially those in developing countries (Mara 1996). In Africa today, over half the population is without access to safe drinking water and two-thirds lack a sanitary means of excreta disposal. Lack of access to these most basic services required to maintain health lies at the root of many of Africa's current health, environmental, social, economic and political problems. Hundreds of thousands of African children die annually from water- and sanitation-related diseases. More people are without adequate services today than in 1990, and at the current rate of progress full coverage will never be achieved (WSSCC 1998).

Water quality is deteriorating all over the world because of pollution. Some cities in developing countries treat only about 10% of their sewage (Björklund 1997). Even in South Africa, an alarming proportion of sewage waste in many towns and cities across the country does not reach treatment plants, but flows untreated into streams and rivers, with negative effects on the health of people reliant on these water resources (DWAF 1999). This is regarded as one of the most pressing water quality problems in the country. In many cases, even when sewage waste reaches the treatment plant, poor operation or a malfunctioning system means that partially treated sewage effluent is discharged into rivers (DWAF 1999).

Sanitation systems based on flush toilets, sewers and central treatment plants can therefore not solve the sanitation problem (Winblad 1996b). Methods of providing good sanitation without the concomitant use of large volumes of water should rather be sought. It has been shown that cistern flush toilets can use about 15 000 litres of (potable) water per person per year (Winblad 1996b), which South Africa can ill afford. This figure is based on a person using a conventional toilet flushing 8-10 litres of water 4 or 5 times a day. If one assumes that about 20 million people in the country have access to a waterborne sanitation system, it implies that 300 million m^3 of drinking water per annum are flushed into the sewers. According to DWAF (1997) the country will reach the limits of its economically usable, land-based fresh water resources during the first half of this century. The current maximum yield is some 33 290 x 10^6 m^3/year while the projected utilisation by 2030 is 30 415 x 10^6 m^3/year, leaving a surplus of only 2 875 x 10^6 m^3/year by this time. Sanitation strategies that support a conservation approach should therefore be followed.

However, the problem can also not be solved by systems based on various kinds of pit toilets (Winblad 1996b). These toilets are subject to various problems that may make implementation difficult, if not impossible. Geotechnical conditions, such as hard or rocky

ground for instance, as are found in many areas of South Africa, may require additional expensive resources for excavation of pits, or the structure may need to be raised in order to minimize the volume of excavation. In other cases, non-cohesive soils (found for example in some coastal plains) will require a pit to be lined in order to prevent collapse of the structure. Pits should preferably also be avoided in areas where hydrogeological investigations indicate a potential for groundwater contamination. These toilets are also unsuited to densely populated urban or peri-urban areas, owing to the increased risk of environmental pollution. Full pits are a further problem, as emptying them is an expensive, unpleasant and unhealthy process, the burden of which often falls on local authorities that may be ill equipped for the job.

Some other solution should be sought in these cases. If a dry toilet is designed and constructed in such a way that that the faeces receptacle can be quickly and easily emptied, with minimal risk to human health, then one of the biggest operation and maintenance problems associated with these toilets will be obviated. If the excreta can also be productively and safely used for fertilizing crops and improving poor soils, the technology will become even more attractive.

According to Simpson-Hébert (1997), the approach to sanitation worldwide should be ecologically sustainable, i.e. concerned with protection of the environment. This means that sanitation systems should neither pollute ecosystems nor deplete scarce resources. It further implies that sanitation systems should not lead to degrading water or land and should, where possible, ameliorate existing problems caused by pollution. This argument is supported in the discussion above concerning South Africa. More research and better designs are needed. Human excreta can be rendered harmless, and toilet designs that do this in harmony with agricultural and social customs hold promise for the future (Simpson-Hébert 1996). It has been recommended (Simpson-Hébert 1997) that a demand should be created for sanitation systems that move increasingly toward use and recycling of human excreta.

Problems with conventional sanitation systems have been shown to include inadequate institutional capacity to deal with the sanitation process, a fixation with providing either a full waterborne system or a VIP toilet, the social acceptability of various systems, and the perception that dry, on-site sanitation systems are inherently inferior. The basic purpose of any sanitation system is to contain human excreta (chiefly faeces) and prevent the spread of infectious diseases, while avoiding damage to the environment. An alternative sanitation technology known as urine-diversion (UD) performs these functions with fewer operational and maintenance problems than those associated with conventional VIP toilets, and also provides a free, easily accessible and valuable agricultural resource for those who wish to use it. This technology represents one aspect of an approach, or philosophy, termed “ecological sanitation” (also known as “ecosan”). According to Esrey et al (1998) key features of ecosan are prevention of pollution and disease caused by human excreta, treatment of human excreta as a resource rather than as waste, and recovery and recycling of the nutrients. In nature, excreta from humans and 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 break this cycle.

UD technology has been used successfully for decades in countries such as Vietnam, China, Mexico, El Salvador, Ecuador, Guatemala, Ethiopia and, since 1997, also in Zimbabwe and South Africa (the author was responsible for implementing South Africa’s first UD project, near Umtata in Eastern Cape). Various Scandinavian and European countries have also implemented different UD schemes in the last few years. The most

important characteristic of this technology is the low moisture content in the faeces receptacle. The urine is diverted at source by a specially designed pedestal and is not mixed with the faeces. A schematic representation is given in Figure 1.1, while a typical UD toilet pedestal is illustrated in Figure 1.2. A pit is not necessary, as the entire structure may be constructed above ground, or may even be inside the dwelling. Ash, dry soil or other suitable material is sprinkled over the faeces after defecation. This serves to absorb the moisture and control flies and odours. The generally dry conditions in the faeces receptacle facilitate the desiccation of the contents, which assists pathogen destruction. The desiccated faecal matter makes a good soil conditioner while the urine, when diluted with water, is an excellent fertiliser, being rich in the nutrients nitrogen, phosphorus and potassium.

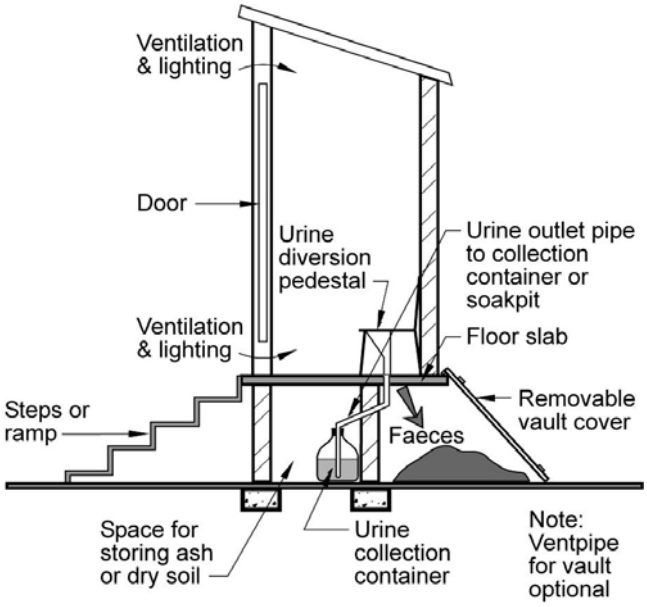


Figure 1.1: Schematic representation of a urine-diversion toilet

Figure 1.2: A typical urine-diversion toilet pedestal

1.3 BACKGROUND TO THIS INVESTIGATION

As mentioned above, UD systems have been successfully implemented in many countries, including South Africa where more than 60 000 (current figure, June 2007) of these toilets have been built since the implementation of CSIR's pilot project in 1997. However, despite much research having been carried out internationally and locally, various questions still remain, particularly on the health aspects of operation, maintenance, and excreta use or disposal. In contrast to composting, which is generally well understood, not enough is known about the dehydrating processes taking place inside the faeces vault, and there is still disagreement on safe retention periods and microbiological stability of the final product. The roles of dryness, pH, temperature and time in pathogen destruction also need to be further clarified. In addition, it is critically important that toilet users are able to operate and maintain their systems easily and safely, particularly while emptying the vaults and recycling or otherwise dealing with the contents. Engineers need to understand and take all these issues into consideration before they can properly design and implement sustainable UD sanitation systems.

It is therefore important to develop guidelines for sanitation practitioners that set out best practices for design and operation of UD toilets. Design recommendations are important because good design facilitates easy operation, and also promotes rapid pathogen destruction. Easy operation in turn directly influences the health risks associated with removing faecal material from the vaults by minimising contact with untreated material. The rate of pathogen destruction in a UD toilet is mainly dependent on temperature, dryness and pH, although detailed quantification of these parameters is still lacking and needs to be further researched. These parameters are also influenced by different types of bulking agents (e.g. ash, lime, sawdust, leaves, etc). If the interrelationship of these factors, together with time, could be determined and graphically illustrated, it would represent a valuable new tool for project implementers.

Handling of faecal material is an aspect inherent in the operation of UD ecological sanitation systems, because emptying of the vault is usually done using hand tools. If the faecal material is also used for agricultural purposes then further handling must of necessity take place. As such, there is a health concern, both for the person(s) handling the material and for the wider public who may be consumers of the fertilised crops. It is therefore necessary that these health concerns be quantified, in order that proper regulation may take place. These aspects are examined in more detail in chapter 2 (literature review), particularly section 2.6, as well as in chapter 4 (field trials on food crops). These two chapters form the basis of the rationale for the thesis, as set out in chapter 3.

This thesis is written from the perspective of an engineer, for engineers who are involved in the implementation of UD ecological sanitation systems. As such, it is not intended to be a microbiological treatise, but is concerned with health aspects that are, or should be, of concern to sanitary engineers. Proper implementation of UD toilets requires a working knowledge of the mechanisms of pathogen die-off in the toilet vaults, in order to ensure suitable design and construction methods aimed at enhancing this die-off, and also so that effective operation and management procedures may be put in place, particularly for handling, disposal and/or use of faecal material. The intention is to develop practical guidelines for this purpose, for both the designer and the regulator, and the microbiological aspects are thus dealt with only in detail sufficient for understanding the scope of the problem.

CHAPTER 2
ECOLOGICAL SANITATION: LITERATURE REVIEW

2.1 INTRODUCTION

2.1.1 STRUCTURE OF LITERATURE REVIEW

This literature review is based largely on the Water Research Commission (WRC) publication TT 246/05 entitled "*Ecological sanitation – Literature review*", which emanated from WRC project number K5/1439 entitled "*Strategy for the furtherance of knowledge and good practice of ecological sanitation (ecosan) technology in South Africa*" (Austin et al 2005). The writer was the project leader and main author. Some modifications have been made to the original text.

The review begins with a general overview of the South African sanitation experience, with specific reference to on-site technologies. Subsequently, the need for alternative technologies is examined. The review then explores the relationship between sanitation, the environment and public health, and links these concerns to the development of urine-diversion (UD) toilets.

Design and management practices for UD toilets in various countries, including South Africa, are then investigated, with the aim of illustrating the wide variety of methods and materials used. Operational aspects of UD toilets are subsequently addressed by examining current practices in urine and faeces management, both in South Africa and abroad. Because sanitation is for people, the review then studies the perceptions and experiences of UD toilet users around the world and attempts to identify how they are affected by design, implementation practices or other factors.

As many operational practices are associated with use of excreta for agricultural purposes, this aspect is then investigated in some detail, with experiences from various countries being described. The penultimate section of the review presents an in-depth investigation of the health and safety aspects of urine-diversion toilets, with particular attention to the use of urine and processed faeces in food gardens.

The final section of the review is devoted to a summary of the most pertinent issues identified, an indication of what matters remain unresolved, and an assessment of how the review should influence and guide the present research.

2.1.2 SANITATION: THE SOUTH AFRICAN EXPERIENCE

In South Africa (as in most developing countries of the world) the most commonly used sanitation technologies are waterborne sewerage at one end of the scale and pit toilets at the other. There are some intermediate technologies, such as septic tanks, but it is a fact that everybody aspires to the top-of-the-range article. This is so despite implications such as high water usage, high operation and maintenance costs, and the advanced technology and institutional capacity required for removal, treatment and disposal of the

excreta. Ventilated improved pit (VIP) toilets have unfortunately also acquired the stigma of being a “poor man’s solution” to the sanitation problem, which has tarnished the image of this basically sound technology (Austin and Van Vuuren 2001).

Many community sanitation schemes have been successfully implemented utilising VIP toilets. However, others have been problematic, often due to poor design and construction practices or to social factors such as a lack of community buy-in, or a combination of these. Sufficient attention is not always given to factors such as environmental impact, social issues, water-supply levels, reliability or institutional capacity (Austin and Van Vuuren 2001). The result has often been a legacy of poorly planned and inadequately maintained systems provided by well-intentioned but shortsighted authorities and developers (Austin and Duncker 2002).

South Africa’s GNP classifies it as partly developed and partly undeveloped. It is an unequal economy with large discrepancies in wealth between rich and poor. Some of its inhabitants have a high level of service; others have very little at all. The combination of these factors has brought about resistance to the use of on-site sanitation in the country, centred around issues such as (Fourie and van Ryneveld 1994):

- A perception that the use of on-site sanitation implies “second class”;
- a perception that there is plenty of money in the country for a high level of service;
- a disbelief that waterborne sewerage costs as much as it does;
- a perception that waterborne sewerage is a robust system, whereas it is in fact a fragile system that is sensitive to misuse and the use of inappropriate cleansing materials. Furthermore there is a lack of appreciation of the consequences of failure of such systems;
- a perception that on-site sanitation is unhealthy, that it does not work as well as full waterborne sewerage, and will cause disease; and
- concern that on-site sanitation may pollute the country’s scarce water resources.

At all levels, the problem is related to socio-cultural, educational and institutional issues, with the lack of appropriate facilities and inadequate guidelines being a contributory factor. There is a need for new approaches and technologies that support alternative sanitation efforts (Austin and Duncker 2002).

In its 1996 draft sanitation policy, the South African government stressed that sanitation was not simply a matter of providing toilets, but rather an integrated approach that encompassed institutional and organizational frameworks as well as financial, technical, environmental, social and educational considerations. It was recognised that the country could not afford to provide waterborne sanitation for all its citizens – nor, for that matter, should it necessarily aspire to do so. The basic level of sanitation service in South Africa was defined in the Draft White Paper on National Sanitation Policy as a “ventilated improved pit (VIP) toilet in a variety of forms, or its equivalent, as long as it meets certain minimum requirements in terms of cost, sturdiness, health benefits and environmental impact” (DWAF 1996). In the September 2001 White Paper, the definition “basic level of service” has been replaced by the term “adequate sanitation”, which is judged by criteria that the service should promote health and safety, and that it should be attainable and sustainable socially, economically, environmentally and technically (DWAF 2001).

2.1.3 THE NEED FOR ALTERNATIVE SANITATION TECHNOLOGIES

Sanitation is an extremely complex issue. It is an issue that impacts on the daily lives of every human being inhabiting this planet, particularly in the developing countries where the level of service is either poor or nonexistent. There is no single solution that can be applied as a universal panacea and the situation will continue to worsen unless new approaches are adopted (Austin and Duncker 2002).

Simpson-Hébert (1996) proposes a number of interrelated guiding principles, among which are the following:

- The sanitation sector must continue to innovate low-cost facilities for people with different needs, from different climates, and with different customs. It is wrong to choose one or two technologies and push them as "the solution". A particular product may be right for a certain section of the market, but not for all consumers and conditions. More research and better designs are still needed.

- There is a need in some societies to recycle human excreta as fertiliser, as has been done for centuries in various parts of the world. Human excreta can be rendered harmless, and toilet designs that do this in harmony with agricultural and social customs hold promise for the future.

- Toilets are consumer products: their design and promotion should follow good marketing principles, including a range of options with attractive designs based upon consumer preferences, and also be affordable and appropriate to local environmental conditions. Sanitation systems should neither pollute ecosystems nor deplete scarce resources. Systems should also be capable of protecting people from excreta-related diseases as well as interrupting the cycle of disease transmission.

Sanitation programmes that fulfil these principles simultaneously have a greater likelihood of long-term sustainability. Simpson Hébert (1997) consequently makes, inter alia, the following recommendations for implementing sanitation programmes:

- impetus should be provided for research and development for a range of systems applicable to differing cultural and environmental conditions; and

- a demand should be created for systems that move increasingly toward use and recycling of human excreta.

According to Winblad (1996b), there exists an erroneous assumption that the basic problem is one of "sewage disposal", while in actual fact the problem is the disposal of human faeces and urine, not sewage. This is because the human body does not produce "sewage". Sewage is the product of a particular technology. To handle faeces and urine separately should not a great problem, as each human produces only about 500 litres of urine and 50 litres of faeces a year. The problem arises only when these two substances are mixed together and flushed into a pipe with water to form sewage. This means that, instead of only fifty litres of problem material, it becomes necessary to deal with 550 litres of polluted, dangerous and unpleasant sewage.

Urine-diversion sanitation technology is based on the concept of keeping these two substances separate. The main advantages of this approach are, firstly, that valuable nutrients such as nitrogen, phosphorus and potassium are found in urine, and secondly,

the dangerous pathogens present in faeces are more easily isolated from the environment (Austin and Duncker 2002).

According to Dudley (1996) “conventional” sanitation options may be suited to certain situations, but in other circumstances where both water and space are scarce there is a clear need for permanent, emptiable toilets which do not require water. Such circumstances are becoming increasingly common. When limits are placed on other variables, for example money and the depth of the water table, the circumstances where options such as sewers and pit toilets are viable become fewer, while the need for permanent, emptiable, waterless toilets grows.

Even if the sanitation crisis can be communicated to and understood by more people, the need to find sustainable alternatives to conventional approaches for both developed and developing countries remains. Sanitation can no longer be a linear process where excreta are hidden in deep pits or flushed downstream to other communities and ecosystems. Sustainable and ecological sanitation requires a holistic approach (EcoSanRes 2003).

2.1.4 URINE-DIVERSION TECHNOLOGY AS AN ALTERNATIVE TO PIT TOILETS

Many community sanitation schemes have been successfully implemented utilising VIP toilets. As mentioned in chapter 1, others have failed, usually due to poor design and construction practices or to social factors such as a lack of community buy-in, or a combination of these. New or unknown technologies are often viewed with suspicion or rejected out of hand. Some cultural beliefs and practices may also make it difficult to introduce alternative technologies into a community (Austin and Duncker 2002). Attempts have been made to find simple, universally applicable solutions to sanitation problems; however, these often fail because the diversity of needs and contexts is ignored. Urban needs usually differ from rural needs, the technological options offered are limited and often inappropriate, and critical social issues such as behaviour are either ignored altogether or badly handled (Simpson-Hébert 1995). Furthermore, the scope of environmental protection becomes so broad that the main purpose of sanitation provision is often lost. Current approaches also tend to stifle innovation.

VIP toilets, correctly engineered and implemented, are a good means of providing sanitation in areas where financial factors preclude the provision of a higher level of service. Full pits are a problem, however. In many cases the owners will not be in a financial position to empty them, even if the toilets have been constructed with this in mind (e.g. removable cover slabs). While there may be plenty of available space in rural areas to dig further pits, this will seldom be the case in densely populated urban areas. This aspect does not even take into account the cost of digging a new pit and moving or rebuilding the superstructure, so for all practical purposes the initial investment is lost when the pit fills up. Some other solution should be sought in these cases, and the ventilated improved double pit (VIDP) toilet has gone some way in addressing this problem (Austin and Van Vuuren 2001).

To address these shortcomings, it has been necessary to think beyond the limitations imposed by traditional methods of providing dry sanitation. There is an increasing awareness worldwide of the environmental issues associated with sanitation. Furthermore, pressure on land to produce more food to feed the ever-growing populations of developing countries has made the utilisation of valuable natural resources, including human excreta, of greater significance. The concept of ecological sanitation, or “ecosan”

as it is also known, is seen as an alternative solution to some of the problems associated with pit toilets, environmental degradation and food shortages (Austin and Duncker 2002).

The technology of ecological sanitation, or "dry box" toilets, has been used successfully for many years in a number of developing countries, e.g. Vietnam, China, Mexico, El Salvador, Ecuador, Guatemala and Ethiopia, and recently also in Zimbabwe and South Africa. Even in a highly developed country such as Sweden there is a great deal of interest in the technology (Esrey et al 1998; Hanaeus et al 1997; Höglund et al 1998; Jönsson 1997; Wolgast 1993). A schematic representation of the technology is given in chapter 1, Figure 1.1.

Ecological sanitation systems 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 some unfamiliar features such as urine-diversion pedestals or squatting plates. In addition, they require more promotion, support, education and training than VIP toilets (Esrey et al 1998).

A concern is often expressed that some ecological sanitation systems are too expensive for low-income households in developing countries (Esrey et al 1998). Ecosan systems need not cost more than conventional systems. While some systems may be sophisticated and expensive, others are relatively simple and low-cost. There is often a trade-off between cost and operation: lower-cost solutions mean more manipulation and care of the sanitation system, while with higher-cost solutions manipulation and care can be reduced. Ecosan systems need not be expensive to build because (Esrey et al 1998):

- the entire structure can be built above ground – there is thus no need for expensive digging and lining of pits; and

- urine is diverted, no water is used for flushing and the volume of the processing vault is fairly small, as it is emptied periodically.

The introduction of ecosan systems is bound to lower the total cost of urban sanitation in particular. If a waterborne system is being considered, the sewers, treatment plants and sludge-disposal arrangements will cost several times as much as an ecosan system, while for ordinary VIP toilets the institutional capacity required for desludging full pits may be nonexistent. These are important considerations for developing countries, where public institutions face stringent financial limits (Esrey et al 1998). Furthermore, households will have a wider choice of sanitation systems and thus have more freedom to decide what is affordable and most suitable for them.

2.1.5 THE ENVIRONMENT AND PUBLIC HEALTH: THE ARGUMENT FOR ECOLOGICAL SANITATION

Environmental problems undermine the process of development, which is further hampered by rapid population growth. In all developing countries, especially in sub-Saharan Africa, the population growth in the urban areas alone is outstripping the capacity of these regions to provide for basic needs such as shelter, water and sanitation. In the city of Dar es Salaam in Tanzania, to name but one example, pit toilets and septic tanks with drainfields serve about 76% of the population, and this has caused serious faecal pollution of the groundwater, which is generally only 1 m to 3 m below ground level. Faecal coliform levels of up to 3 000/100 ml have been recorded (Kaseva 1999).

Simpson-Hébert (1997) maintains that one of the constraints to providing efficient sanitation in urban areas is the myth that the only good sanitation system in such places is conventional waterborne sewerage. While this type of sanitation system has been widely successful in controlling the transmission of excreta-related diseases in most cities of industrialised countries, it has also created severe damage to ecosystems and to natural water resources where the wastewater is inadequately treated. Since proper treatment increases the cost and energy requirements of the entire system without being essential to the day-to-day survival of the individual user, this part of the system is often omitted when financial resources are scarce. Consequently, in those cities of developing countries that have a conventional sewer system, only a very small percentage of the wastewater collected is treated at all. In many areas this has resulted in severe ecological damage, with heavy economic consequences.

The success or failure of a sanitation system depends on the interaction of environmental, human and technical factors. The most important environmental aspects are climate, soil and groundwater; these vary from place to place and have a great influence on the choice of the most appropriate sanitation system. The technology selected should therefore be adapted to the local environmental conditions (Winblad and Kilama 1980).

It is better to protect the environment from faecal pollution than to undertake expensive measures to reduce pollution that has already taken place (Feachem and Cairncross 1978). The approach to the sanitation challenge should therefore be ecologically sustainable, i.e. concerned with the protection of the environment. This means that sanitation systems should neither pollute ecosystems nor deplete scarce resources. It further implies that sanitation systems should not lead to a degrading of water or land and should, where possible, ameliorate existing problems caused by pollution. Sanitation systems should also be designed to recycle resources such as water and nutrients present in human excreta (Simpson-Hébert 1997).

In many urban centres, the poorest groups face the most serious environmental hazards and are least able to avoid them or receive treatment to limit their health impact (Wall 1997). By early this century, more than half of the world's population is expected to be living in urban areas. By the year 2025, this urban population could rise to 60%, comprising some 5 billion people. The rapid urban population growth is putting severe strains on the water supply and sanitation services in most major conurbations, especially those in developing countries (Mara 1996). In Africa today, over half the population is without access to safe drinking water and two-thirds lack a sanitary means of excreta disposal (WSSCC 1998). It is a situation in which the poor are adversely affected to a disproportionate degree. Lack of access to these most basic of services necessary to sustain life lies at the root of many of Africa's current health, environmental, social, economic and political problems. Hundreds of thousands of African children die each year from water- and sanitation-related diseases. Despite significant improvements during the International Drinking Water Supply and Sanitation Decade (1981-1990), progress has now stagnated. More people are today without adequate services in Africa than in 1990, and at the current rate of progress full coverage will never be achieved (WSSCC 1998).

Western sanitation solutions were designed and built on the twin premises that human excreta are waste products suitable only for disposal, and that the environment is capable of assimilating the waste. Times have changed and these premises are outdated. Current sanitation interventions contribute, either directly or indirectly, to many of the problems faced by society today: water pollution, scarcity of fresh water, food insecurity, destruction and loss of soil fertility, global warming and poor human health (Esrey and Andersson 1999).

Although conventional sewage systems transport excreta away from the toilet user, they fail to contain and sanitise, instead releasing pathogens and nutrients into the downstream environment. This is considered the "linear pathogen flow" (Esrey et al 1998). These systems mix faeces, urine, flush water and toilet paper with greywater and industrial effluents, often overtaxing the design capacity of the treatment plants, if such a facility exists, as very few communities in the world are able to afford fully functional sewage systems. Flushing sanitation systems have a "dismal track record" because all sewage systems contaminate the environment (EcoSanRes 2003).

Far more common than flush sanitation is the pit toilet, primarily because it is inexpensive and requires no infrastructure. This method also fails to contain and sanitise excreta since pathogens and nutrients may seep into the groundwater. Deep pit toilets also fail to recycle since the excreta are too deep for plants to make use of the nutrients. Pits are prone to periodic flooding, causing them to spill their contents, and are often poorly maintained, continuing to be a source of disease and pollution (EcoSanRes 2003).

The "linear pathogen flow" is also described as a "flush-and-discharge" sanitation system (Esrey et al 1998). For each person, some 500 litres of urine and 50 litres of faeces are flushed away each year, together with 15 000 litres of pure water. Bath, kitchen and laundry water (greywater), amounting to a further 15 000 to 30 000 litres, is then added. Further down the pipe network, heavily polluted water from industries may also join the flow. Thus at each step in the flush-and-discharge process the problem is magnified. The dangerous component, 50 litres of faeces, is allowed to contaminate not only the relatively harmless urine but also the large amount of pure water used for flushing and an equal or even larger amount of greywater (Esrey et al 1998). This linear, or "open" system is illustrated in Figure 2.1.

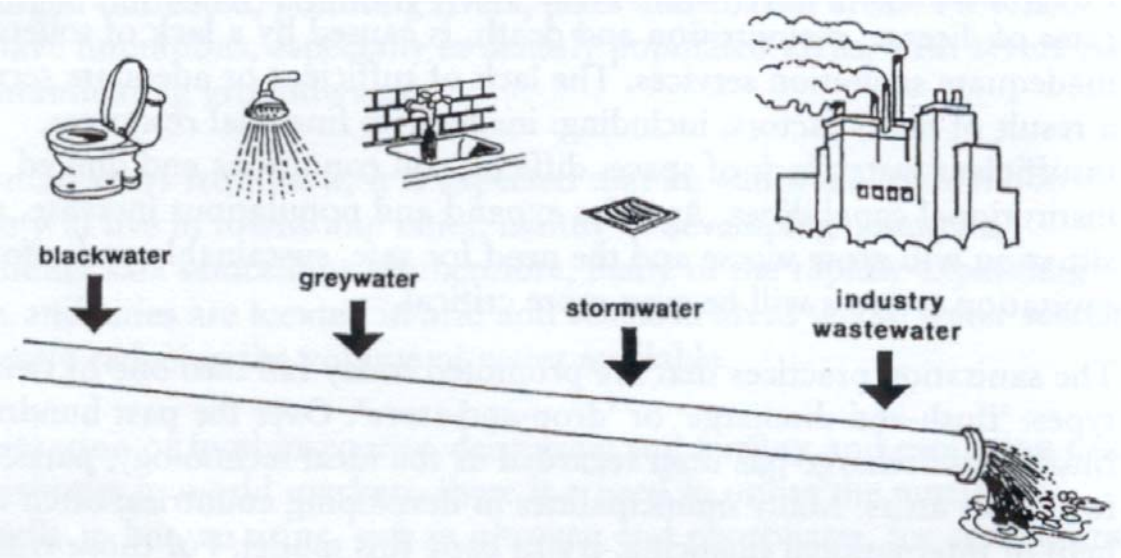


Figure 2.1: The linear, or open, flow system (Esrey et al 1998)

The ecosan approach to sanitation promotes a cycle, or "closed" system instead, where human excreta are treated as a resource. Excreta are processed on site and then, if necessary, further processed off site until they are completely free of disease organisms (Esrey et al 1998). The nutrients contained in the excreta are then recycled by using them as fertiliser in agriculture (Figure 2.2).

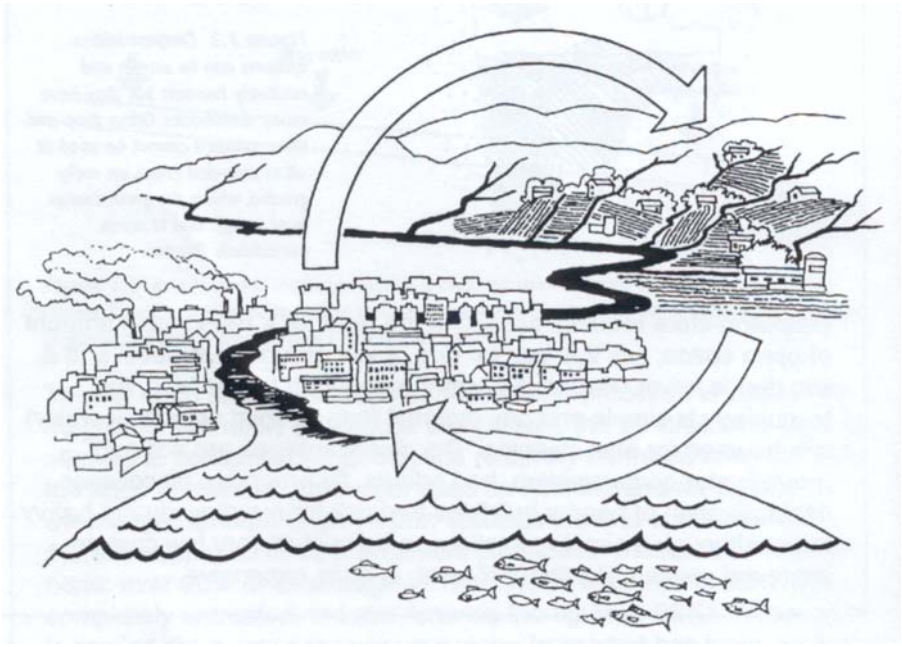


Figure 2.2: The cycle, or closed loop, system (Esrey et al 1998)

Closed-loop wastewater management and sanitation helps restore the remarkable natural balance between the quantity of nutrients excreted by people each year and the quantity required to produce their food (GTZ 2002). Ideally, ecosan systems enable the almost complete recovery of all nutrients and trace elements from household wastewater and their use in agriculture. They help preserve soil fertility and safeguard long-term food security. The technology employed can be simple, low-tech arrangements or sophisticated high-tech systems. These range from composting or urine-diversion dry systems to water-saving vacuum sewage systems with separate collection and subsequent treatment of urine, faeces and greywater, through to membrane technology for material separation and hygienisation. Of key importance are innovative logistics to return nutrients to farmland, marketing strategies for the recovered nutrients and directions for their safe application in agriculture (GTZ 2002).

Ecosan defined (EcoSanRes 2003)

Ecological sanitation can be viewed as a three-step process: containment, sanitisation and recycling of human excreta. The objective is to protect human health and the environment while reducing the use of water in sanitation systems and recycling nutrients to help reduce the need for artificial fertilisers in agriculture. Ecosan represents a conceptual shift in the relationship between people and the environment, and is built on the necessary link between people and soil (Figure 2.3).

Ecosan systems are designed around true containment of pathogens and provide two ways to render human excreta innocuous: dehydration and decomposition. The preferred method will depend on climate, groundwater tables, amount of space and intended purpose for the sanitised excreta.

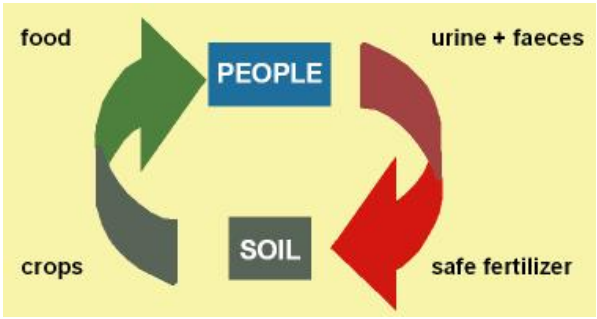


Figure 2.3: The concept of ecological sanitation (EcoSanRes 2003)

Dehydration is the chemical process of destroying pathogens by eliminating moisture from the immediate (containing) environment. Some drying materials, like wood ash, lime and soil are added to cover the fresh deposit. Ash and lime increase the pH, which acts as an additional toxic factor to pathogens if it can be raised to over 9,5. The less moisture the better, and in most climates it is better to divert the urine and treat it separately. The toilet units may be single or double-vault.

Soil composting toilets make use of the process of decomposition, a biological process carried out by bacteria, worms and other organisms to break down organic substances. In a composting environment, the competition between organisms for available carbon and nutrients continues until the pathogens are defeated by dominant soil bacteria. Soil-composting toilets are constructed using shallow vaults where soil and ash are added after each use. The vaults are used alternately and, once sanitised and composted, the contents are removed and used in agriculture.

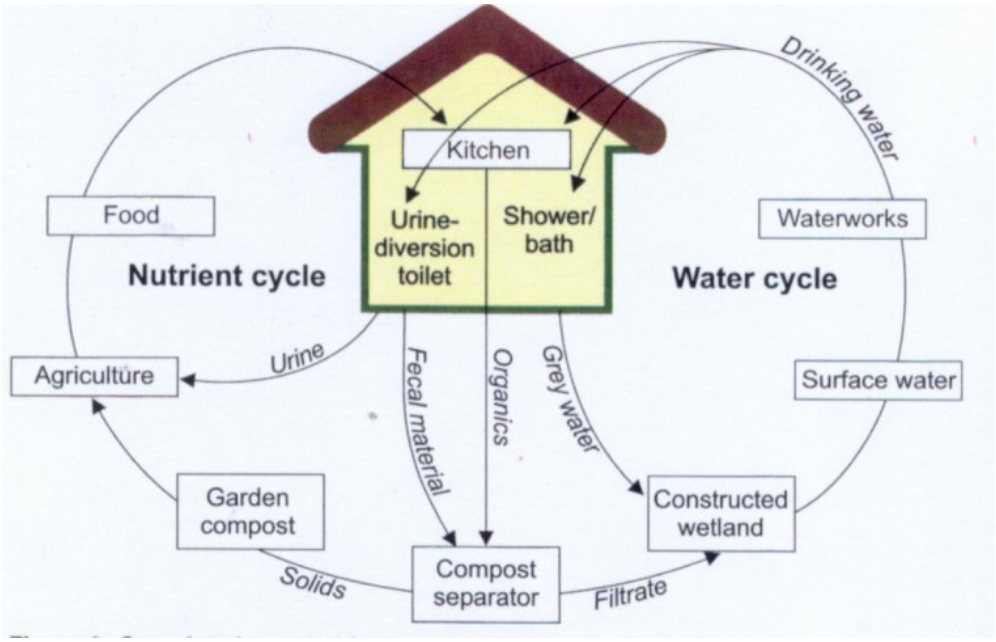


Figure 2.4: Complete household ecosan
(M. Oldenburg (Otterwasser) quoted in EcoSanRes 2003)

The ecological sanitation approach can be broadened to cover all organic material generated in households (kitchen and food wastes). If these organic materials are sorted within the home, rather than mixed with solid waste and dumped, they become valuable recyclable materials once composted. Greywater can be treated using biological systems such as evapotranspiration beds and constructed wetlands, and rainwater harvesting can be implemented to harness water for personal hygiene and irrigation. Figure 2.4 illustrates all the options in a fully functional ecosan household.

The Bellagio statement:
Clean, healthy and productive living: A new approach to environmental sanitation[1]

In the world today, 1,2 billion people are without access to safe drinking water, 3 billion are without proper sanitation, and 50% of solid wastes remain uncollected. Meeting at Bellagio from 1 to 4 February 2000, an expert group brought together by the Environmental Sanitation Working Group of the Water Supply and Sanitation Collaborative Council (WSSCC) agreed that "current waste management policies and practices are abusive to human well-being, economically unaffordable and environmentally unsustainable." The group called for a radical overhaul of conventional policies and practices world-wide, and of the assumptions on which they are based, in order to accelerate progress towards the objective of *universal access to safe environmental sanitation, within a framework of water and environmental security and respect for the economic value of wastes.*

The principles governing the new approach are as follows:

1. Human dignity, quality of life and environmental security should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local setting.
    - Solutions should be tailored to the full spectrum of social, economic, health and environmental concerns.
    - The household and community environment should be protected.
    - The economic opportunities of waste recovery and use should be harnessed.

2. In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and providers of services.
    - Decision-making at all levels should be based on informed choices.
    - Incentives for provision and consumption of services and facilities should be consistent with the overall goal and objective.
    - Rights of consumers and providers should be balanced by responsibilities to the wider human community and environment.

3. Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes.
    - Inputs should be reduced so as to promote efficiency and water and environmental security.

[1] The WSSCC has defined environmental sanitation as: "Interventions to reduce peoples' exposure to disease by providing a clean environment in which to live, with measures to break the cycle of disease. This usually includes hygienic management of human and animal excreta, refuse, wastewater, stormwater, the control of disease vectors, and the provision of washing facilities for personal and domestic hygiene. Environmental sanitation involves both behaviours and facilities which work together to form a hygienic environment."

- Exports of waste should be minimised to promote efficiency and reduce the spread of pollution.
- Wastewater should be recycled and added to the water budget.

4. The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, community, town, district, catchment, city) and wastes diluted as little as possible.
   - Waste should be managed as close as possible to its source.
   - Water should be minimally used to transport waste.
   - Additional technologies for waste sanitisation and reuse should be developed.

2.1.6 CONCLUSIONS

Conventional waterborne sewerage systems, generally the most sought-after sanitation technology, have been responsible for widespread environmental pollution in many countries. Although socio-economic issues are often responsible for this, a lack of institutional capacity has been shown to be an important contributory factor. On the other hand, on-site sanitation systems such as VIP toilets have acquired the stigma of a "second-class solution" in South Africa and have brought about resistance to on-site systems in general. Poorly engineered on-site systems have also contributed to pollution in many cases.

Due to sanitation being an extremely complex issue, there is no "universal solution"; new approaches need to be adopted and impetus provided for research and development of systems catering for differing cultural and environmental conditions. It has been argued that sanitation approaches based on the use of large amounts of (potable) water, as well as those based only on pit toilets, cannot solve the sanitation problem. Sanitation should no longer be regarded as a linear process – to be sustainable, a holistic approach incorporating wider issues (e.g. amelioration of poor quality soils, poverty alleviation and food shortages) is required instead.

Ecological sanitation (ecosan) has been recommended as an alternative solution to some of the problems associated with pit toilets, environmental degradation and food shortages. This technology has been used successfully in many countries, both developing and developed, for many years. It is based on a three-step process: containment, sanitisation and recycling of human excreta. It also complies with the Bellagio Principles of safe environmental sanitation within a framework of water and environmental security and respect for the economic value of wastes.

2.2 URINE-DIVERSION APPLICATIONS: EXAMPLES OF CURRENT PRACTICE

2.2.1 INTRODUCTION

To address the shortcomings of VIP toilets, it has been necessary to think beyond the limitations imposed by traditional methods of providing dry sanitation. There is increasing awareness worldwide of the environmental issues associated with sanitation. Furthermore, pressure on land to produce more food to feed the ever-growing populations of developing countries has made it imperative to utilise natural resources, including human excreta, wherever possible. The concept of ecological sanitation, or ecosan as it is also known, is seen in many countries as an alternative solution to some of the problems associated with pit toilets, environmental degradation and food shortages (Austin 2000).

In the alternative approach to sanitation – ecological sanitation – excreta are processed on site, and if required, off site, until completely free of pathogens and inoffensive. The faeces are sanitised close to the place of excretion, and then applied to the soil to improve its structure, water-holding capacity and fertility. Valuable nutrients contained in excreta, mostly in urine, are returned to the soil for healthy plant growth (Esrey et al 2001).

It is a different way of thinking about sanitation: a **closed-loop approach** in which the nutrients are returned to the soil instead of water or deep pits. Ecological sanitation is not merely a new toilet design – the closed-loop approach is also a zero-discharge approach, keeping water bodies free of pathogens and nutrients (Esrey et al 2001).

Sanitation using the technique of urine diversion is applied in many parts of the world. Various examples are described in the following pages. The examples are intended to illustrate various aspects of ecosan toilets and show the diverse range of styles, methods and traditions.

2.2.2 EXAMPLES FROM OTHER COUNTRIES

(a) Yemen

In the old city of Sanaa a single chamber dehydrating toilet with urine diversion is placed in the bathroom several floors above street level (Figure 2.5). In a traditional Yemeni townhouse the upper floors have toilet-bathrooms next to a vertical shaft that runs from the top of the house down to the level of the street. The faeces drop through a hole in the squatting slab and down the shaft, while the urine drains away through an opening in the wall and down a vertical drainage surface on the outer face of the building. Personal cleansing with water takes place on a pair of stones next to the squatting slab. The water is drained off in the same way as the urine. As Sanaa has a hot, dry climate, the urine and water usually evaporate before reaching the ground, while the faeces dehydrate quickly. They are collected periodically and used as fuel (Esrey et al 1998).

This example illustrates how urine diversion can work in a multi-storey building and how climate can influence the design and operation of the toilet.

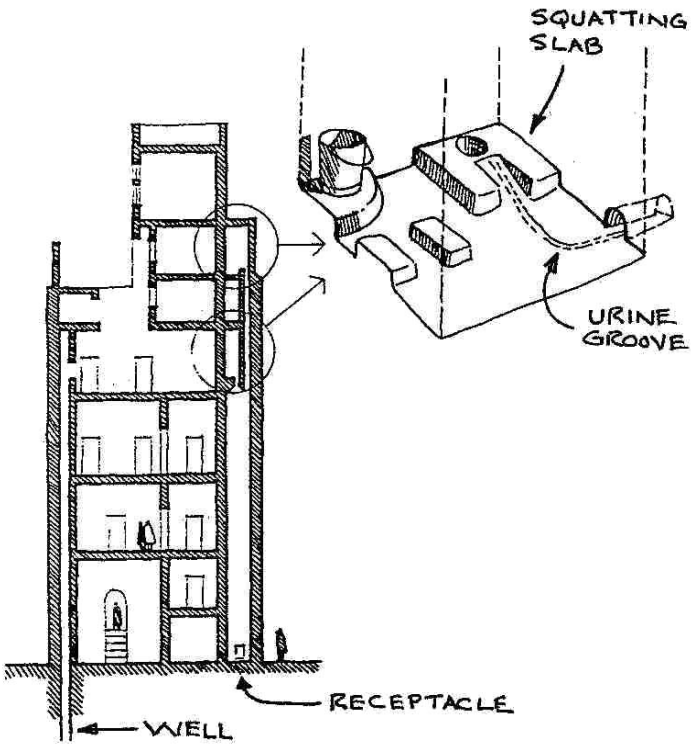


Figure 2.5: Section through a house in the old part of Sanaa, Yemen
(Esrey et al 1998)

(b) Vietnam

The Vietnam example is a double-chamber toilet built above ground, with drop-holes, footrests for squatting and a groove for conducting urine to a container (Figure 2.6). Faeces are dropped into one of the chambers while the other one is kept closed (i.e. the chambers are used in rotation, similar to a conventional VIDP toilet). The faeces are covered with kitchen ash, which absorbs moisture and deodorises them. Paper used for personal cleansing is put into a bucket and later burnt, while the dehydrated faecal material is used as a soil conditioner (Esrey et al 1998; Winblad 1996b).

The Vietnamese double-vault originated in the 1950s, when peasants who were using human excreta as manure found that composting reduced the smell and improved its fertiliser value. This became the key component of a rural sanitation programme for disease prevention and increased food production that began in North Vietnam in 1956. After much experimentation it was found that the addition of kitchen ash effectively neutralised the bad odours normally associated with anaerobic decomposition, and also destroyed intestinal worm ova – after a two-month composting period 85% of the ova were found to have been destroyed (World Bank 1982). According to Van Buren et al (1984), these composting latrines produce more than 600 000 tons of organic fertiliser each year and have also been responsible for a substantial reduction in intestinal diseases.

This example illustrates the inherent simplicity of design, operation and maintenance of a urine diversion toilet and how it can contribute to improved health and nutrition.

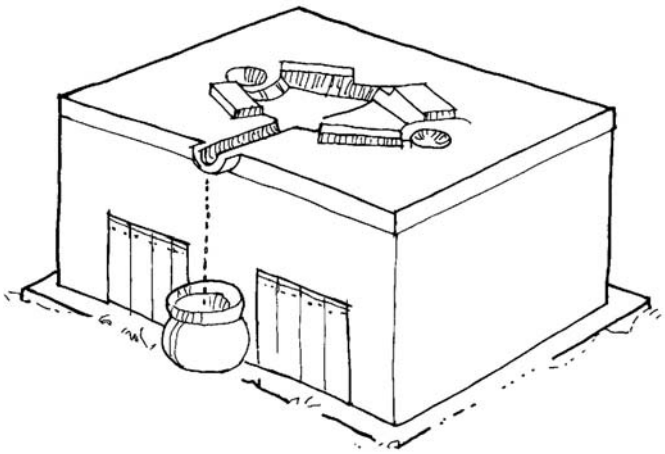


Figure 2.6: The Vietnamese double-vault dehydrating toilet, shown here without the superstructure. Each vault is about 0,8m x 0,8m square and about 0,5m deep. The drop-hole not in use is closed with a stone and sealed with mud or mortar (Esrey et al 1998)

(c) El Salvador

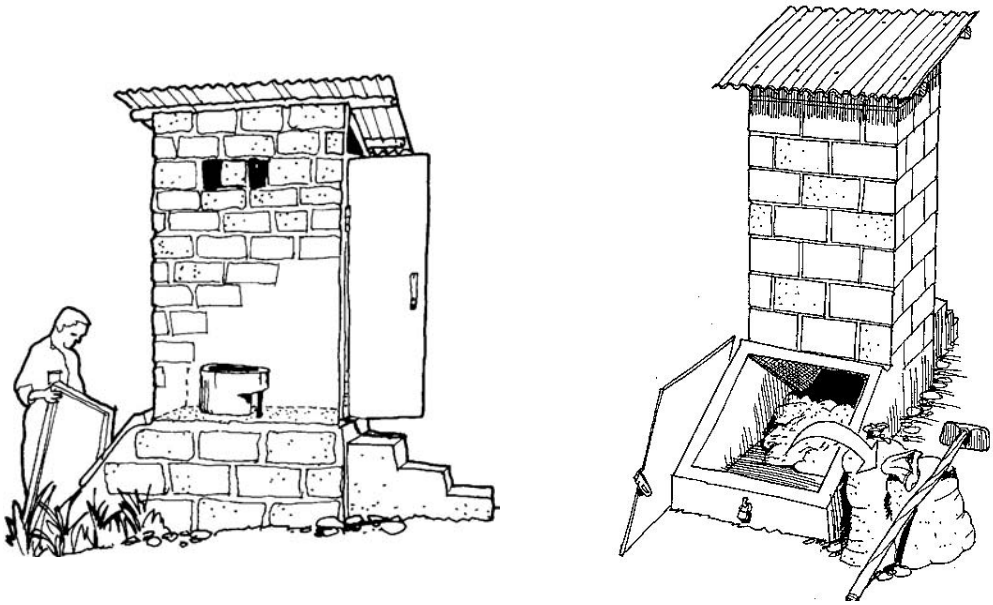
Some experimental urine diversion toilets have been equipped with a solar heater (Figure 2.7(a)). The main purpose of the heater is to increase evaporation in the chamber and thereby accelerate dehydration of the faeces. The example shown is from the community of Tecpan, near San Salvador. As there is no tradition of using human urine as fertiliser in Central America, the urine is piped into a soakpit beneath the toilet chambers. Wood ash and/or a soil/lime mixture is added to the processing vault, while toilet paper is placed in a container next to the pedestal and periodically burned. At intervals of one to two weeks the lid acting as solar heat collector is removed and the faeces/ash/soil pile beneath the pedestal raked to the rear of the vault, beneath the solar heater. This dry, odour-free pile is removed every couple of months and used as soil conditioner, as illustrated in Figure 2.7(b) (Esrey et al 1998; Winblad 1996b).

This example illustrates easy operation and maintenance. It should be noted that the vault lid intended as a solar heater was also one of the subjects of research for this thesis (see chapter 5).

(d) Ecuador

Figure 2.8 illustrates an example of a double-chamber solar-heated dehydrating toilet in Ecuador, high up in the Andes Mountains. At this altitude there is no need for urine diversion as the natural evaporation takes care of any excess liquid. The recycling system was chosen to help combat the problem of declining soil fertility in the region (Esrey et al 1998).

This example illustrates an interesting use of building materials as well as simple design.



(a) (b)

Figure 2.7
(a) Dehydrating toilet with urine diversion and solar-heated vault in El Salvador.
(b) Removing the desiccated faeces for use as soil conditioner.
(Esrey et al 1998)

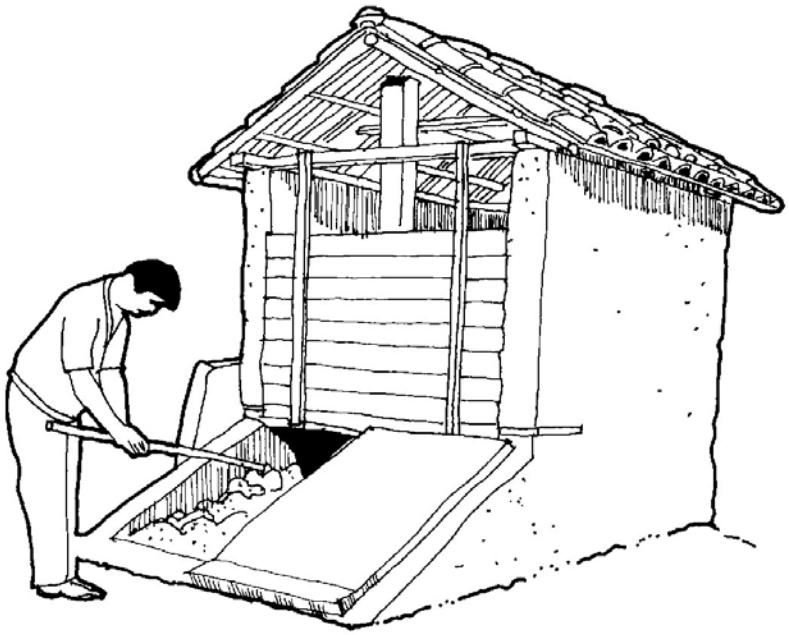


Figure 2.8: A solar-heated dehydrating toilet in Ecuador
(Esrey et al 1998)

(e) Mexico

In the Mexican city of Cuernavaca, a number of middle-class families live in modern dwellings where urine-diversion toilets of a high standard, based on the Vietnamese double-vault version, are installed in-house (Figure 2.9). This urban application is of particular significance because it demonstrates that careful management of an ecosan system, resulting from high motivation and understanding on the part of the families involved, can make an extremely simple technology work very well in an urban area. When properly managed, these toilets have no smell and do not breed flies (Esrey et al 1998).

The pedestals are made of concrete polished to a high-class finish, after which they are painted. Fibreglass moulds are used for casting the pedestals (Figure 2.10).

These examples illustrate that dry urine diversion toilets are not intended for poor people only, but can be used in any setting.

Figure 2.9: The Mexican version of the Vietnamese double-vault toilet, installed in the bathrooms of modern houses in the city of Cuernavaca. The toilets have movable urine-diversion pedestals. The processing chambers below the bathroom floor are accessible from outside the house (César Añorve, CITA, A.C., Mexico)

(f) Sweden

Sweden has advanced, modern urine-diversion sanitation systems. The pedestals are made of porcelain, in both dry and flushing versions (Figure 2.11). The flushing version is often found in high-density residential apartments or cluster housing. The urine is collected and stored in underground vaults, from where it is collected by farmers, while the faeces are flushed into a conventional waterborne sewerage system for further treatment. The reduced nutrient load of this sewage, due to the exclusion of nitrogen and phosphorus found in the urine, reduces the cost of treatment. The front compartment of the bowl, used for urine collection, is flushed with a spray of approximately 200 mℓ of water from a nozzle on the side of the bowl, while the rear compartment is flushed from a

conventional toilet cistern. However, this type of flushing toilet is not regarded as an ecological sanitation system, even if the urine is diverted (Austin and Duncker 2002).

These examples illustrate that urine diversion toilets can be made of high class material.

The use of urine-diverting toilets in Sweden goes back to the nineteenth century. Figure 2.12 illustrates a toilet dating from 1880.

(a) (b)

Figure 2.10: Mexican urine-diversion pedestal cast in concrete.
(a) The pedestal, which can be fitted with a conventional seat and lid.
(b) The pedestal shown alongside its fibreglass mould.
(Austin and Duncker 2002)

(a) (b)

Figure 2.11: Swedish urine-diversion pedestals for
(a) dry system and (b) flushing system.
(Austin and Duncker 2002)

Figure 2.12: Portable urine-diversion toilet made in 1880 in Sweden
(http://www.wost-man-ecology.se/affarsideen.html)

(g) Bolivia

Dry toilets incorporating urine diversion have been built by the community in El Alto, near La Paz, Bolivia (Figure 2.13). This is a peri-urban settlement on a plateau about 4 000m above sea level. Locally available materials and components were used in a very simple type of construction. This type of toilet has a wooden bench seat while the urine collector consists of a wide plastic funnel. Under the hole in the seat are two buckets. Faeces deposited in the bucket are covered by a mix of ash, lime and sawdust, while used toilet paper is placed in a separate container and burned periodically. Full buckets are emptied into a bin for further storage and dehydration until safe to use on the land. Urine is collected in a container and used as liquid fertiliser.

Simplicity and the use of local materials is the message here.

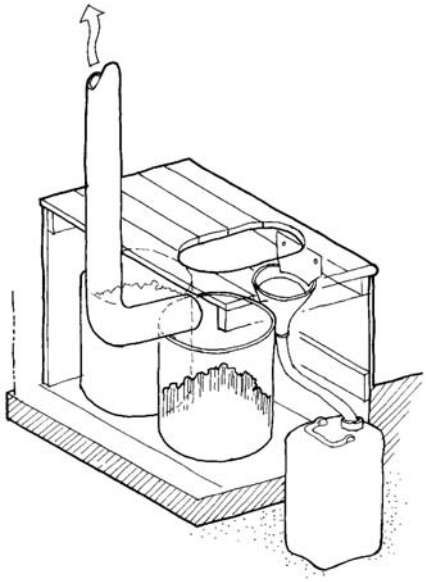


Figure 2.13: Urine-diversion toilet in El Alto, Bolivia (Sanres 2000)

(h) China

In China, many ecosan facilities have been built in Guangxi province (Figure 2.14). These are double-vault, ventilated urine-diversion toilets, built indoors. Fibreglass squatting pans were developed as part of a programme funded by the Swedish International Development Cooperation Agency (Sida) and are now produced in a factory in the city of Nanning (Sanres 2000). Porcelain squatting plates are also produced in a factory outside Beijing (Esrey et al 1998).

These examples illustrate a high class installation as well as innovation.

(a) (b)

Figure 2.14. Urine-diversion ecosan toilets in Nanning area, China.
(a) Toilet in a house. One bucket contains ash and the other bucket is for disposal of toilet paper, while the water can is used for rinsing the urine bowl.
(b) School toilet. This version has a prototype ash dispenser. Ash or sand is stored in the "cistern" and depressing the foot-pedal spreads a small amount over the faeces deposited in the toilet. (Sanres 2000).

(i) Zimbabwe

All ecological sanitation approaches in Zimbabwe are based on:

(a) providing a means of removing human excreta safely and simply from the toilet;
(b) preparing human excreta for use in agriculture by encouraging the formation of humus; and
(c) reducing the pollution of groundwater and atmosphere as much as possible (Esrey et al 2001).

Various types of toilet systems are used to promote the principles of ecological sanitation in Zimbabwe, including single- and twin-pit composting systems in which the cultivation of trees and other plants, including food crops, is encouraged (Esrey et al 2001).

Mvuramanzi Trust, an organisation supporting water and sanitation initiatives in rural areas of Zimbabwe, is actively involved in promoting ecosan. Community members are enthusiastic participants and take part in the building process, which also helps them to acquire marketable skills. Urine-diverting toilets are built, consisting of a prefabricated wooden superstructure, asbestos roof, concrete floor slab, brick chamber and stairs, and a mortar pedestal similar to the Mexican version (Figure 2.15). The emphasis is on simplicity, which makes it easy for the units to be built with relatively unskilled labour (Proudfoot 2001).

(a) (b)

Figure 2.15: Urine-diversion toilets in Zimbabwe.
(a) A simple but well-built toilet with wooden superstructure.
(b) Women from the community engaged in casting floor slabs. The slabs are simple structures, consisting of 60mm thick concrete reinforced with barbed wire.
(Proudfoot 2001)

2.2.3 EXAMPLES FROM SOUTH AFRICA

The following examples have been chosen to illustrate the wide variety of urine diversion toilet designs in the country. Both single and double vault types are used and prefabricated superstructures have made an appearance. One of the most important aspects is the incorporation of toilets as part of the dwellings. However, poor quality workmanship has been a feature of many UD projects and it appears in some instances as if not much has been learned from overseas developments.

Since 1997, when South Africa's first urine-diversion sanitation project was implemented in three rural villages near Umtata in the Eastern Cape, thousands of these toilets have been installed in various parts of the country.

(a) Eastern Cape

The Umtata pilot project consisted of 30 units, which were built for research and development purposes. They are single-vault brick structures with concrete floor slabs and zinc roofs (Figure 2.16). The pedestals are made of rotationally moulded plastic obtained commercially. Urinals were included for the menfolk. Faeces are collected in separate wooden or plastic containers in the chamber beneath the pedestal and are rotated when full (the toilet vaults are large enough to hold two containers). While being aware of the fertilising properties of excreta, the villagers do not actively use it, but simply dispose of the dehydrated faeces in their maize fields without working it into the soil, while the urine is led into shallow soakpits (Austin and Duncker 2002).

Ash from the home owner's cooking fire is stored in a plastic bin inside the toilet structure and this is sprinkled over the faeces after defecation, which effectively prevents odour and keeps flies away, as well as absorbing the inherent moisture and aiding dehydration. An additional advantage is the high pH value of the wood ash (about 10,5), which assists pathogen destruction. Another plastic bin is used for storing used anal cleansing material; this is disposed of at regular intervals by burial (Austin and Duncker 2002).

Due to the novelty of urine diversion in South Africa at the time, it was necessary to organise community workshops to facilitate understanding and acceptance of the technology. In addition, because of the low level of health and hygiene awareness in the villages, hygiene-awareness workshops were held before the completed toilets were handed over to the new owners (Austin and Duncker 2002).

(a) (b)

Figure 2.16: The Eastern Cape pilot urine-diversion project near Umtata. (a) Toilet structure; (b) rotationally-moulded plastic pedestal.
(Austin and Duncker 2002)

(b) Northern Cape

In many parts of the Northern Cape there is only a thin layer of topsoil covering the hard, rocky material below. This makes it difficult and costly to construct any form of pit toilet, and urine diversion is a good solution to the sanitation problem in such areas (Austin and Duncker 2002). In fact, the initial marketing strategy used in the communities was that urine-diversion toilets were the only affordable option, given the geology of the area, otherwise residents would have to continue using the bucket system (Holden et al 2003).

Numerous UD sanitation projects have been implemented in various areas (Austin and Duncker 2002). Some are built as separate structures, while others are added onto the outside of a house but with the entrance from inside. Both single and double chambers are used and either a plastic or a mortar pedestal is installed. Some toilet structures are built in-situ using various types of bricks, while others consist of complete units made of prefabricated concrete panels, which are obtained commercially (Figures 2.17 to 2.23). In Campbell, many old bucket toilets have been converted to urine diversion, which is an easy and economical means of upgrading these unacceptable facilities.

(a)

(b)

Figure 2.17: Double chamber urine-diversion toilet added onto house in Campbell, Northern Cape. (a) Exterior view; (b) interior view.
(Photographs: R. Holden)

Faeces are mostly collected on the floor of the chamber or, in the case of the prefabricated toilet units, in a net suspended beneath the pedestal. Ash or sand is sprinkled on the faeces and used anal cleansing material is deposited in the chamber. There is no culture of re-use in these areas and the desiccated faeces are often simply buried nearby. Occasionally they may be burned inside the chamber, together with the used cleaning materials. This is an easy method of disposal, as only ash remains behind (Austin and Duncker 2002).

(a) (b)

Figure 2.18: Double chamber urine-diversion toilets in Spoegrivier, Northern Cape. (a)Toilet added onto house; (b) separate toilet structure.
(Photographs: R. Holden)

(a) (b)

Figure 2.19: Commercial toilet unit made from prefabricated panels, Groblershoop, Northern Cape. (a) The vault may be partially beneath the ground; (b) faeces are collected in a net under the pedestal.
(Photographs: CSIR)

Figure 2.20: Conversion of bucket toilets in Campbell, Northern Cape.
(Photograph: R. Holden)

(a)

(b)

Figure 2.21: Urine-diversion toilets in Merriman, Northern Cape.
(a) This toilet has been installed inside the bathroom; (b) the vault is outside the bathroom wall and has an inspection hole in the slab to enable the owner to check the volume of accumulated faeces. (Photographs: CSIR)

(a) (b)

Figure 2.22: (a) Free-standing brick toilet structure in Alheit; (b) toilet built into house, Britstown, Northern Cape. (Photographs: CSIR)

Figure 2.23: Toilets in Hanover, Northern Cape, are constructed with alternating drop-holes for the pedestal, but with a single vault. (Photographs: CSIR)

(c) eThekwini, KwaZulu-Natal

Due to logistical difficulties experienced with providing an emptying service for pit toilets in the metropolitan area, the eThekwini City Council decided in May 2001 that basic on-site sanitation would in future be provided in the form of urine-diversion toilets instead (Harrison 2006). The toilets are of the double vault type, with the substructure consisting of prefabricated concrete panels and the superstructure of cement bricks with a zinc roof (Figure 2.24(a)). A commercially available plastic pedestal is installed on one of the vaults, while the opening for the second vault is covered with a concrete plug until it is required for use (Figure 2.24(b)). A plastic urinal is also provided.

(a) (b)

Figure 2.24: Typical double vault urine-diversion toilet provided in eThekwini.
(Photographs: F. Stevens, eThekwini Water Services)

(d) North West

In the Taung region of North West, more than 600 hundred urine-diversion toilets have been constructed in 11 villages. These are mainly of the single vault type, with brick walls and corrugated iron roofs, and are free-standing units. The vault covers are made of either corrugated iron or concrete. The former are, however, poorly fabricated and ill-fitting. Pedestals are mainly of the concrete variety and neatly painted, but many of the urine pipes are blocked, often as a result of ash being put into the urine compartment by children. The toilets are illustrated in Figures 2.25 and 2.26.

(a) (b)

Figure 2.25: This urine-diversion toilet in Kokomeg, in the Taung area, is well maintained. The structure has a concrete vault lid and a proper window.
(Photographs: CSIR)

(a) (b)

Figure 2.26: Urine-diversion toilets in Matsheng, in the Taung area.
(a) Badly-fitted corrugated iron lid on the vault; (b) blocked urine pipe.
(Photographs: CSIR)

(e) Johannesburg, Gauteng

A urine-diversion toilet pedestal may also be retrofitted into an existing house. Richard Holden lives in the suburb of Bellevue, Johannesburg. He removed the existing flushing toilet from his bathroom and replaced it with a Mexican-type urine-diversion one made from concrete. The work entailed breaking through the wall and floor of the bathroom, excavating a chamber beneath and patching everything up again (Figure 2.27).

Figure 2.27: Retrofitted urine-diversion toilet in Richard Holden's house in Bellevue, Johannesburg (Photograph: CSIR)

2.2.4 CONCLUSIONS (Austin and Duncker 2002)

The examples described in this section illustrate that urine-diversion toilets are suited to virtually any country and are acceptable to various cultures and income groups, rich or poor, urban or rural, squatters as well as sitters. It is clear that simplicity is an inherent feature of the technology, and this brings monetary rewards in terms of reduced capital costs, as well as simplified operation and maintenance. Both householders and local authorities will thus benefit from implementation of the technology. Simplicity is also important for active participation of a community in the organising and building phases of a project.

Possibly the biggest advantage of urine-diversion toilets is that no pits are required and that they may be installed indoors. When properly operated, there is no smell and no fly breeding, the latter being an important community health aspect. Properly constructed, they are attractive to use and easy to keep clean, both critical factors that also benefit community health in low-income areas. In addition, although not a precondition for the implementation of these systems, use of the excreta resource is an additional benefit for people wishing to make use of it.

2.3 DESIGN AND MANAGEMENT ASPECTS OF ECOSAN TOILETS

2.3.1 INTRODUCTION

Urine-diversion ecosan toilets require a higher level of commitment from users than do other forms of dry sanitation, such as VIP toilets. The reason is that they are more sensitive to, and consequently less tolerant of, abuse. In many of the poorer and under-serviced communities in South Africa, pit toilets are often used as rubbish depositories as well. The use of anal cleansing materials other than tissue paper, such as rags, plastic bags, newsprint, maize cobs and even stones, is also common, and these objects then end up in the pits. Furthermore, wastewater may occasionally be poured into the pits. If one considers the nature of a dry-box toilet, it becomes obvious that abuse of this nature can only lead to failure of the system. However, the need for a higher level of commitment should be seen in the light of the many benefits associated with ecosan toilets when compared to pit toilets (Austin and Duncker 2002).

Urine-diversion ecological sanitation systems 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 require more promotion, support, education and training than VIP toilets (Esrey et al 1998).

Probably the most unfamiliar aspect of ecosan toilets is that they require some handling, at household level, of the products. While some cultures do not mind handling human excreta (faecophilic cultures), others find it ritually polluting or abhorrent (faecophobic cultures). Most cultures are probably somewhere between these two extremes and Esrey et al (1998) maintain that when people see for themselves how a well-managed ecosan system works most of their reservations disappear.

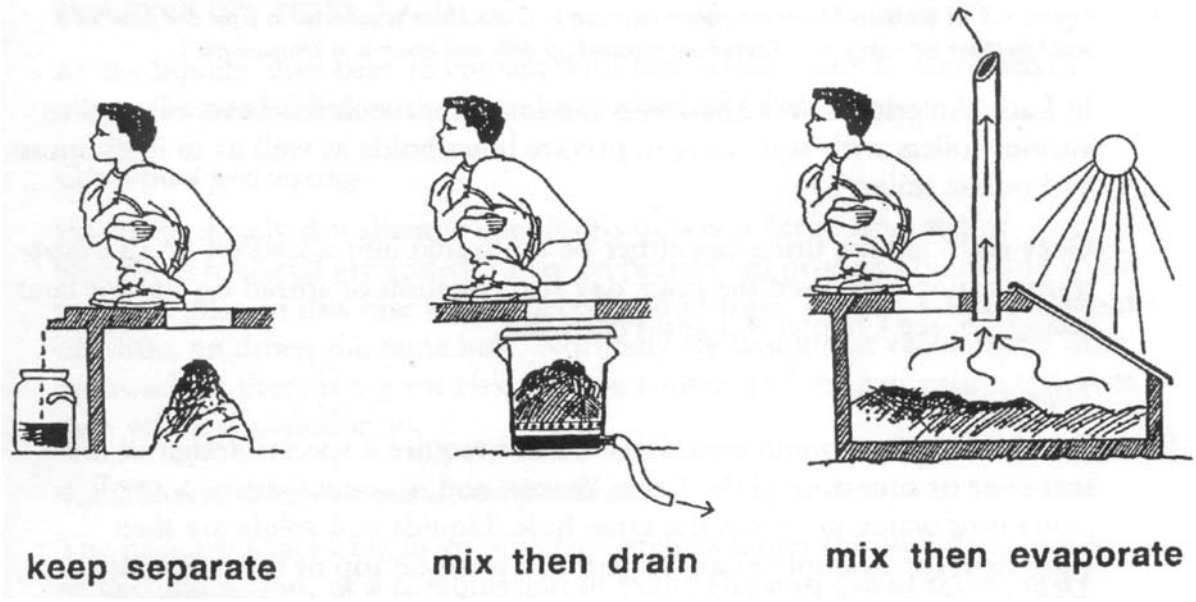
A more important point about handling is that once ecological sanitation has gone to scale and hundreds or thousands of units are in use in a certain area, individual households no longer need to handle the products at all. At that scale the output from ecosan toilets can be collected, further processed and safely disposed of by neighbourhood collection centres with trained personnel (Esrey et al 1998).

The potential advantages of ecosan systems can only be realized as long as the system functions properly. There is, particularly with a new concept, the risk that those who plan, design and build do not fully understand the basic principles involved and how they relate to local conditions. This may lead to an inappropriate selection of options. With the right system in place, the most common reasons for failure are lack of participation from the user, lack of understanding of how the system works, defective materials or workmanship, and improper maintenance (Esrey et al 1998).

The following sections provide an overview of current methods and practices. Important aspects discussed include urine and faeces management, disposal of anal cleansing material, absorbents and bulking agents, ventilation and fly control, dimensions and construction methods.

2.3.2 URINE MANAGEMENT

A basic question when designing an ecosan system is whether to divert urine or to receive combined urine and faeces in a single receptacle. If the latter approach is used, effective processing will require later separation of the urine from the faecal matter. There are three options: urine diversion, urine separation and combined processing (Esrey et al 1998).



(a) (b) (c)

Figure 2.28: Three options for dealing with liquids in ecological sanitation systems
(Esrey et al 1998)

(a) Urine diversion (Figure 2.28 (a))

There are at least three good reasons for not mixing urine and faeces: it is easier to avoid excess moisture in the processing vault, the urine remains relatively free from pathogenic organisms, and the uncontaminated urine is an excellent fertiliser. However, urine diversion requires a specially designed pedestal or squat plate that is functionally reliable and socially acceptable. Once collected, the urine can either be infiltrated into a soakpit or an evapotranspiration bed, used for irrigation or stored on site for later collection (Esrey et al 1998).

(b) Urine separation (Figure 2.28 (b))

Systems based on urine separation do not require a special design of pedestal or squat plate. Urine and faeces go down the same hole, after which the urine can be drained through a net or grille. As the urine has been in contact with faeces it must be sterilised or otherwise treated before it can be recycled as fertiliser (Esrey et al 1998).

(c) Combined processing (Figure 2.28 (c))

Under extremely dry climatic conditions or where large amounts of absorbent material are added, it may be possible to process liquids and solids together. Also in this case, urine and faeces go down the same hole. With this system, however, there is a risk that the contents of the processing vault become malodorous (Esrey et al 1998).

(d) Disposal of collected urine

Various ways to dispose of the urine have been suggested, which also cater for people not interested in actively re-using it (Figure 2.29) (Esrey et al 1998).

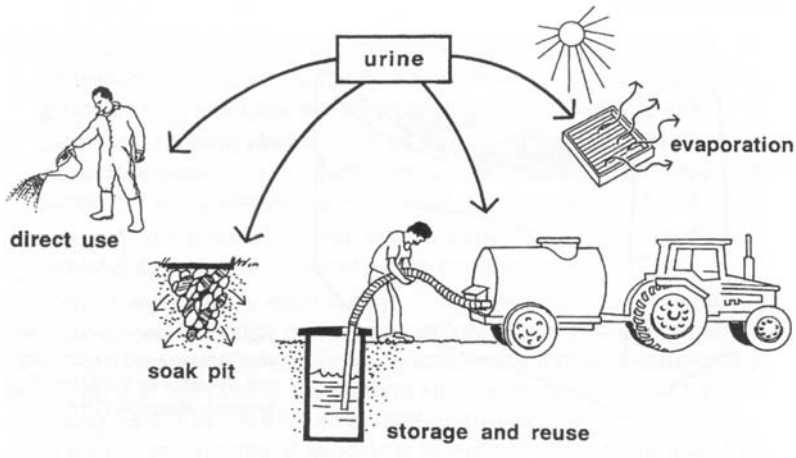


Figure 2.29: Alternative ways of handling/using urine diverted from toilets
(Esrey et al 1998)

(e) Discussion

Whichever method is used for collection/disposal, it is seen that urine is not difficult to manage. It should be noted, however, that the method will influence the management of faeces, because diverting the urine means that the faeces will dehydrate, while mixing it with the faeces means that the latter will be more likely to undergo a composting process.

2.3.3 FAECES MANAGEMENT

(a) Dehydration versus composting

The primary processing in an ecosan system is either through dehydration or decomposition, or a combination of both. The purpose of primary processing is to destroy pathogenic organisms, to prevent nuisance and to facilitate subsequent transport, secondary processing and end use (Esrey et al 1998).

When something is dehydrated all the water is removed from it. In a *dehydrating toilet* the contents of the processing chamber are dried with the help of heat, ventilation and

addition of dry material. The moisture content should be brought below 20%. At this level there is rapid pathogen destruction, no smell and no fly breeding. A requirement for dehydration is, except in very dry climates, the diversion and separate processing of urine (Winblad 1996b). The faeces chamber can be solar-heated by means of a black-painted lid and small amounts of ash, sawdust or dry soil are added after each use. The faeces may be desiccated within a few weeks. The desiccation process, while not producing a material as rich as true compost, still acts to enrich soil to which it is added (Dudley 1996).

Composting is a biological process in which, under controlled conditions, various types of organisms break down organic substances to make a humus. In a *composting toilet*, human excreta are processed together with organic household residues. Optimal conditions for biological decomposition should be sought. This means that sufficient oxygen should be able to penetrate the compost heap to maintain aerobic conditions. The material should have a moisture content of 50-60% and the carbon:nitrogen balance (C:N ratio) should be within the range of 15:1 to 30:1 (Winblad 1996b).

In order to function correctly, a composting toilet requires the addition of carbonaceous (organic) matter to maintain the correct C:N ratio. Further, in order to get true composting, air must be able to reach all parts of the toilet contents. The need to turn and ventilate the heap is not just to allow oxygen to play its part in the chemical process, but also to facilitate evaporation in the depths of the heap. The most common problem with composting toilets is an excess of moisture, which slows or stops the aerobic decomposition process and leads to bad smells. On the other hand, when a desiccating toilet is well managed, the contents of the processing chamber can be reduced to an apparently innocuous state very rapidly (Dudley 1996).

(b) Solar heaters

Solar heaters, in the form of a black-painted lid, can be fitted to the processing vaults in order to increase evaporation. This is more important in humid climates where urine is mixed with the faeces. It is also more important in a system based on dehydration than in one based on composting. The heater should be close-fitting so that it prevents water as well as flies from entering the processing chamber (Esrey et al 1998).

(c) Single or double vault

The primary concern with a single-vault device is pathogens in fresh faeces. Although the amount of fresh faecal material at any one time is relatively small, this amount can contaminate a large pile. The management system adopted must ensure isolation of faeces until pathogens have been reduced to acceptable levels, and with single-vault toilets the faecal material is usually transferred to another pile/bin/container for further processing before being recycled. The benefits of a single-vault toilet are, however, that less space is required and construction costs are reduced (Esrey et al 1998).

An innovative method of preventing fresh faeces from contaminating an existing faecal pile was developed in Tecpan, El Salvador, which eliminates the need for opening the vault and using a rake or hoe to shift the pile away from its position beneath the pedestal. Each toilet unit incorporates a fixed “pusher” which is used to shift the faecal pile into the solar-heated processing chamber (Figure 3.30) (Esrey et al 1998).

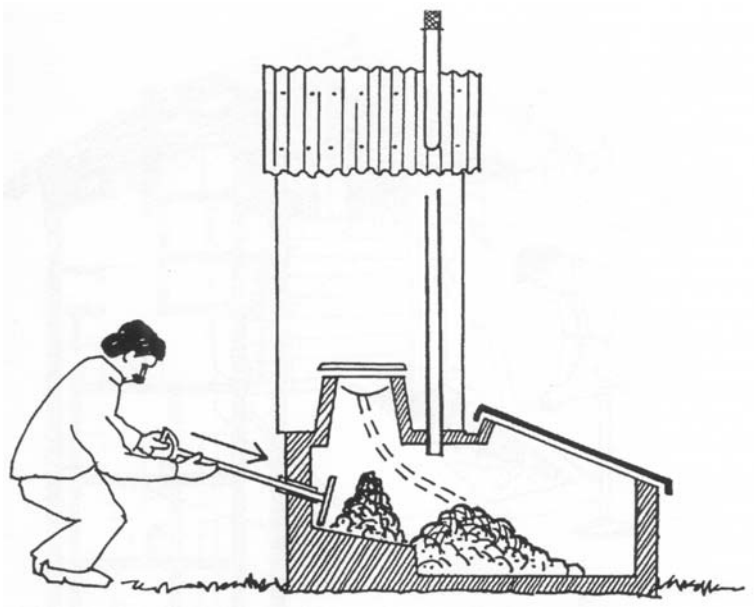


Figure 2.30: The "pusher" used to move the faecal pile, El Salvador
(Esrey et al 1998)

Many toilets have been designed with two vaults, each with its own pedestal or squatting slab. In these systems each vault is used alternately for a certain period. When the switch is made from one vault to the other, the contents of the vault that has been dormant are emptied, the assumption being that after several months without new faecal material being added, the contents should be safe to handle (Esrey et al 1998).

In single-vault systems, the faecal material needs to be collected in a way that facilitates storage and easy removal from the vault. It can be collected and stored in either of two ways - in a suitable container or in a heap on the floor of the vault. For the former method, two separate containers are required. When the first container is full, it is moved to one side and the second one moved into place beneath the pedestal. By the time the second container is full (usually a few months, depending on the size of container and number of users) all the material in the first one should be sufficiently dehydrated to resemble a crumbly type of soil with a slight musty, not unpleasant, odour. It should then be removed from the container and stored in a sack for a further period, as there may still be vast numbers of viable pathogens present. A minimum total storage period of twelve months, from the time when the container is full to eventual use in the garden, is recommended (Austin and Duncker 2002).

The second method of collection and storage, in a heap on the floor of the vault, is recommended, although it involves a little bit of extra attention. A heap is not subject to the confines of a container, and the material is therefore able to "breathe". When the heap reaches a certain size, it should be raked to the side of the vault where it can dehydrate for a further period, until the space is needed to store further material. If possible, this heap should be turned over by spade or rake every fortnight or so – this action will further aerate the heap. Further storage in a sack for a total storage period of twelve months is also recommended in this case. It is also essential that easy access to the vault be provided in order to facilitate the task as much as possible (Austin and Duncker 2002).

Due to the fact that storage time is an important factor in microbial inactivation, the size and orientation of the vaults are critical design aspects. Moe and Izurieta (2003) maintain that large, partitioned vaults with good solar exposure contribute significantly to pathogen destruction.

(d) Disposal of anal cleansing material (Austin and Duncker 2002)

Various methods are practised for the disposal of anal cleansing material. It is usually recommended that these materials not be put into the vault, as the lack of moisture prevents their breakdown. A special container should be kept next to the toilet for storing used cleansing materials, which may then be periodically disposed of by burning or burial. Alternatively, where a well-operated solid waste removal service exists, the used materials can simply be enclosed in a suitable bag and disposed of in the rubbish container.

Where faecal material is re-used in the garden, some ecosan practitioners deposit toilet paper into the vault. When the faecal material is subsequently mixed in with garden soil and watered, the paper decomposes. It should be noted that only soft tissue paper can be used in this case, and the quantity may need to be restricted, depending on the size of garden and extent of re-use.

In very hot and dry climates (e.g. Northern Cape), where faeces dehydrate rapidly, people may simply deposit all cleaning paper into the vaults and periodically burn everything to ashes – paper as well as dehydrated faeces. Where reuse of the faecal products is not desired, this is a relatively easy way to dispose of the contents of the vault.

(e) Absorbents and bulking agents (Esrey et al 1998)

Absorbents like ash, lime, sawdust, husks, crushed dry leaves, dry soil, etc, are used to reduce smells, absorb excess moisture, and make the pile less compact as well as less unsightly for the next user. They should be added immediately after defecation in order to cover the fresh faeces. Bulking agents like dry grass, twigs, wood shavings, etc, are also used to make the pile less compact and to allow air to enter and filter through the heap.

(f) Disposal of vault contents

Various options are available for disposing of the contents of the vaults, which, as discussed above, may or may not contain anal cleansing material. While use for improving soil fertility is widely practised in a number of other countries (see section 2.5: Agricultural utilisation of human excreta from ecosan toilets), this is not yet common in South Africa.

Two methods of dealing with the vault contents have thus far emerged in South Africa:

- Burning. This has been successful in the dry Northern Cape, where hard cleaning paper is also used (Holden et al 2003). In some other parts of the country, however (for example Eastern Cape), people refuse to do this due to a belief that they will contract anal infections (Austin and Duncker 1999).
- Composting or burying. This method was used from the outset in the Eastern Cape pilot project near Umtata. It is also common for the people to simply empty the contents of the containers into their fields, without consciously making an effort to mix it into the soil. The beneficial effect on the crops is evident, however (Austin and Duncker 1999). This practice also evolved in Namaqualand, where the people

> initially buried the faecal material, but in the course of time came to realize that a transformation had taken place and subsequently, after some encouragement, began to plant vegetables (Holden et al 2003). In eThekwini, villagers were informed from the beginning of the urine-diversion implementation process that the City Council regarded these systems as truly "on-site" and they were therefore expected to deal with the products themselves, on their properties (Harrison 2006).

According to Cordova (2001), the local government in León, Mexico, provides a free roadside pickup of "toilet products" twice a month. This action was decided upon due to the indiscriminate dumping by residents of bags of semi-processed faecal matter. Residents now place their bags on the kerb outside their homes, which are then collected by the garbage collection agency employed by the council, using a truck. The final destination of the bags is, however, not described.

A number of writings deal with various technologies and methods used for emptying on-site sanitation facilities such as pit toilets, bucket latrines, etc. (Gordon 1997; Gupta 1997; Kirango, Muller and Hemelaar 1997; Muller 1997; Rulin 1997; UWEP 1999). These publications describe neighbourhood-based systems such as MAPET (Dar es Salaam, Tanzania), VACUTUG (Nairobi, Kenya), MINIVAC (eThekwini, South Africa), animal-drawn carts (Yichang City, China and Bamako, Mali) and human scavengers (Ghaziabad, India), as well as conventional mechanised systems such as vacuum tankers. However, very few of these experiences can be considered as being applicable to emptying the vaults of urine-diversion dry-box toilets. The latter is a different process altogether, due to the nature of the biosolids and accessibility of the vaults. With a well-designed and correctly operated UD toilet, this should normally be a relatively simple manual task (Austin and Duncker 2002).

(g) Discussion

Management of faeces in an ecosan toilet requires more attention than urine. It is also a completely different process to that of a pit toilet. Further, it is seen that there is less handling of faecal material in a double vault toilet than there is with a single vault type. Toilet designs should be simple and should facilitate the easy removal of faecal material from the vaults. Anal cleansing material should also be disposed of in an environmentally safe manner.

(h) Possible future scenarios

Simpson-Hébert (2001) asserts that it is logical for the organic wastes from food produced in rural areas and consumed in cities to be returned to the rural areas to replenish soils. She argues that the sustainability of cities will rest upon a foundation of recycling all products, including excreta, in a systematic and healthy way, and that solid wastes should be dealt with at the place where they are created. She maintains further that city planners need to plan now for neighbourhood recycling stations, called "eco-stations", where all wastes generated by communities can be recycled. The output of such eco-stations will be compost for urban and rural agriculture, with the objective of zero emissions and zero landfilling. Products of ecological toilets, the urine and sanitised faeces, could be collected house-to-house along with other household garbage and taken to the eco-station. Urine, which requires no further processing before collection, could be collected weekly. Dried faeces would be collected every six months, allowing time for complete desiccation and pathogen destruction. Urine, after minimal further processing, could be sold for fertiliser,

while the dried faecal products could be further processed through composting with other organic products and then also sold for fertiliser and soil conditioner. There are many areas in and around cities where organic fertiliser and compost can be used, e.g. for urban and rural agriculture, parks and golf courses, mine site rehabilitation, reforestation, and for rejuvenation of waste areas such as old quarries and badly eroded land.

Simpson-Hébert (2001) goes on to say that eco-stations could be managed by municipalities, by user-cooperatives or by private enterprise. They could be labour intensive or highly mechanized. With an estimated 1 billion tons of domestic garbage and 300 million tons of human faeces being generated worldwide each year, there would be no shortage of materials. With one eco-station for every 20 000 people in urban areas, a considerable number of new jobs could be created. For the tens of thousands of people around the world already working informally as garbage pickers and recyclers, eco-stations could formalize this sector, provide safe working conditions, decent pay and job security, while giving dignity to people who would be providing an important public service. The author concludes that eco-stations could be the next step in ecological sanitation, and that they would contribute to urban sustainability.

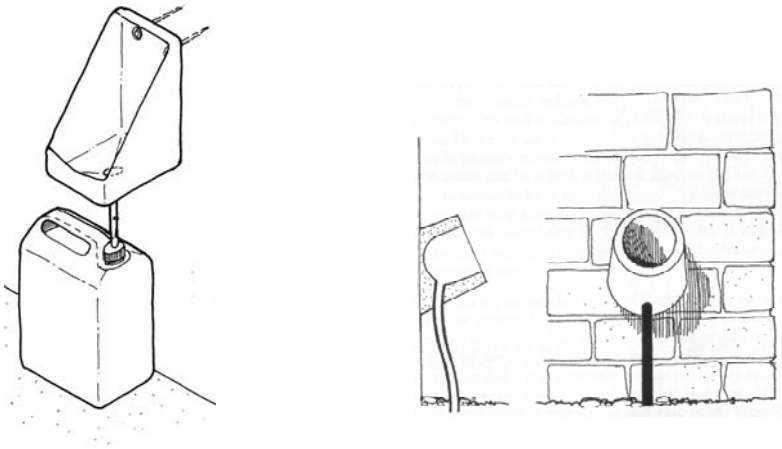
Muller (1997) supports this viewpoint, saying that excreta collection should be an integral part of an urban waste management system, in which the collection and recycling of excreta and solid waste, as well as their final treatment and disposal, should take place in an environmentally sound and sustainable manner. She adds that excreta collection should not be an isolated activity, but rather a service that is integrated into the urban institutional system. A collection service could be operated by a combination of different types of organizations, with small, informal enterprises taking care of the removal and first transfer of human excreta, while either the municipality or a private contractor provides the secondary transfer and disposal service. A neighbourhood transfer point, from where a secondary service transports the collected excreta to another site for treatment (e.g. as in Ghaziabad and Accra), provides a concrete example of the technical and operational interlinkages between the municipal sanitation department and private actors.

2.3.4 DIMENSIONS, METHODS AND MATERIALS

The illustrations in the previous section of this chapter are evidence of the wide range of materials, methods and styles that can be used to build ecosan toilets. Any suitable materials, including brick, stone, wood, thatch, corrugated iron, wattle and daub, gum poles, rammed earth blocks, precast concrete, ferrocement, etc. can be used for the superstructure, while seating arrangements may be plastic, concrete, porcelain or wood. Toilets may even be installed indoors, as part of a house. Austin and Duncker (2002) comment that as long as the basic principles governing urine-diversion sanitation are adhered to, the appearance and cost of the toilet units are matters of individual preference.

Building materials should meet the criteria of strength, durability and weather resistance, and have good thermal properties. Preference should, moreover, be given to locally available or traditional materials and methods, in order to encourage poorer communities to take part in self-help building schemes. Innovation is encouraged: for example, making a simple urinal from an old 5-litre plastic container or, alternatively, from a small, hand-moulded clay or ferrocement pot (Austin and Duncker 2002). Some examples are shown in Figure 2.31.

Information on dimensions is sparse. However, from a study of existing toilets in South Africa and elsewhere, it appears that the norm is to adopt the same practice as for building a VIP toilet. Internal superstructure dimensions are therefore typically 850 mm to 1 000 mm wide and 900 mm to 1 200 mm long for both single and double vault toilets. Vaults are usually 600 mm to 800 mm deep. Austin and Duncker (2002), however, state that the internal floor area should provide space for an ash/soil container, a container for used anal cleaning material if desired, and possibly also a urinal; minimum dimensions of 1 150 mm by 1 150 mm are therefore recommended.



(a) (b)

Figure 2.31: Examples of simple, easily made urinals.
(a) Using a 5 litre container and (b) using a clay or ferrocement pot
(a) Austin and Duncker 2002; (b) Esrey et al 1998

(a) (b)

Figure 2.32: "Kiddie-seat" adaptations for urine-diversion pedestals.
(a) Swedish version (wood) and (b) South African version (plastic).
(Photographs: CSIR)

Provision for small children is sometimes made, as they often have difficulty in defecating in the right place and consequently soil the urine bowl instead. A common adaptation to the urine-diversion pedestal in Sweden is a wooden “kiddie-seat” (Figure 2.32(a)), while in South Africa a plastic version is available (Figure 2.32(b)).

2.3.5 CONCLUSIONS

Human excreta are usually easier to handle when urine and faeces are kept separate, as in urine-diversion toilets. It is accepted that such toilets are more sensitive to abuse than, for instance, VIP toilets, and therefore require a higher level of commitment from users. They also require a higher level of social intervention in the form of promotion, support, education and training. The many benefits associated with ecosan toilets can only be realized if the systems function properly.

As long as the basic principles of this particular sanitation technology are adhered to, the materials used, appearance and cost of the toilets are matters of individual preference. Various types of building materials may be used, and many innovative concepts are in evidence around the world.

The primary processing in an ecosan toilet may operate on either a dehydrating or composting principle, or a combination of both. Depending on which option is used, urine may be diverted and kept separate from the faeces, mixed with the faeces and drained, or mixed and evaporated. Urine may also be disposed of by using it as a fertiliser or, alternatively, draining it to a shallow soakpit.

Management of faeces is a much more critical issue. Various methods are in use for treatment and storage; these include keeping fresh and old faeces separate by moving the piles around inside the vaults, using double-vault toilets, ensuring good ventilation, and covering the faeces with bulking agents such as ash, soil, lime, sawdust, etc. Storage time is an important factor in the pathogen reduction process, and faeces management processes should aim to maximise this aspect.

Final disposal of faecal material allows various options. Use as a soil conditioner for food gardens, as well as in wider agricultural applications, is practised in many countries. Where communities are not disposed towards this custom, faeces (and anal cleansing materials) may simply be buried or burned. The level of local government involvement in excreta disposal is an important issue, and may impact significantly on the sustainability of ecosan projects.

The vision of community eco-stations for recycling of urban waste has been raised. This concept requires strategic input at the highest level of municipal management, as any system of excreta collection will require integration with the whole urban waste management system. However, such a concept, if successfully implemented, could enhance urban sustainability, create numerous jobs and formalise a large sector of poor people currently engaged in informal subsistence activities related to solid and organic wastes.

2.4 CONSIDERATIONS IN IMPLEMENTATION AND MARKETING

2.4.1 INTRODUCTION

This section of the literature review focuses on various socially oriented aspects of urine diversion sanitation systems implemented in various parts of the world, urban and rural, in both developed and developing countries.

The sanitation policy of the South African government stresses that sanitation is not simply a matter of providing toilets, but rather an integrated approach that encompasses institutional and organisational frameworks as well as financial, technical, environmental, social and educational considerations (DWAF 1996).

The White Paper on Basic Household Sanitation (DWAF 2001) is based on a set of principles where sanitation is about being a human right and about environment and health. Sanitation improvement must be demand-responsive and supported by an intensive health and hygiene programme. The programme should ensure community participation as well as integrated planning and development. The programme should also ensure co-operative governance while at the same time promoting delivery at local government level. Services provided should be affordable and sustainable for the households as well as for local government.

“Sanitation” refers to the principles and practices relating to the collection, removal or disposal of human excreta, household wastewater and refuse as they impact upon people and the environment. Sanitation is any system that promotes sanitary, or healthy, living conditions. It includes systems to manage wastewater, stormwater, solid waste and household refuse and it also includes ensuring that people have safe drinking water and enough water for washing (DWAF 2002). The focus here is on the safe management of human excreta. The basic purpose of any sanitation system is to contain human excreta (chiefly faeces) and prevent the spread of infectious diseases, while avoiding danger to the environment (Austin and Duncker 2002).

Sanitation includes both the “software” (understanding why health problems exist and what steps people can take to address these problems) and “hardware” (toilets, sewers and hand-washing facilities). Together, they combine to break the cycle of diseases that spread when human excreta are not properly managed (DWAF 2002).

Ecological sanitation is a sanitation system that turns human excreta into something useful and valuable, with minimum risk of environmental pollution and no threat to human health. It is a sustainable closed-loop system that treats human excreta as a resource, not as a waste product. Excreta are processed until they are free of disease organisms. The nutrients contained in the excreta may be recycled and used for agricultural purposes (Austin and Duncker 2002).

As a policy requirement, sanitation should be an integrated approach that encompasses various components, including the social component, i.e. community participation (DWAF 2001).

2.4.2 A GLOBAL OVERVIEW OF URINE-DIVERSION PROJECTS

This section focuses on the processes followed by various countries in the implementation of urine-diversion sanitation projects. These phases are:

- Planning;
- marketing;
- design;
- health and hygiene awareness and education;
- operation and maintenance;
- use of human excreta; and
- monitoring and evaluation.

(a) Planning

Many failures of urine-diversion sanitation projects have occurred as a result of exclusion of the community from the implementation process (from the onset until completion). This has been the case in several countries. Some reasons for failure of ecological sanitation toilets include (Esrey et al 1998):

- Lack of participation from the user;
- lack of understanding of how the system works;
- defective materials and workmanship; and
- improper maintenance.

Although guidelines for ecosan project planners, professionals and field workers are being discussed, there is presently no training manual on awareness-raising for community workers and no toolbox for ecosan implementation (Source 2003).

South Africa

During the planning phase of a project, the following factors have been found important in South Africa for ensuring sustainability (Austin and Duncker 1999):

- Involvement and consultation is the first step towards full participation and empowerment of the community. During this stage, the developer or agency implementing the project should workshop the concept with the community;
- the technical aspects should be discussed to facilitate an understanding of the operation and maintenance of the toilets;
- the concepts should be illustrated or demonstrated to the community;
- the process of the proposed project should be discussed in detail;
- questions should be answered and problem areas clarified;
- cultural taboos and beliefs that need to be addressed during the implementation of the projects should be brought to the attention of the project team;
- the community members should always be consulted regarding their opinion of the proposed project and their roles in it, as well as their interest in participating in the project;
- the community as one of the stakeholders (consumers/end users) must be part of the decision-making process;
- the proposed plan should be tabled and revised according to the needs and cultural beliefs of the community, as well as the needs and requirements of the developer and/or sponsor;

- the community should decide on the beneficiaries of any experimental or demonstration toilets that will be constructed, as well as the construction starting time and location of such toilets;
- options regarding the design and/or building material should be discussed with the community; and
- the issue of continuous monitoring and evaluation (to ensure proper maintenance and use) should also be taken into consideration during project planning.

Mexico

In Mexico, which has been described as the "dry sanitation capital of the world" (Peasey 2000), several experiences have been recorded relating to the implementation of ecological sanitation programmes. Some negative experiences resulted from the implementation of technologies without prior work in the communities (Duque 2002). This is often the case with unilateral initiatives taken by local governments. To some extent, these initiatives are not connected to the expectations of the population and are therefore rejected. As a result, many dry toilets are used for unintended purposes (sheds or small chicken coops).

On the other hand, Duque (2002) highlighted that the more positive experiences mostly coincided with preparatory work having been carried out with user populations, including demonstration sites in the communities that had already adopted these technologies; community diagnostic workshops with an emphasis on ecological considerations; and collective analysis of problems and possible solutions in which the advantages, disadvantages, viability and freedom to adopt the technology and its methods were discussed and decided upon by each household. Furthermore, he felt that local government units should give additional incentives or assistance in order to build dry toilets, install greywater filters and collectors to catch rainwater.

Zimbabwe

Guzha (nd) presents a case study on ecological sanitation alternatives in the water-scarce peri-urban settlements of Harare, using the people's approach. He highlighted that through participatory self-appraisal, health and hygiene promotion, community development committees were formed and tasked to manage the affairs of the settlements. Community mobilisation, empowerment and participation were crucial prerequisites in implementing successful community projects, particularly in informal peri-urban situations with diverse socio-political persuasions.

The main challenge here was the need to engage the beneficiaries (community participation) throughout the process in order to ensure sustainability of the project and acceptance of urine-diversion technology.

(b) Marketing principles / promotion methods

The success and acceptance of a new technology, in every situation, lies in the marketing strategies used. These strategies should be customised to suit the needs of various communities. Much work needs to be carried out to change the mindset of beneficiaries. Peasey (2000) indicated that trial periods in a community, lasting several years, are necessary to demonstrate the advantages of dry sanitation.

South Africa

When introducing a new technology, especially something as personal as a new way of going to the toilet and the handling of faeces and urine, social and cultural considerations must be uppermost in one's mind (Holden and Austin 1999). Factors found to be important in South Africa include men's urinating method (i.e. standing up), the disposal of anal cleansing materials, and the disposal of urine and faeces.

It is recommended that the following promotional programmes be considered in order to motivate people to invest in urine-diversion toilets (Austin and Duncker 2002):

- The holding of special community meetings to discuss and encourage participation;
- the use of good examples to demonstrate acceptable toilets, e.g. by building these at the local school or at the homes of prominent people in the community;
- school programmes where children are taught about the importance of good sanitation; and
- holding other community-supported events involving drama and music where sanitation is promoted.

Local health officers and support organisations could be requested to help with the compilation and presentation of a suitable promotional programme.

From their experience in the South African sanitation programme, Holden, Terreblanche and Muller (2003) contend that the marketing of ecological sanitation is no different from any other kind of sanitation technology, and that people are motivated by reasons other than health to improve their sanitation arrangements, e.g. safety, security, comfort, privacy, convenience, lack of odour, etc. Householders do not primarily choose ecological sanitation in order to close the nutrient loop, but rather because it is the technology that best satisfies their aspirations and physical requirements. The authors state that, until the proponents of ecological sanitation understand this and let people make informed choices rather than insisting on aspects such as use of excreta, ecosan will "remain an interesting side-show rather than a mainstream solution in the quest for sustainable sanitation." They maintain that the introduction of urine-diversion technology in South Africa has been successful due to its marketing around social factors rather than the benefits of nutrient recycling.

Urine-diversion toilets have also been successfully implemented as part of the bucket eradication programme, as the existing infrastructure is suited to this purpose (see Figure 2.20). Where VIP toilets are not a viable option (e.g. in the hard or rocky ground areas of Northern Cape) urine-diversion systems have been adopted on a large scale (Mvula Trust, nd).

Mozambique

ESTAMOS, a local Mozambican NGO, embarked on two methods to promote ecological sanitation (Dos Santos and Breslin 2001):

- Implementing model ecological toilets in family homes; and
- using radio as a social marketing tool.

The idea behind the first method was to build some toilets at the homes of influential people within the community and also some in the homes of ordinary community

members, in order to demonstrate that these types of toilets are a possibility for everyone. For example, two male chiefs and one female chief received toilets, while the other recipients were regular community members. This was to ensure that other community members would visit the toilets, learn about them and, in turn, create greater interest and demand.

In the second method, an interview of about 5 minutes was taped. The interview consisted of an explanation of the principles behind ecological sanitation, followed by a talk with a community member who had received such a toilet, in order to hear what he/she felt about the toilet. There was also an open invitation for people to visit this toilet. The programme was run for two weeks during prime listening time. However, no results were recorded regarding the impact of the radio programme.

It was recommended that better community organisation should be in place to promote ecosan toilets, which may include community events and visits to people's homes.

Source (2003) reports that many Mozambicans are investing in alternative sanitation solutions, such as ecosan, even where they already have a conventional pit toilet, because of advantages such as less odour, fewer flies, simple handling, stability in the rainy season, fertilising benefits and prestige.

Mexico

Mexico was successful in creating RedSeco (Ecological Sanitation Network) together with other civic organisations, small business entrepreneurs, and research institutions to promote ecological sanitation. Workshops for regional promoters were held throughout the project rather than trying to cover all issues at the beginning. Promoters shared the problems and solutions as they arose. All workshops were held in a central location. There was a feeling that rotating the workshop site among the regions would probably have improved the educational process for promoters and families. Also, designating two local promoters to attend the workshops and share responsibilities would provide a better foundation for the project as a whole. Educational materials produced for (and during) the project were very helpful. These included posters for promotion and use, a construction manual, information sheets for trouble-shooting, explanatory brochures, and a promoter's kit consisting of these materials as well as ideas for conducting workshops (Clark 2001).

Owing to an increase in the demand for dry toilets in Mexico, César Añorve (an independent entrepreneur) and Espacio de Salud (ESAC, a small NGO concerned with promoting improved health and environmental conditions among low-income groups) decided to give the highest priority to the training of community workers. As a result of this focus, they have jointly developed and produced educational and training materials including an attractive, full colour poster showing a range of dry toilet models, as well as the basic technical design drawing. ESAC responds to the communities' demands through the use of participatory methods to assist them in analysing the cause of their problems and to identify possible solutions (WEDC nd).

The Water Supply and Sanitation Collaborative Council (WSSCC) Working Group on Sanitation emphasises the importance of sanitation promotion and hygiene education in their Sanitation Promotion Kit, and links the value of excreta with ecology (Simpson-Hébert and Wood 1998, as quoted by Peasey 2000).

Philippines

The information material developed during the first phase of the project in Tingloy, Philippines, was mainly targeted at conducting training on ecological sanitation. Materials that were disseminated for use and reference after the training included:

- A colour poster with recommendations on how to use and maintain a urine-diversion toilet; and
- a monitoring sheet on use and maintenance of urine-diverting toilets (performance).

Materials disseminated for use and reference after training were translated from the original versions found in two Spanish books (one for households and the other for facilitators monitoring the visits). Because these materials were directly translated and not adapted to the Philippine context and local situation of Tingloy, they were actually not appropriate, and were not always correctly understood. Later on, this was pointed out and explained to the partner families in household visits by the project team, and the materials were not distributed anymore (UWEP 2003).

The official handing over ceremony of the toilets to respective families stimulated and encouraged the families to start using them, as until then they had been somewhat hesitant to do so because they saw the toilet as the property of the Philippine Centre for Water and Sanitation – International Training Network Foundation (PCWS-ITNF). The official handover included reading and signing a letter (by the partner family representative, project team representative and respective rural sanitary inspector, handing out a certificate with user guidelines, and photographs (UWEP 2003).

China

When ecosan toilets were introduced in Guangxi province in 1998, most of them were built inside the dwellings. The developers were initially faced with the challenge of finding a family that would agree to have a demonstration toilet built inside their house, but the idea was pursued in order to encourage community “buy-in” into the project. If the demonstration units were built outside, then all other toilets would also have had to be built outside. This would have increased the cost (there are large cost savings associated with locating a toilet indoors), and would become less convenient to use by the family and consequently difficult to maintain. In this regard, demonstration played a major role in promoting the new technology (Jiang 2001).

(c) Design

When designing the toilets, it is of vital importance to take into account the needs and cultural beliefs raised by the communities during the planning phase (Austin and Duncker 1999). The design of ecosan toilets should be tailored to suit the needs of a particular community in order to enhance the sustainability of the project. There is a wide range of materials, methods and styles that can be used.

South Africa

Austin and Duncker (2002) encourage creativity and imagination in the design of toilets, as long as the basic principles governing urine-diversion sanitation are adhered to. The use of locally available or traditional materials (and methods) should be given preference.

This, in turn, will encourage poor communities to participate in self-help building schemes and enable them to maintain the toilets themselves.

An example of taking a community's cultural values into account is evidenced by the design of the toilet units in the South African pilot project near Umtata, Eastern Cape. During the community liaison process that preceded construction of the toilets, the issue of the disposal of used anal cleansing material was discussed. The people indicated that they wanted to put this material into a separate container, the contents of which would be buried periodically, because burning of the material would not be acceptable for cultural reasons. Space for a plastic bucket for storing the used cleaning material was therefore incorporated into the superstructure. Other options discussed and decided by the communities were the type of brick, colour of paint, type of faeces receptacle (wood, plastic, etc), the urinal and actual locations of the toilets (Austin and Duncker 1999).

Mexico

From the lessons learnt in Mexico for sustainable replication of the toilets, it was strongly recommended that various design options should be considered with the families, enabling them to weigh the advantages and disadvantages of different alternatives prior to implementation of the project. When families were allowed to design their own toilet (with minimal technical support), they tended to build a single-vault toilet, but after considering more options, their analysis led them to the shallow-pit "arbour-loo", with responsibility for building a permanent double-vault toilet in the future (Clark 2001).

Mozambique

From the small survey carried out by ESTAMOS among twelve families who received fossa alterna toilets, three months after starting to use them, a concern was expressed that the pits were too shallow and would fill up quickly because of the large families. This raised the issue as to whether people would manage the systems properly (Dos Santos and Breslin 2001).

The reason for the shallow pit depths of these toilets therefore needed to be explained further, which was an indication that the principles and concepts of ecological sanitation had not been fully explained to the community. This could have been due to lack of information dissemination by the field workers and/or insufficient knowledge of ecological sanitation by the fieldworkers themselves. It was thought that people's concerns about shallow pit depths might also pass with time as they became accustomed to the new systems and actually saw that the toilets did not fill as rapidly as they initially thought (Dos Santos and Breslin 2001).

Philippines

According to the UWEP (2003) report, the Tingloy ecological sanitation pilot project was implemented in the municipality of Tingloy, Maricaban Island, Batangas Province, under an Integrated Sustainable Waste Management (ISWM) programme. During the first phase of the project, the respective partner households and community representatives were insufficiently involved in the process of designing and constructing the toilets. Construction was not supervised carefully enough and proceeded in a too-rushed way. The construction method (ferrocement technique) and materials used (moulds, ferrocement) were also unknown in the project area. Thus, the outcome of this project phase was that the demonstration toilets constructed could not be used for their intended purpose, had several operational problems and were inconvenient to use.

Learning from the design errors in Phase 1, and based on information gathered during in-depth consultation with the partner families, the PCWS-ITNF developed a new design for urine-diversion toilets. The approach followed in the final stage of this pilot project was to:

- Include participatory involvement of all actors in the process of design, development and review;
- hold meetings with a community developer and technical designer together;
- approach the participating family (recipient of a toilet) as a project partner that has rights and duties;
- explore the island and surrounding areas for local industries, workshops, craftsmen and materials that could be utilised in the design, development and scaling-up of ecosan activities; and
- believe that the outcome of the design process should be a pleasant and affordable toilet facility that sends out an environmental, health and hygiene promotion message, and which is easily replicable and adaptable by other families.

The UWEP (2003) report stated further that this toilet design has potential for a self-replicating effect among neighbouring households, i.e. the toilets themselves are promoters for ecosan developments in Maricaban Island. The use of local materials and expertise is also encouraged in order for the design to become the product of the community.

(d) Health and hygiene awareness and education

Apart from the well-known literature on health and hygiene aspects of sanitation provision in general, and dry sanitation technologies in particular, no references to these aspects with a specific focus on ecological sanitation could be found.

In South Africa, it is generally recognised that behaviour change can come before the construction of an adequate toilet facility. PHAST tools such as contamination routes assist in the addition of a simple hand-washing facility to a toilet, improvement in water management, safe disposal of children's faeces, etc. All these actions incrementally improve health, and each one on its own is easily achievable at household level (Holden 2004).

(e) Operation and maintenance

Any toilet system needs basic maintenance. Keeping it clean, understanding what repairs and replacements will be needed, and understanding its weak points, are all essential factors (DWAF 2002). Providing information on how to use and maintain a toilet system is an integral part of any sanitation improvement programme. Proper operation and maintenance of the toilets are crucial factors in the success of any sanitation scheme, and these should be duly considered during the planning and design processes. Urine-diversion ecosan toilets require a higher level of commitment from users than do other forms of dry sanitation such as VIP toilets. The reason is that they are more sensitive to, and therefore less tolerant of, abuse. However, the need for a higher level of commitment should be seen in the light of the many benefits associated with ecosan toilets when compared to pit toilets (Austin and Duncker 2002).

South Africa

During the planning phase of the pilot ecosan project in Eastern Cape, community meetings were held in each village. The technical aspects were discussed in order to facilitate an understanding of the operation and maintenance of the toilets. The community asked questions, and problem areas were clarified. Cultural taboos and beliefs, which needed to be addressed during the implementation of the project, were brought to the project team's attention. During the construction phase, when the first five toilets in each village had been completed, a training session on operation and maintenance aspects was facilitated, during which the various operational aspects were again discussed (Austin and Duncker 1999).

Community-level operation and maintenance is the most efficient method of ensuring a self-sustaining project. Local people should be trained in simple procedures for maintenance of urine-diversion sanitation systems. A team could be established to service and repair damage to the toilets. The following should be kept in mind when selecting eligible people for this team (Austin and Duncker 2002):

- Level of education;
- knowledge of an official language;
- knowledge of local languages;
- relevant experience or skills;
- age and sex;
- good local standing; and
- permanence in the area.

The sanitation committee (elected by the community) should be responsible for supervision and remuneration of these persons, while the community should agree to the payment/contribution of an agreed nominal fee for repair of the systems (Austin and Duncker 2002).

It is of great importance for development agencies to collaborate closely with communities from project inception, through all stages of infrastructural development, to a period of care after completion of the project. Monthly or bi-monthly visits to the area should take place after completion of the project in order to assist beneficiaries in operating and maintaining their toilets. This will ensure proper use of the toilets and therefore also the success of the project (Austin and Duncker 2002).

Mozambique

In the study conducted in Lichinga and Mandiba towns (Niassa Province) the interviewers from ESTAMOS observed that some toilets had odour problems because people did not want to put in too much ash/soil, as they were worried about the shallow depths of the pits and that they would fill up quickly. However, adding enough soil and ash is an important aspect of ecological sanitation (Dos Santos and Breslin 2001).

China

The results of a project evaluation in China indicate that ecosan toilets, when properly operated, can destroy pathogenic organisms, prevent fly breeding, are odourless, do not contaminate the environment, save water, and make possible the recovery of urine and faeces as fertilisers (Jiayi and Junqi 2001).

Mexico

The toilets and the superstructures from the second programme in Mexico were in a better state of repair than those from the first programme. This possibly encouraged householders to maintain the toilets properly, with the used toilet paper collected, and the toilet floor, basin and urine separator kept clean. Some problems, however, seemed universal (Peasey 2000):

- The urine diverter blocked from time to time, through incorrect use of the toilet or children putting toilet paper or stones down the tube;
- small children found it difficult to use the urine diverting toilet seat correctly; and
- if the urine tube was buried (led into a soakpit), then when it rained, the soil became saturated and the urine was not absorbed into the ground.

However, Espacio de Salud (ESAC) reports that the government-sponsored dry toilet installations are not always well received. The reason for this is that they are usually constructed without the homeowner's request, and with inadequate, incorrect or complete absence of instructions regarding their proper use and maintenance. Steinfeld (1999) indicated that the toilets are best accepted, used and maintained when they are voluntarily adopted by homeowners, who fully understand the systems and receive maintenance support from a local organization.

(f) Use of human excreta

Dry sanitation with use of excreta is promoted as an appropriate technology for community settings without sewerage or plentiful water. It has been heralded as solving many of the problems encountered with other sanitation systems. These include fly breeding, smell, groundwater contamination, short pit life and pit collapse. It is also claimed that sufficient destruction of disease-causing organisms (pathogens) is achieved, which enables safe handling of compost (Peasey 2000). There are other benefits too, such as the energy savings in reduced commercial fertilizer production and transport thereof to/from the centres of production and use. A further advantage mentioned is that, unlike septic tanks and pit latrines, which very often are a significant source of mosquito breeding, composting and desiccating toilets do not provide sites for this (Calvert 2000).

Peasy (2000) cautions that the enthusiasm generated by this technology seems to have overshadowed the most important issue, i.e. whether the end products from dry sanitation toilets are safe to handle and use as soil conditioners and plant fertilisers in community settings.

It is also evident that cultural taboos and perceptions in many parts of the world will have to change before people will accept using their faeces and urine as fertiliser for food crops (Source 2003).

South Africa

The owners of ecosan toilets in the Eastern Cape pilot project were against collecting and using the urine. It was therefore arranged to lead it into soakpits instead, with the option of converting to collection at a later stage (Austin and Duncker 1999). Some of the villagers disposed of the desiccated faeces in the maize fields and healthier plants were obtained (Austin and Duncker 1999).

Mozambique

The possibilities for excreta use were studied in two small towns in Niassa Province. The promotion of ecological sanitation in the district makes sense, as the province is primarily an agricultural area and most people (both males and females) who participated in the study were farmers. Nine of the families interviewed stated that they would use the resulting compost in their fields in the future. Two of the families said they would not use the compost because it was a very new idea. Due to the novelty of ecosan for people in Niassa, it was felt that time was needed for them to change their attitudes. Follow-up work still needs to be done with families who are using the compost in order to ascertain their opinions. This information could then be used to help change the attitudes of people who are not using the compost on their fields (Dos Santos and Breslin 2001).

Mexico

In response to rapid inflation, high unemployment and inadequate nutrition in Mexico City, Anadeges (a network of NGOs) developed a method of growing vegetables in containers using human urine as fertiliser. The project was launched in 1998 and more than 1 200 urban households currently participate (Esrey et al 1998).

(g) Monitoring and evaluation

It is of paramount importance to monitor and evaluate the entire project process, both during and after implementation, and to suggest changes where deemed necessary. The need for evaluations became apparent after repeated project failures throughout developing countries (Austin and Duncker 2002). The aim of conducting evaluation is to assess whether the intended benefits of the project have been achieved or not. In broad terms, the following aspects should be monitored (DWAF 2001):

- The involvement of communities, the promotion of health and hygiene awareness, and education;
- the impact of sanitation improvement programmes on the health of communities;
- compliance with the integrated environmental management approach, and environmental impacts of the sanitation systems;
- the allocation, application and management of funds; and
- construction of the sanitation facilities.

South Africa

From their experience in South Africa, Austin and Duncker (2002) support the above monitoring procedure, but feel that the following aspects should also be included:

- An assessment of the appropriateness of the technology used as well as overall performance of the sanitation project;
- a comparison of people's hygiene practices and habits after completion of the project with those observed prior to its implementation;
- an assessment of people's attitudes towards their sanitation systems;
- determining the impact of the community participation and involvement process in the project; and
- the provision of feedback to developers regarding their original planning assumptions, for the purpose of modifying future project designs, if necessary, and to enable successes to be repeated in other projects.

Austin and Duncker (2002) further state that the community should be involved in the evaluation process because valuable data will be provided and general community participation encouraged. The evaluation should be done in two parts: while the project is in progress and throughout its construction period, and after the completion of the project.

Philippines

Monitoring problems were encountered during the follow-up of the Tingloy ecosan pilot project. The construction process was only partly supervised by PCWS-ITNF staff and monitored twice: the first time during actual construction of the first toilet units and again after construction of the units was complete. During these monitoring visits one of the project team members and household members were questioned on the process of the project, and the main findings of the monitoring visits were as follows (UWEP 2003):

- The respective household and community representatives were insufficiently involved in the process of designing and constructing the toilets;
- construction was not supervised carefully enough and proceeded in a too-rushed way;
- the toilet facilities constructed could not be used as dry ecological (urine-diverting) toilets, because of technical errors in their design; and
- the toilet facilities constructed had several operational errors and were inconvenient to use.

As a result, PCWS-ITNF decided to conduct in-depth consultations with the respective households in order to establish what needed to be done to improve the facilities so that they could be classified as dry ecological (urine-diverting) toilets and be convenient to use.

Prior to the official handing-over ceremony, PCWS-ITNF visited the project's respective partner families each time they went to Tingloy. During these visits the toilet facilities were checked for correct use and maintenance, damages, problems etc. The families were invited to express their comments and suggestions. One of the partner families was hesitant to start using their toilet facility, despite the fact that everything was ready. When asked the reason for not using it, the family members indicated that they felt ashamed that a project team member (a young woman of Dutch nationality) came to inspect their toilet and excreta products. As that seemed to be a bottleneck in the project, measures were taken to overcome this – at the point of handing over the facilities to the partner families, it was agreed with the Rural Sanitary Inspectors that they would follow up the monitoring. In case of design problems, it was agreed that PCWS-ITNF would still assist during the remaining project time.

China

In order to guarantee the quality of ecosan toilets constructed in Guangxi province, core teams were trained to direct the villagers in the construction process and proper use of the toilets. There were core teams at both county and village levels. The county level office coordinated all ecosan work, including monitoring the progress and quality of the construction work. Team members were drawn from the county government's departments of sanitation, construction, education and information, and also from the women's union (Jiang 2001).

2.4.3 GENDER PERSPECTIVES (Hannan and Andersson 2001)

The contribution of ecological sanitation to empowerment, sustainable livelihoods, poverty reduction initiatives and decentralised management systems will be significantly enhanced if gender perspectives become an integral part of future developments. Gender perspectives on conventional sanitation systems have not been well established. It is difficult to generalise on this aspect in sanitation, given that women and men are not homogenous groups and gender relations are context-specific. There are, however, a number of gender aspects that influence how women, compared with men, are involved in and benefit from improvements to sanitation. Women's perceptions, needs and priorities in relation to sanitation can be quite different from men's. In East Africa, safety (particularly for children) and privacy were found to be the main concerns of women. What men want in relation to sanitation, however, has never been specifically assessed. Sanitation programmes, as with many other development programmes, have been built around assumptions on some sort of "gender-neutral" person who does not exist in reality. Men's interests, needs and priorities in relation to sanitation may well be as neglected as women's.

Attention to gender perspectives in sanitation programmes has often been limited to analysis of women's contributions relative to men's, and the impacts on women in terms of anticipated benefits, within the framework of the existing division of responsibilities. It has also been presumed that participation in sanitation programmes is automatically positive for women. The possible socio-economic costs involved, given the multitude of other responsibilities women have, are normally not considered.

Gender perspectives on ecological sanitation have not yet been specifically explored. Women are actively involved in food crop production and concerned about food security in many countries, and would be directly affected by increased access to soil nutrients provided through ecological sanitation and the concomitant potential for increasing food production. Given women's overall prime responsibility for the health and well being of families in many areas, it could also be assumed that women would support ecological sanitation on the basis of health gains. Furthermore, since women have the responsibility for tending the cooking fires, their involvement is also needed for ensuring a supply of ashes for use in the toilets.

The claims that ecosan approaches will lead to decentralised management systems that foster social cohesion and empowerment will only be realised if the questions of socio-economic equity are addressed. In particular, there is a need to give greater attention to gender perspectives in management and governance issues linked to ecological sanitation. Ecosan approaches can only be empowering if both women and men have the possibility of influencing the direction of, participate actively in the implementation of, and benefit from, these approaches. Men also need to be sensitised to the important contributions of women in the area of sanitation and encouraged to provide more support for their equitable involvement.

Integrating gender perspectives, or giving attention to both women and men, in ecological sanitation programmes is important for securing human rights and social justice. It is also critical for ensuring that the goals and objectives of ecological sanitation, particularly in relation to sustainable livelihoods and poverty reduction, are effectively achieved.

2.4.4 **SANITATION IS A BUSINESS** (SDC 2004)

The publication "Sanitation is a business: Approaches for demand-oriented policies" by the Swiss Agency for Development and Cooperation (2004) makes a number of statements concerning the necessity of involving the private sector in sanitation provision. These are given verbatim below:

(a) Sanitation is a business

"Until now, sanitation has been seen as an unpopular 'obligation,' a headache and an unwelcome burden for more successful water programmes. But the case for meeting the Millennium Development Goals in sanitation is overpowering and can only be achieved if the private sector becomes more actively involved in sanitation. Under the new paradigm, sanitation has to be seen as an opportunity – actually, as a business."

(b) Histories, age-old beliefs

"Top-down approaches, based on the conviction that poor people have 'to be told' to practice hygiene and must 'be given latrines' will not succeed. It is an unacceptable prejudice that poor people are unconcerned by their own hygiene. Most people know exactly what they want. They aspire to cleanliness, comfort and a better life, and this can be converted into a demand.

It is a proven fact: even poor people are willing to pay for hygiene and for suitable services. All over the world, an increasing number of businesses – sometimes very small – are making a living from sanitation. As they do so, they are providing a good service to their customers, who are often poor people. Sanitation is an opportunity for both the user and the provider."

(c) A new paradigm

"The new paradigm is built on two pillars:

(i) A drastically more active public health policy which puts water, sanitation and hygiene very high on the political agenda, but where the focus should entirely be on the demand side, on market creation and on the enabling environment. Instead of providing top-down solutions (with 'one size fits all' subsidies), governments and civil society should actively work together to promote the creation of markets for sanitation and hygiene. This can be done with social mobilisation campaigns and/or financial incentives (intelligent subsidies) to invest in sanitation. Both instruments should focus on encouraging desirable behaviours and attitudes (the 'carrot') and discouraging bad practices (the 'stick'). Public investments such as costly sewage systems should be made in a form which encourages the private sector in the best way.

(ii) A radically more active involvement of the private sector on the supply side is needed, to deliver creative and innovative solutions that provide better services for all customers, including the poor. The private sector can also play a major role in demand creation with innovative marketing campaigns and communication strategies.

Private entrepreneurs must be invited to see the water, sanitation and hygiene sector as an opportunity for good business. Accordingly, they will invest in these 'new' markets, designing new products and services that fulfil the dreams of people, and which respond to their needs."

(d) Demand and behavioural change

"The demand for sanitation is built not only upon gentle coercion (obligations) but also upon people's desires. The business sector cannot survive without cultivating and responding to this demand. If private business can cater to the needs of poorer customers as well as meeting the demands of wealthier groups, the business community can become one of the key partners to reach the MDG in sanitation.

Once demand for latrines has been created, an opportunity has arisen for the private sector to design, make and deliver a solution that fully satisfies this demand. If the customer is poor, then the product must – above all – be modestly priced. If the customer is wealthier, then the product may be of a higher quality and a better design. There is never only one solution: it is not true that 'one size fits all'."

2.4.5 CONCLUSIONS

The common thread running through all the aspects discussed, namely project planning, marketing of concepts, design of the toilets, health/hygiene awareness raising, toilet operation and maintenance, use of excreta, as well as post-project monitoring and evaluation, is seen to be effective community liaison. Ensuring people's participation in all aspects of a project is a prerequisite for success.

Support for ecological sanitation comes from many quarters, e.g. international agencies such as UNDP and UNICEF, donors such as Australia, Germany and Sweden, international NGOs such as CARE and WaterAid, and local and national NGOs.

Achieving ecological sanitation solutions requires a change in how people think about human excreta. In some societies, human excreta are considered a valuable resource, and the handling of excreta poses no problems. Many countries have accepted these sanitation systems, although much work remains to be done on promotion, to enable people to change their attitudes on issues such as use of excreta for agricultural purposes. Regarding the removal of faecal matter or emptying the vaults, other avenues should be explored, particularly in cases where the household members are not willing to do so.

Operation and maintenance are further aspects requiring attention. Communities will generally accept dry sanitation programmes when sufficient time and energy are committed by the project team. However, programmes should be adaptable to local conditions and should react to a need rather than impose ideas.

There are benefits to be gained from installing some toilets in the houses of important community members. Once neighbours and others in the community realise the benefits, then they will generally also be eager to adopt the technology.

Ongoing training of the sanitation committee, fieldworkers and community members in ecological sanitation principles and practices is necessary for the sustainability and success of ecosan projects. Further marketing or promotion strategies should be developed, and those that are available should be implemented for a longer period of time. Perseverance during training is required and it should be borne in mind that it is always difficult (or it takes time) to change people's attitudes about new methods or technologies.

Ongoing monitoring and evaluation of ecosan projects should be a priority, considering that the toilets represent a new system and need to be managed correctly if the goals of ecological sanitation are to be met. It is evident that there have been problems with, and lack of support for, this aspect of the ecosan process in various parts of the world. The problems are usually caused either by a lack of sufficient involvement of the community during this phase, or because the implementing agency conducts it only partially. Lack of monitoring and evaluation poses difficulties in measuring the success of the project or impact on the community.

Attention to gender aspects, in particular taking into account the specific requirements of both women and men in ecological sanitation projects, is considered to be crucial for attaining the objectives of social justice and sustainability.

It is evident that there is a strong need for the development of guidelines for the successful implementation of ecosan projects.

Finally, it is necessary for the private sector to be involved in sanitation provision, and for this provision to be demand-based. The poor should be recognised as having the same needs and aspirations regarding sanitation and hygiene as anyone else, and attractive and suitable hardware products should be made available to suit all sectors of society. Businesses that advertise ecosan toilets should be developed that are capable of providing several different options and designs, and possibly even a maintenance contract for removing excreta if the customer desires it.

2.5 AGRICULTURAL UTILISATION OF HUMAN EXCRETA FROM ECOSAN TOILETS

2.5.1 INTRODUCTION

In order to grow plants that supply our food, fertilisers such as nitrogen, phosphorus and potassium and about 25 other additional elements have to be supplied. Today, artificial fertilisers account for the largest share of these nutrients but, at the present rate of use, the available resources will be rapidly depleted. Use of excreta as fertiliser has been implemented only to a limited extent. Rather, they have been flushed out into the rivers, resulting in a lack of oxygen in the aquatic resources. These resources have also been polluted with pathogenic microorganisms to the extent that many large rivers have become virus contaminated more or less permanently. It is thus better to create a closed system, with no pollution from bacteria or viruses, where *human* fertilisers are harvested and used to feed the following year's crops (Wolgast 1993). Nutrients are removed from fields with the harvested crops; in sustainable agriculture, therefore, the amounts of nutrients removed from a field should be returned to it (Jönsson 1997). Today, there is mainly an outflow of nutrients from farms to society. For a sustainable society, Vinnerås (2002) maintains that it is necessary to recycle these excreta back to the farms.

Ecological sanitation regards human excreta as resources to be recycled, rather than as wastes to be disposed of. Esrey et al (1998) maintain that the notion of excreta being merely waste with no useful purpose is a modern misconception, which is at the root of pollution problems resulting from conventional approaches to sanitation. According to them there is no waste in nature, and all the products of living things are used as raw materials by others. Recycling sanitised human urine and faeces by returning them to the soil restores the natural cycle of life-building materials that has been disrupted by current sanitation practices.

Where crops are produced from soil, it is imperative that the organic residues resulting from these crops are returned to the soil from which the crops originated. This recycling of all residues should be axiomatic to sustainable agriculture (Gumbo nd).

There are many reasons for recycling the nutrients in excreta. Recycling prevents direct pollution caused by sewage being discharged or seeping into water resources and ecosystems. A secondary benefit is that recycling returns nutrients to soils and plants, and reduces the need for chemical fertilisers. It restores good soil organisms to protect plants, and it is always available locally, wherever people live (Esrey et al 1998).

However, Schertenleib (2002) recognises that excreta contain both dangerous materials (pathogens in faeces) as well as beneficial components (nutrients in urine). He states that the challenge of modern sanitation practice is to find ways to:

(a) contain the dangerous part of the excreta in order to prevent transmission of diseases;
(b) use the beneficial part of the excreta productively; and
(c) avoid damage to the natural environment.

This section of the literature review discusses the fertilising and soil conditioning properties of human excreta and gives examples of beneficial excreta use in agriculture in various countries.

2.5.2 HUMAN EXCRETA AS FERTILISERS

For adult persons who maintain approximately the same mass during their lifetimes, the excreted amounts of plant nutrients are about the same as the amount eaten. The excreted amounts of plant nutrients depend on the diet and thus differ between persons as well as between societies (Jönsson 1997; Jönsson and Vinnerås 2003). Vinnerås[a] et al (2003), quoting Guyton (1992), note that the volume of faeces produced per person depends on the composition of the food consumed, with meat and other foods low in fibre producing smaller volumes than food high in fibre. Table 2.1 was developed in 1997, based on the average Swedish diet and circumstances.

Table 2.1: Estimated Swedish averages for mass and distribution of plant nutrient content in urine and faeces, expressed as percentages of total mass excreted (based on Jönsson 1997)

Parameter	Urine		Faeces		Total toilet waste	
	g/p.d	%	g/p.d	%	g/p.d	%
Wet mass	900 – 1200	90	70 - 140	10	970 - 1340	100
Dry mass	60	63	35	37	95	100
Nitrogen	11	88	1,5	12	12,5	100
Phosphorus	1,0	67	0,5	33	1,5	100
Potassium	2,5	71	1,0	29	3,5	100

Vinnerås[b] et al (2003) have since revised these values (Table 2.2):

Table 2.2: Proposed new Swedish default values for urine and faeces (based on Vinnerås[b] et al 2003).

Parameter	Urine g/p.d	Faeces g/p.d	Toilet paper g/p.d	Blackwater (urine + faeces) g/p.d
Wet mass	1 500	140	24	1670
Dry mass	58	30	23	111
Nitrogen	11	1,5	-	12,5
Phosphorus	1,0	0,5	-	1,5
Potassium	2,7	1,0	-	3,7

Based on Tables 2.1 and 2.2 above, it is estimated that roughly 65 to 90% of the excreted nitrogen, phosphorus and potassium are to be found in the urine. Furthermore, plant nutrients excreted in urine are found in chemical compounds that are easily accessible for plants. Initially 80 to 90% of the nitrogen is found as urea, which rapidly degrades to ammonium and carbon dioxide as follows (Jönsson 1997):

$$CO(NH_2)_2 + 3H_2O \leftrightarrow CO_2 + NH_4^+ + 2OH^-$$

The urea degradation increases the pH value of the urine from its normally slightly acidic state (pH 6 when excreted) to a value of approximately 9. The phosphorus in the urine is in the form of phosphate, while the potassium is in the form of ions. Many chemical fertilisers contain, or dissolve to, nitrogen in the form of ammonium, phosphorus in the form of phosphate and potassium in the form of ions. Thus, the fertilising effect of urine ought to be comparable to the application of the same amount of plant nutrients in the form of chemical fertilisers (Jönsson 1997). According to Johansson et al (2000), the effect of human urine applied to a spring crop in Sweden corresponded to 80-90% of the effect with the same amount of nitrogen in the form of mineral fertiliser. Vinnerås (2002), quoting Kirchmann and Pettersson (1995), Elmqvist et al (1998) and Johansson et al (2000), notes that field trials and pot experiments have shown diverted human urine to be comparable to mineral fertilisers. It was found that for nitrogen, the fertilising effect is equal to, or just a little bit poorer than, mineral fertilisers, while for phosphorus, the fertilising effect is equal to, or just a little bit better than, mineral fertilisers.

The faeces contain undigested fractions of food with plant nutrients. However, organically bound plant nutrients are not plant available. The undigested food residuals have to be degraded before their plant nutrients become available, therefore the plant availability of the nutrients in faeces is expected to be slower than the plant availability of the nutrients in urine (Jönsson 1997).

Drangert (1996) estimates that the amount of human-derived nutrients from two persons is sufficient to produce food for at least one person. According to Wolgast (1993) the fertilisers excreted by one person are sufficient to grow 230kg of cereal each year, as illustrated in Table 2.3. The table is based on an average human production of 500 litres of urine and 50 litres of faeces per year.

Table 2.3: Annual excretion of fertiliser by humans, compared with the fertiliser requirement of cereal (Wolgast 1993)

Fertiliser	500 litres urine	50 litres faeces	Total	Fertiliser need for 230kg cereal
Nitrogen (N)	5,6kg	0,09kg	5,7kg	5,6kg
Phosphorus (P)	0,4kg	0,19kg	0,6kg	0,7kg
Potassium (K)	1,0kg	0,17kg	1,2kg	1,2kg
Total N+P+K	**7,0kg (94%)**	**0,45kg (6%)**	**7,5kg (100%)**	**7,5kg**

As described above, Vinnerås[b] et al (2003) have since revised the values of the fertiliser contents in urine and faeces. In order to enable a direct comparison with Table 2.3, these revised values are given in Table 2.4.

Human urine is seen to be the largest contributor of nutrients to household wastewater. If no phosphate detergents are used, at least 60% of the phosphorus and 80% of the nitrogen in household wastewater comes from urine. The total quantities of nutrients in human urine are significant when compared with the quantities of nutrients in the mineral fertilisers used in agriculture. For example, it is estimated that in Sweden the total yearly production of human urine contains nitrogen, phosphorus and potassium equivalent to 15 to 20% of the amounts of these nutrients used as mineral fertilisers in 1993. Thus, by

separating human urine at source, the amounts of nutrients recycled to arable land can be significantly increased while at the same time the nutrient load of wastewater can be significantly decreased (Jönsson 1997).

Table 2.4: Annual excretion of fertiliser by humans (based on Vinnerås[b] et al 2003).

Fertiliser	550kg urine	51kg faeces	Total
Nitrogen (N)	4,0kg	0,6kg	4,6kg
Phosphorus (P)	0,4kg	0,2kg	0,6kg
Potassium (K)	1,0kg	0,4kg	1,4kg
Total N+P+K	**5,4kg (82%)**	**1,2kg (18 %)**	**6,6kg (100 %)**

The fertilising effect of urine is similar to that of a nitrogen-rich chemical fertiliser, and should be used similarly. It is therefore best used on nitrogen-demanding crops and vegetables. As a rule of thumb, a concentration of 3-7 grams of nitrogen per litre of undiluted urine can be expected (Vinnerås[a] et al 2003).

The fertilising effect of source-separated urine has been tested in some experiments in Sweden and appears to be almost as good as that of the corresponding amount of chemical fertiliser, provided that ammonia emission from the urine is restricted. The uptake of urine nitrogen by barley harvested at flowering stage was found to be 42% and 22% at two application rates, while the uptake of ammonium nitrate-nitrogen at the same application rates was 53% and 28% respectively. The lower uptake of urine nitrogen has been explained by higher gaseous losses of nitrogen (i.e. ammonia) from urine than from ammonium nitrate. The utilisation of urine phosphorus, however, was found to be 28% better than that of chemical fertiliser. The barley fertilised with urine derived 12,2% of the phosphorus, while that fertilised with dipotassium hydrogen-phosphate derived only 9,1% from the fertiliser. In a field experiment, the nitrogen effect of stored urine on oats was compared to that of ammonium nitrate fertiliser at three different application rates. The human urine, which was surface-spread and immediately harrowed into the ground, gave approximately the same yield as the corresponding amount of chemical fertiliser (Jönsson 1997).

Using the recycled toilet products as fertilisers will therefore save chemical fertilisers containing almost the same amount of nutrients and thus also the resources needed to produce and distribute them (Jönsson 1997). According to Vinnerås (2002), the largest single energy requirement in the conventional production of rapeseed in Sweden is the manufacture of the mineral nitrogen fertiliser used.

Jönsson (2002b) also notes that reduction of the amount of urine, and therefore the nitrogen load, in sewage, reduces the electrical energy requirements of a wastewater treatment plant by up to 36% due to the fact that less aeration is needed. He estimated further that the energy break-even transport distance for urine was approximately 95km with a truck or 221km with a truck and trailer. There will also be correspondingly less nutrient emissions from the plant. He states that, if all urine is diverted, the nitrogen emissions will probably decrease by 80-85% and the phosphorus emissions by 50%.

A further advantage of using human urine instead of chemical fertilisers or sewage sludge is the very low concentration of heavy metals found in urine (Jönsson 1997). This viewpoint is supported by Hanaeus et al (1997), who state that the quality of sewage sludge is not fully trusted by agriculturalists due to the risk of hazardous compounds being present. Cadmium, for example, bio-accumulates in the food chain. According to Höglund et al (1998), human urine in Sweden contains less than 3,6mg Cd/kg P, while commercial chemical fertilisers contain approximately 26mg Cd/kg P. Furthermore, the sludge from the 25 largest sewage plants in Sweden was found in 1993 to contain an average of 55mg Cd/kg P.

Vinnerås (2002) states that urine and faeces contribute only very small amounts of heavy metals to sewage, as most of these contaminants originate from greywater and other sources. This is illustrated in Table 2.5.

Table 2.5: Amounts of heavy metals, in mg per person per year, found in various recyclable nutrients (based on Vinnerås 2002).

Source	Cu	Cr	Ni	Zn	Pb	Cd	Hg
Blackwater	440	11	30	3 900	8,0	4,0	3,6
Urine	37	3,7	2,6	16	0,73	0,25	0,3
Sewage	12 000	1 400	2 100	22 000	1 600	56	36

Plant nutrients can be divided into two categories, namely macronutrients and micronutrients. The total uptake of macronutrients is approximately 100 times that of micronutrients. The macronutrients are the elements nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg). Of these, yearly additions are usually needed of the first four (N, P, K, S), while the soil supply of Ca and Mg is usually sufficient provided the pH is not too low. All over the world, nitrogen is frequently the most limiting nutrient for plant growth (Vinnerås[a] et al 2003).

The micronutrients found in urine are also essential for plant growth, but the uptake of these elements is in small (micro) amounts. The elements normally considered to be micronutrients are boron, copper, iron, chloride, manganese, molybdenum and zinc (Vinnerås[a] et al 2003, quoting Frausto da Silva and Williams 1997). These nutrients come mainly from the degradation of organic material and erosion of soil particles. Only in special circumstances does scarcity of micronutrients limit plant growth. When human excreta are used as a fertiliser, the risk of such deficiency is minimal as excreta contain all the micronutrients required.

Although desiccated faeces contain fewer nutrients than urine, they are a valuable soil conditioner. They may be applied to the soil to increase the organic matter content, improve water-holding capacity and increase the availability of nutrients. Humus from the decomposition process also helps to maintain a healthy population of beneficial soil organisms that actually protect plants from soil-borne diseases (Esrey et al 1998). Vinnerås[a] et al (2003) argue that the main contribution from the faecal matter is the phosphorus and potassium content and the increase in buffering capacity in areas where soil pH is low.

Discussion

All authors are in agreement that human excreta are excellent sources of plant nutrients. While slightly different figures are quoted for the excreted amounts, it is seen that the most fertilising value is found in urine, with faeces being a good soil conditioner. Urine in particular compares favourably with chemical fertiliser, and authors agree that the very low quantity of heavy metals found in urine is an added advantage.

2.5.3 SOME PRACTICAL EXAMPLES OF AGRICULTURAL UTILISATION OF HUMAN EXCRETA

(a) Japan

This country introduced the practice of reusing human excreta for agriculture in the 12th century, which lasted until the middle of the 19th century. Farmers purchased urine and faeces from people in the urban areas and, due to the country's closed policy, typhoid, cholera and other communicable diseases were virtually unknown. Farmers also used to place buckets at street corners in the towns and villages, collecting free urine from pedestrians and providing a simple public toilet at the same time (Matsui 1997).

(b) China

In China, farmers have commonly used nightsoil, often untreated, to grow food. In Guangxi province, however, double-vault urine-diversion toilets have gained popularity recently, and over 30 000 toilets have been built in densely populated rural and urban areas. Rooftop gardening uses only urine to grow vegetables, such as cabbages, beans, pumpkins and tomatoes. In the fields, both urine and faeces are used to grow corn, rice and bamboo (Esrey and Andersson 2001).

(c) India

In a pilot project in Kerala, urine is diverted into a growing area attached to the back of the toilet, where bitter gourds are grown. The project has met with success and there is a demand for more toilets to be built (Esrey and Andersson 2001).

(d) Guatemala

In Guatemala, deforestation and erosion are serious problems throughout the highland areas. This is the result of the high population density in these zones, together with inequitable land distribution and the use of the more gently sloping and flatter lands for the cultivation of cash crops, thereby forcing the subsistence crops to be cultivated on steep slopes. To counteract this situation of increased soil loss, the use of human faecal matter as soil conditioner by subsistence farmers is of particular value. While it is recognised that this practice may not solve the area-wide problems of deforestation and soil erosion, it is regarded as an appropriate and low-cost method for improving the fertility and productivity of the soil of the individual farming family and for the country as a whole. The farmers are aware that the application of chemical fertilisers to the fields without replenishing the organic fraction leads to an impoverishment of the soil (Strauss and Blumenthal 1990).

Double-vault urine-diverting toilets were introduced here because they were regarded as the most suitable technology for the people of the area. Ash, or a mixture of ash and soil or of lime and soil, is added after defecation. This, together with the separation of urine, renders the faecal material alkaline, with a pH of around 9. This enhances pathogen die-off. The mixture of decomposed, humus-like material of faecal origin and ash, called "abono", is dried in the sun and then stored in bags upon removal from the vault until the farmer uses it in his fields at the time of tilling. The potassium levels of the "abono" are much higher than ordinary excreta due to the addition of ash, which is very rich in potassium. On average, the application rate of "abono" amounts to the equivalent of about 2 500 to 3 000kg/ha for each plant cycle. With the average "abono" production rate of about 425kg per year per family, the family's fertilising potential for maize crops is approximately 1 900m^2 on the basis of the phosphorus content of the "abono" and 2 580m^2 on the basis of potassium, but only about 123m^2 on the basis of the nitrogen content. The fertiliser from these toilets is therefore complemented by the collected urine, or else nitrogen-fixing crops such as legumes are planted in rotation with other crops (Strauss and Blumenthal 1990).

(e) Zimbabwe

A unique tree-panting method that is combined with a composting toilet, called the *arbourloo*, is used in Zimbabwe. A small hole suitable for planting a tree is dug; the size is approximately 600 x 600 x 600mm, thus forming a shallow pit for a toilet. A lightweight, removable slab is placed over the hole and a simple toilet structure, which is also easily movable, is erected above it. The unit is fitted with a conventional pedestal or squat plate. The shallow pit fills up relatively quickly with faeces, which are covered with ash or soil. As soon as the hole is full, the superstructure is moved to another similar hole, while the first hole is topped up with soil and a fruit tree planted in it. In this way, whole orchards of productive fruit trees are grown. The most commonly planted trees are avocados, paw-paws, mulberries, mangoes and guavas (Morgan 1999).

Figure 2.33: Arbourloo in a paw-paw plantation or "sanitary orchard".
(Morgan 1999)

(f) Ethiopia

A popular practice here is FAITH gardening (**F**ood **A**lways **I**n **T**he **H**ome). The concept is based on a vegetable garden divided into sections that are planted in rotation, at intervals of a few weeks. Thus, while some patches are producing food, others have seed still germinating. In this way there is a constant supply of available food. The vegetable patches are well composted with "human manure" and any other suitable organic material, such as garden refuse. Urine is also used as a liquid fertiliser. Excellent results are obtained (Edström 1999).

Figure 2.34: Gunder Edström of SUDEA demonstrating this FAITH garden in Addis Ababa, Ethiopia.
(Photograph: CSIR)

(g) Sweden

Sweden is probably the country with the most advanced system of collection and use of human urine, where it is practised by farmers on a large, mechanised scale. There are a number of settlements (called "eco-villages") or apartment blocks in the country where the residents have ecological sanitation systems with urine-diversion toilets. The urine from all the houses or apartments is collected in large underground tanks, and what the residents do not use themselves is collected by farmers in road tankers and used for fertilising their crops. The usual practice is to spray it onto the lands while they are being prepared for planting, and then harrow it into the soil before sowing the seed.

(h) Discussion

The various authors describe how human excreta are productively used to boost agricultural production in various countries. It is seen that urine and faeces complement each other in the soil.

2.5.4 SMALL-SCALE CROP EXPERIMENTATION IN ZIMBABWE

Morgan (2003) describes a number of experiments utilising human urine and faeces as fertilising agents for various food crops in Harare, in which he compared growth of the plants in the local poor quality sandy topsoil with that in humus from urine-diverting toilets (a mixture of faeces, soil and wood ash). An analysis of the two growing media is shown in Table 2.6, which illustrates the value of the faecal material from a UD toilet.

Table 2.6: Analysis of humus (faeces, soil and wood ash) from urine-diverting toilets (Morgan 2003).

Soil source	pH	N	P	K	Ca	Mg
UD toilet	6,72	232	297	3,06	32,22	12,06
Local topsoil	5,50	38	44	0,49	8,05	3,58

Note: N and P are expressed as ppm, and K, Ca and Mg as meq/100g

Various trials were performed on a variety of vegetables using urine diluted with water at a ratio of three parts water to one of urine as a liquid feed. Seedlings were planted in containers and irrigated with plain water for a period of one to four weeks to allow them to stabilise in their new environment (young seedlings do not react well to a urine mixture). Thereafter the 3:1 water/urine mix was applied three times per week, interspersed with regular watering at other times in order to keep the plants turgid and healthy. For the maize trials the urine was diluted in the range 3:1, 5:1 and 10:1 with water. The plants were fed with this mixture once per week and also watered regularly at other times.

After a certain growing period the crop was harvested and weighed. Some of the results are illustrated in Table 2.7 and Figures 2.35 to 2.38.

Table 2.7: Plant trials for various vegetables, tomatoes and maize (based on Morgan 2003).

Plant	Urine : water application	Duration of growth	Yield
Lettuce	Water only	30 days	230g
Lettuce	3:1 urine, 0,5ℓ x 3 per week	30 days	500g (2 fold increase)
Spinach	Water only	30 days	52g
Spinach	3:1 urine, 0,5ℓ x 3 per week	30 days	350g (6 fold increase)
Covo	Water only	8 weeks	135,5g
Covo	3:1 urine, 0,5ℓ x 1 per week	8 weeks	204g (1,5 fold increase)
Covo	3:1 urine, 0,5ℓ x 3 per week	8 weeks	545g (4 fold increase)
Tomato	Water only	4 months	1 680g (total of 9 plants)
Tomato	3:1 urine, 0,5ℓ x 3 per week	4 months	6 084g (3,6 fold increase)
Maize	Water only	3 months	6g/cob (average)
Maize	10:1 urine, 0,5ℓ x 1 per week	3 months	62 g (10 fold increase)
Maize	5:1 urine, 0,5ℓ x 1 per week	3 months	138g (23 fold increase)
Maize	3:1 urine, 0,5ℓ x 1 per week	3 months	169g (28 fold increase)
Maize	3:1 urine, 0,5ℓ x 3 per week	3 months	211g (35 fold increase)

Figure 2.35: Two basins planted with rape and spinach. The basin on the left has been fed with a 3:1 mix of water and urine, three times per week interspersed with normal watering. The basin on the right has been irrigated with water only (Morgan 2003).

Figure 2.36: Urine has a pronounced effect on maize. The plant on the right is being fed with 0,5ℓ of a 3:1 mix of water and urine three times per week. The plant on the left is irrigated with water only (Morgan 2003).

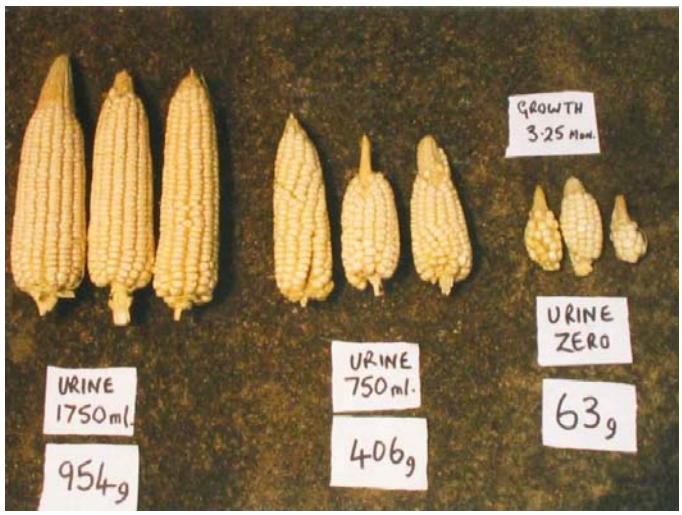


Figure 2.37: Total cob yield from maize planted in three 10ℓ basins. On the left the maize was fed 1 750mℓ urine per plant over a 3,5 month period, resulting in a crop of 954g. A reduced crop resulted from reduced input of urine (middle). Plants on the right were irrigated with water only, and produced a very poor yield (Morgan 2003).

Figure 2.38: A single photograph shows the effect of different amounts of urine applied to maize plants over a 3-month period. On the left the plants have been fed a 3:1 mixture of water and urine at a rate of 125mℓ per plant per week, which produced a mean cob weight of 211g. The 3:1 mixture was applied to the next group at 40mℓ per plant per week, which led to a mean cob weight of 169g. A 5:1 mix was applied to the third group at 27mℓ per plant per week, giving a mean cob weight of 138g. The next plants on the right were fed with a 10:1 mix at 15mℓ per plant per week, resulting in a mean cob weight of 62g. The plants on the far right were fed with water only and produced a mean cob weight of only 6g. 99,4% of the total cob mass shown in this photograph is derived from the nutrients provided by urine (Morgan 2003).

These trials reveal the great value of urine when used as a liquid feed for various plants, and particularly for leafy vegetables (lettuce, spinach, covo, etc). The results from an extensive series of maize trials also revealed that production of maize could be increased in poor sandy soil by the application of urine alone, but if the sandy soil had humus added, then the production increased even further. The further increase gained from the addition of humus is due to the presence of nitrifying bacteria in the humus, which convert the urea and ammonia in urine into nitrate ions, the form in which they can be taken up by the plants (Morgan 2003).

The results further show that, for a family practising subsistence agriculture, a huge increase in vegetable and maize production is possible, especially in areas where the soil is poor or access to manure or commercial fertiliser is difficult or expensive. Thus, in forming links between ecological sanitation and improved food production, good agricultural practice and a culture of soil improvement is encouraged (Morgan 2003).

A potential problem identified by Morgan (2003), however, concerned the possible accumulation of sodium chloride in the soil due to the relatively high proportion of this salt found in urine. Simons and Clemens (2003) also cautioned that urine should not be used in excess in order to avoid yield losses due to high inputs of sodium chloride.

Discussion

This section not only illustrates the remarkable effect of human excreta on agricultural production, but confirms once again how urine and faeces complement each other in the soil.

2.5.5 NITROGEN LOSSES IN URINE

Source-separated urine is a highly concentrated and unstable solution. During storage, bacterial urease hydrolyses urea to ammonia and bicarbonate, causing a pH increase (the pH is related to the concentration of ammonia, NH_3). As a result, 90% of the total nitrogen is present as ammonia and the pH is near 9. After storage, urine contains a large amount of non-ionised ammonia, which can volatilise when the urine solution is agitated during transport or application as fertiliser (Udert et al 2002). Therefore the prevention of ammonia losses during storage and after soil application is important for efficient use of human urine. Hellström and Kärrman (1996) emphasise the importance of constructing the collection, storage and handling system for human urine so that losses are minimised, because the experience from storage and handling of animal urine is that nitrogen losses can be large. Hellström et al (1999) agree that losses from the spreading of animal urine can be high, but maintain that losses from collection and storage of human urine are small, however. Losses can be minimised by preventing the decomposition of urea to ammoniacal nitrogen, i.e. the sum of NH_4-N and NH_3-N. Because the decomposition of urea leads to an increase in pH and an increase in the concentration of ammoniacal nitrogen, there is a risk of nitrogen losses through ammonia evaporation. These losses could be reduced by preventing ventilation during storage and by injecting or harrowing the urine into the soil when spreading.

Hellström et al (1999) conclude that a decrease in pH will inhibit the decomposition of urea, and that it should be possible to use acids to reduce the pH to about 3. Because the overall objective of the source separation system is to use the urine as a fertiliser, it would

be suitable to use acids with a fertiliser value, e.g. phosphoric acid or sulphuric acid. This is supported by Hanaeus et al (1996), who state that the conversion of urea to ammoniacal nitrogen during storage of urine is greatly inhibited by addition of 26 mmol of H_2SO_4 per litre of undiluted urine and a cool temperature. However, they also caution that contamination of urine with faecal matter or wastewater will significantly increase the decomposition rate of urea.

In extensive field tests, Johansson et al (2000) found that ammonia losses during the application of urine in the spring (i.e. just before planting) never exceeded 10% of the amount of nitrogen applied and were usually considerably lower. Furthermore, the ammonia losses measured after the application of urine in the growing crop were negligible, because the growing crop protected the soil surface from wind and sun. He maintains that where the system is properly designed, nitrogen losses during transportation and storage are less than 1%, while the losses associated with application may be less than 2%, depending on the technology used.

Discussion

It appears as if there is some disagreement about the extent of nitrogen loss in urine during storage, transport and use.

2.5.6 CONCLUSIONS

Artificial fertilisers currently account for most of the nutrients needed by food crops. While human excreta contain virtually all the nutrients that plants require, they have been utilised for their fertiliser value only to a limited extent. Instead, much of the nutrient value in excreta finds its way into aquatic resources, where it is responsible for, among other things, problems of oxygen depletion. Many agriculturalists maintain that it is better to create a closed system by recycling nutrients back to the farmlands from where they originated. Ecological sanitation regards excreta as a valuable resource, not simply as a waste to be disposed of.

Extensive studies have been carried out to determine the fertilising value of human excreta, for various types of crops. Humans excrete some 6,6kg of plant nutrients in the form of nitrogen, phosphorus and potassium annually. Urine has been found to contain approximately 65 to 90% of these nutrients, and many field trials have confirmed it to be a fertiliser of virtually equivalent value to commercial chemical products. In addition, as opposed to wastewater sludge, urine contains very small amounts of heavy metals. While faeces contain much fewer nutrients, they increase the organic content and improve the water-holding capacity of soils.

Human excreta have been productively used as fertiliser and soil amendment in many countries. Although this practice is still limited if examined on a worldwide basis, it has become a popular method of increasing food production, especially among lower income communities that are dependent on subsistence farming for survival, often on poor soils. A number of scientific studies have confirmed the substantial agronomic value of excreta in recent years.

2.6 HEALTH AND SAFETY ASPECTS OF URINE-DIVERSION ECOSAN TOILETS AND EXCRETA USE

2.6.1 INTRODUCTION

Ecological sanitation (ecosan) regards human excreta as a resource to be recycled rather than as a waste to be disposed of. Recycling nutrients to soils and plants reduces the need for chemical fertilisers and restores good soil organisms to protect plants (Esrey et al 1998).

The alternatives to conventional wastewater treatment include systems that separate or divert urine and faeces in order to utilise the nutrients more efficiently. In regions without a sewerage network, nutrient utilisation as well as improved sanitation is possible by not mixing the fractions and avoiding flushwater. If the faecal fraction is kept dry there will be less leaching from pit toilets and the smell will be reduced. The main reasons for separating urine and faeces are thus to recycle the plant nutrients in urine and to obtain a faecal fraction that is more practical to treat and safer to handle (Schönning 2001a).

The goal of ecological sanitation is to safely treat human faeces and provide a low-cost fertiliser and soil conditioner for use in agriculture. Urine-diverting toilets store faeces for a period of time under conditions that are intended to promote inactivation of faecal pathogens (Esrey et al 1998).

This section of the literature review is aimed at determining what information is available to assist the understanding of environmental factors affecting the survival of excreted pathogens in faeces and urine.

2.6.2 HEALTH RISKS OF EXCRETA USE

Development of a sustainable sanitation system includes the utilisation of nutrients from human urine and faeces in agriculture. However, the quality of wastewater sludge is not fully trusted among agriculturalists and food producers. One uncertainty is the difficulty of guaranteeing the sludge quality due to the risk of non-analysed but hazardous compounds being present. Another problem, which is indirectly related to the sewerage system, is the fact that a very large part of the population in a modern urbanised society lives on a comparatively small part of the land. Hence the food is transported from a large area to a small one, and a nutrient such as phosphorus will be accumulated near the densely populated areas and inefficiently used if it is not transported back to the areas of food production (Hanaeus et al 1997).

In developing countries, excreta-related diseases are very common, and excreta and wastewater contain correspondingly high concentrations of excreted pathogens: the bacteria, viruses, protozoa and helminths (worms) that cause disease in man. There are numerous infective organisms of public health importance, and many of these are specifically relevant to excreta and wastewater use schemes (Feachem et al 1983).

Whether urine separation and the use of urine can be recommended depends on whether the associated health risks are considered acceptable. These risks can be balanced against benefits like the fertiliser value of human urine. Higher risks from use of waste products may be acceptable in areas where enteric disease is endemic and where it is

more often transmitted through poor hygiene and sanitation (Blumenthal et al 2000). In areas where food is scarce, benefits from larger harvests may reduce other risks such as malnutrition, which causes immunosuppression and makes the individual more susceptible to infections (Schönning 2001b).

Several investigations regarding the impact of wastewater use on the health of people have been conducted. These have often focused on parasites that are endemic in the area of investigation and that are known to be persistent in the environment (Blumenthal et al 1996).

Clear evidence of increased infection rates was found in many investigations, some of them involving irrigation with untreated or poorly treated wastewater. According to Cooper and Olivieri (1998), there are no recorded incidents of infectious disease transmission associated with use of appropriately treated wastewater, possibly because the risk is too low for detection by epidemiological methods.

Even though individual cases of viral infections theoretically could arise from handling urine, they would probably not be recognised by any surveillance system. The risk for an outbreak caused by direct contact with urine is low, since few persons are exposed, e.g. compared to a drinking water supply or recreational water (Schönning 2001a).

However, the agricultural or aquacultural use of excreta and wastewater can only result in an actual risk of infection if all of the following occur (Strauss and Blumenthal 1994):

(a) that either an infective dose of an excreted pathogen reaches the field or pond, or the pathogen multiplies in the field or pond to form an infective dose;
(b) that this infective dose reaches a human host;
(c) that this host becomes infected; and
(d) that this infection causes disease or further transmission.

(a), (b) and (c) constitute the potential risk and (d) the actual risk of infection. If (d) does not occur, the risk of infection remains potential only. The actual risks to public health that occur through waste use can be divided into three broad categories: those affecting consumers of the crops grown with the waste (consumer risk), those affecting the agricultural and pond workers who are exposed to the waste (worker risk), and those affecting populations living near to a waste use scheme (nearby population risk) (Strauss and Blumenthal 1994).

Both proponents and critics of composting toilets and similar waste use technologies agree that human health is always the primary objective of any sanitation system; it must minimise the risk of disease and be capable of destroying or isolating pathogens. Both proponents and critics also agree that well-functioning sanitation together with effective hygiene education will break the cycle of disease (Simpson-Hébert and Wood 1998). The disagreement is about the evidence establishing the safety and practicability of dry sanitation with excreta use as an everyday practice (Peasey 2000).

Dry sanitation with excreta use is promoted as an appropriate technology for communities without sewerage or plentiful water, and has been heralded as solving many of the problems associated with other sanitation systems, for example, smell, fly-breeding, groundwater pollution, short pit life, etc. However, Peasey (2000) cautions that insufficient studies have been carried out on the problems associated with using such technologies in community settings, or on documenting pathogen die-off. She states that “the enthusiasm which this sanitation technology has generated seems sometimes to have overshadowed the most important issue, of whether the end products from dry sanitation toilets *per se* in

community settings are safe to handle and use as soil conditioners and plant fertilisers." She argues further that it is essential for an assessment to be made of the efficiency of dry sanitation in community settings, and that a need exists for documentary evidence to support various claims about different storage periods for ensuring pathogen die-off and safe handling of the compost.

Discussion

Authors agree on the benefits of a good sanitation technology, but disagree on the issue of safety of using faecal material in agriculture.

2.6.3 PATHOGENIC ORGANISMS IN SANITATION SYSTEMS

(a) Introduction

Four major groups of microorganisms can be transmitted through the environment and cause infectious diseases: bacteria, protozoa, viruses and helminths. From a risk perspective the potential presence of pathogens in faeces should always be considered, since there are so many different types of enteric infections and the prevalence is unknown for the majority of them (Feachem et al 1983). In addition, fungi are capable of causing disease in humans and animals, even though only a fraction of the species is parasitic or opportunistic. Pathogens infecting the gastrointestinal tract causing diarrhoeas also have a major significance (Schönning 2001b).

(b) Urinary pathogens

Excreted urinary pathogens are of less concern for environmental transmission than are faecal pathogens. However, when using a urine-diverting toilet, there is a possibility for faecal material to enter the urine part of the bowl and thus contaminate the urine in the collecting tank. Experiments in Sweden have established that, should faecal contamination of source-diverted urine occur, six months of storage time is sufficient for the destruction of pathogenic organisms (Olsson et al 1996; Höglund et al 1998).

In a healthy individual the urine is sterile in the bladder. When transported out of the body, different types of dermal bacteria are picked up and freshly excreted urine normally contains less than 10^4 bacteria per millilitre. Pathogens that may be transmitted through urine are rarely sufficiently common to constitute a significant public health problem, and are thus not considered to constitute a health risk related to the use of human urine in temperate climates (Schönning 2001a).

Bacteria in urine

The bacterial pathogens traditionally known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi and Salmonella paratyphi*. There is a range of other pathogens that have been detected in urine but their presence is not considered significant for the risk of environmental transmission. Leptospirosis is a bacterial infection causing influenza-like symptoms with 5-10% mortality that is generally transmitted by urine from infected animals (Feachem et al 1983).

Human urine is not considered to be an important route for transmission of disease since the prevalence of the infection is low. Infections by *S. typhi* and *S. paratyphi* only cause excretion in urine during the phase of typhoid and paratyphoid fevers when bacteria are disseminated in the blood. This condition is rare in developed countries (Feachem et al 1983).

Mycobacterium tuberculosis and *Mycobacterium bovis* may be excreted in the urine, but tuberculosis is not considered to be significantly transmitted by other means than by air from person to person. *M. tuberculosis* is exceptionally isolated in nature, but has been identified in wastewater coming from hospitals (Feachem et al 1983).

Protozoa in urine

Microsporidia are a group of protozoa recently implicated in human disease, mainly in HIV-positive individuals. The infective spores are shed in faeces and urine, and urine is a possible environmental transmission route. Microsporidia have been identified in sewage and in waters, but no water or foodborne outbreaks have been documented although they have been suspected (Haas et al 1999; Cotte et al 1999).

Viruses in urine

Cytomegalovirus (CMV) is excreted in urine, but the transmission of CMV occurs person-to-person and the virus is not considered to be spread by food or water. CMV infects a large proportion of the population; 50-85% by the age of 40 was reported in USA (Schönning 2001a).

The question has been raised about the possibility of HIV transmission from an infected woman's menstrual blood where urine is collected and used as fertiliser. Discussion by the writer with a medical doctor revealed that the HI virus cannot exist outside the human body in a urine environment, so infection by this route is unlikely.

Helminths in urine

Schistosomiasis, or bilharziasis, is one of the major human parasitic infections, occurring mainly in Africa. When infected with urinary Schistosomiasis caused by *Schistosoma haematobium*, the eggs are excreted in the urine, sometimes during the whole life of the host.

Inactivation of pathogens in urine

In a urine-diversion toilet, the fate of enteric pathogens entering the urine collection container is of vital importance for the hygiene risks related to handling and use of urine. To determine the duration and conditions for sufficient storage of the urine mixture before its use as fertiliser, it is necessary to estimate the survival of various microorganisms in urine as a function of time. Studies have been performed where different microorganisms were added to the urine and their inactivation followed over time (Schönning 2001a).

However, only a limited amount of work has been undertaken on urine treatment other than storage, such as acidification, heating and evaporative concentration. Mainly temperature and elevated pH (9) in combination with ammonia have been concluded to affect the inactivation of microorganisms. Bacteria like *Salmonella* can be inactivated rapidly, whereas viruses are hardly reduced at all at low temperatures (4-5^{o}C) (Schönning 2001a).

Recommendations for the use of human urine

For single households, a urine mixture (urine and water) is recommended for all types of crops, provided that the crops are intended for the household's own consumption and that one month passes between fertilising and harvesting, i.e. time between last urine application and consumption. This approach can probably be used for any smaller system in developing countries, whereas larger (urban) systems may have to be adapted (Höglund et al 2002).

Higher ambient temperatures in many developing country settings will, however, increase inactivation rates and add in safety. One reason for more relaxed guidelines for single households is that person-to-person transmission will exceed the risk from urine related environmental transmission (Schönning 2001a).

If the ammonia content is over 1 mg/l, the pH is over 8,8 and no fresh urine is added, storage of urine for one to six months, depending on the temperature, inactivates any non spore-forming pathogens present, so the urine can then be recycled as a fertilizer to agriculture with negligible hygienic risks (Jönsson et al 1997 & 2000; Höglund et al 1998; Schönning 2001a).

Due to degradation of the urea in urine to ammonia and carbon dioxide, the environment in the soil mixture becomes toxic towards most of the microorganisms present (Höglund et al 1999; Vinnerås et al 1999). A recommendation for urine storage to attain acceptable safety limits has been developed for Swedish conditions and use of the urine as fertiliser after storage at different temperatures, to different crops and different uses of the crops produced. These recommendations vary from shorter storage times (1 month) at 4^{o}C where the urine can be used on crops that are processed before use as fodder or food, to longer storage times (6 months) at 20^{o}C where the urine can be used on all kinds of crops, even those that are consumed raw by humans (Jönsson et al 2000; Schönning 2001a). From field experiments carried out in Denmark, however, Tarnow et al (2003) found evidence of some bacterial regrowth in urine storage tanks. They furthermore found that viable and infective *C. parvum* oocysts appeared to survive in the tanks even after prolonged storage.

(c) Faecal pathogens

Faeces do not always contain pathogens. However, from a risk perspective, their presence should always be considered since there are so many different types of enteric infections and the prevalence is unknown for several of them (prevalence depends on the epidemiological situation, and we do not have the analytical capability to analyse for all the different organisms on a routine basis). To ensure a reduction of pathogens, faeces need to be treated or stored under controlled conditions (Schönning 2001b).

Bacteria in faeces

Bacteria have generally been considered as the leading cause of gastrointestinal illnesses in surveillance systems. Of these bacteria, at least *Salmonella*, *Campylobacter* and enterohaemorrhagic *E. coli* (EHEC) should be considered when evaluating microbial risks from various fertiliser products including faeces, sewage sludge and animal manure (Schönning, 2001b).

The faeces of a healthy person contain large numbers of commensal bacteria of many species. Species of bacteria found in the normal stool, and the relative numbers of different species, will vary among communities. The most widely used indicator has been the faecal coliform *E. coli*, the main constituent of the enterobacteria, enterococci (faecal streptococci), anaerobic bacteria such as Clostridium, Bacteroides and Bifidobacterium. These pathogenic or potentially pathogenic bacteria are used as indicators. They most commonly enter a new host by ingestion (in water, in food, on fingers, in dirt), but some may also enter through the lungs (after inhalation of aerosol particles) or through the eye (after rubbing the eye with faecally contaminated fingers). Diarrhoea is a major symptom of many bacterial intestinal infections. The bacteria may also invade the body from the gut and cause either generalised or localised infections (Feachem et al 1983).

This invasion is characteristic of typhoid infections and other enteric fevers caused by salmonellae. During infections restricted to the gut, bacteria will be passed only in the faeces. When invasion has occurred, bacteria may be passed in the urine as well and will also be found in the bloodstream at some stage. In areas with insufficient sanitation, cholera may occur and constitute a risk for contamination of water (Schönning 2001b).

Protozoa in faeces

Protozoan parasites are pathogens that have developed adaptations that enable them to survive for prolonged periods in the environment. Their hardiness also protects them from destruction by chemical disinfection used in drinking water production processes. The two best known protozoan enteropathogens, *Cryptosporidium parvum* and *Giardia lamblia/intestinalis*, have been studied intensively during the last decade, partly due to their environmental resistance, and have been shown to be highly infectious in humans and identified as agents for waterborne epidemics. Infectious doses are low, especially *Cryptosporidium*, and have been the cause of several large waterborne outbreaks (Schönning 2001b).

Many species of protozoa can infect man and cause disease. Among them are several species that are harboured in the intestinal tract of man and animals, where they may cause diarrhoea or dysentery. Infective forms of these protozoa are often passed as cysts in the faeces, and man is infected when ingesting them. According to Teunis and Havelaar (2002), only three species of human intestinal protozoa are considered to be frequently pathogenic: *Giardia lamblia, Balantidium coli, and Entamoeba histolytica*. *Cryptosporidium* should, however, be added to this list.

Viruses in faeces

Numerous viruses may infect the intestinal tract and be passed in the faeces, whereupon they may infect new human hosts by ingestion or inhalation. One gram of human faeces may contain 10^9 infectious virus particles, regardless of whether the individual is experiencing any discernible illness. More than 120 different types of viruses may be excreted in the faeces, the most commonly identified including rotaviruses, adenoviruses (including poliovirus), hepatitis A virus, reoviruses, enteric viruses and diarrhoea-causing viruses (WHO 1989).

Enteric viruses are now considered to cause the majority of gastrointestinal infections in developed regions. Hepatitis A has also been recognised as a pathogen of concern when applying waste to land and is considered a risk for water- and foodborne outbreaks, especially where sanitary standards are low (Schönning 2001b).

Infectivity varies considerably among different types of viruses and even among different strains of the same virus. Inactivation is a rate process, and the removal of infectivity therefore depends on both the efficiency of removal and the numbers initially present. In faeces and sewage these may be higher than 10^6 per gram and 10^6 per litre respectively (Stroffolin et al 2001).

Viruses are also present in throat secretions, especially during the early stages of infection. These particles are highly infectious and can remain viable for a considerable period under suitable conditions. Infection takes place when the virus is ingested, possibly in food or water (Feachem et al 1983).

Regarding the HI virus, the writer was informed by a medical doctor that, as with a urine environment, a faeces environment is also not conducive to survival of the virus. It is unlikely, therefore, that use of an infected person's faeces in agriculture will can to HIV infection.

Helminths in faeces

In developing countries, helminth infections are of great concern. Many species of parasitic worms, or helminths, have human hosts. Some can cause serious illnesses. Only those helminths whose eggs or larval forms are passed in the excreta are discussed here. Only *Schistosoma haematobium* is voided in the urine; others are excreted in the faeces i.e. *Ascaris lumbricoides, Fasciola hepatica*, etc (Feachem et al 1983).

The eggs of helminths like *Ascaris* are persistent in the environment, and are therefore regarded as an indicator of hygienic quality (WHO 1989). Hookworm, *Trichuris* and *Taenia* infections are also related to poor sanitation.

The study of helminth egg contamination is very important, as they are found in great concentrations in sewage sludge and are very resistant to most treatment processes. Their presence is associated with sanitary risks when sludge is used as an agricultural fertiliser, and processes that are able to eliminate this contamination need to be understood (Asaolu and Ofoezie 2003).

Human helminth infections are a major cause of morbidity and mortality, and are the hardiest of the pathogens of interest in faecal matter intended for handling and use. Ascariasis is one of the most common helminthic infections globally (Feachem et al 1983).

Inactivation of pathogens in faeces

Inactivation of pathogens in faeces is a more complex issue than for urine, due to varying conditions regarding moisture, climatic factors, and construction of the sanitation system, e.g. how well the urine is diverted and whether anal cleansing is practised. During faeces collection, the addition of other material such as ash or lime also needs to be considered, as it may increase the die-off rate of pathogens. The alkalinity of different types of ashes varies, however, and it may be difficult to predict the final pH and related pathogen inactivating effect (Schönning 2001b).

Recommendations for the use of human faeces

These are fully described in section 2.6.6 hereafter.

d) Discussion

Authors are in agreement that pathogens that may be transmitted through urine are rarely sufficiently common to constitute a significant public health problem and are thus not considered to constitute a health risk related to the use of human urine in temperate climates. The inactivation of urinary pathogens in the environment reduces their ability for transmission. Faecal pathogens, however, are much more difficult to inactivate and usually require special measures to be taken, as they can be a major public health concern.

2.6.4 TRANSMISSION ROUTES OF PATHOGENS

Health hazards associated with excreta use are of two kinds: the occupational hazard to those who handle the excreta, which is direct through different means of person-to-person contact, and the risk that contaminated products from its use may subsequently infect humans or animals through consumption or handling, which is indirect and includes vehicle-borne (food, water etc), vector-borne, airborne long-distance and parenteral transmission (injections with contaminated syringes) (Schönning 2001b).

In developing countries especially, excreta-related diseases are very common, and the excreta thus contain high concentrations of pathogens that cause disease in man. Pathogenic organisms enter the human body orally by a number of transmission routes, as illustrated in Figure 2.39.

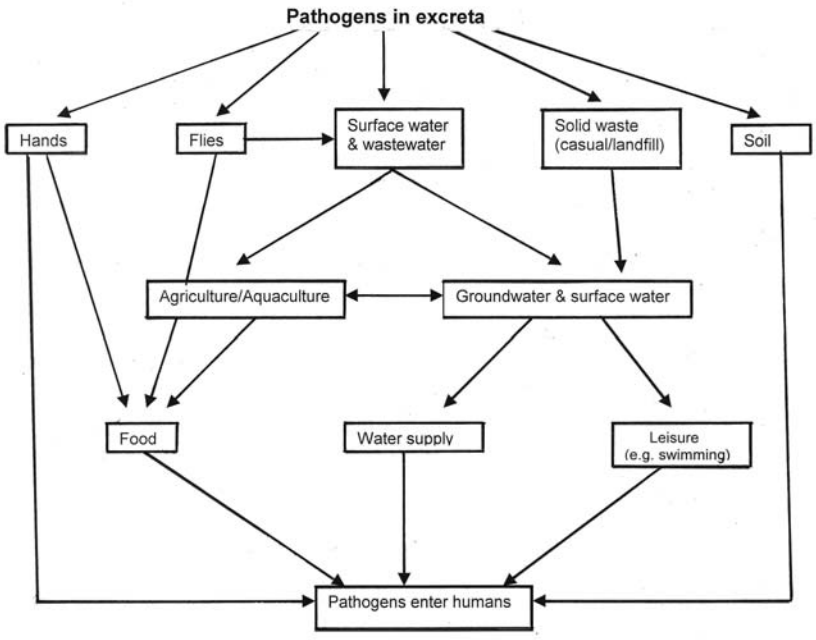


Figure 2.39: Transmission routes for pathogens found in excreta
(Franceys et al 1992).

It should be noted that poor domestic and personal hygiene, indicated by routes involving food and hands, often diminishes or even negates any positive impact of improved excreta disposal on community health (Feachem et al 1983).

Higher incidences of enteric infections in the population have been recorded in epidemiological investigations in areas where wastewater was used on crops (Cifuentes 1998; Bouhoum and Amahmid 2000). Foodborne outbreaks caused by wastewater irrigation of vegetables and fruits have also been documented (Yates and Gerba 1998).

Risk assessments have also evaluated the increased risk from wastewater-irrigated crops. Irrigation with wastewater on crops used for energy or industrial purposes may be safer, but still involves risks for transmission of disease to humans and animals in the surroundings and transport of pathogens to the groundwater (Carlander et al 2000).

The handling and use of all types of insufficiently treated waste products with human or animal origins involve hygiene risks. Whether human excreta (faeces and urine) are used directly, diluted in wastewater (treated or untreated) that is used, or are a constituent of sewage sludge used in agriculture, enteric pathogens will be present and able to cause infections by ingestion of waste products or by consumption of crops that have been fertilised. Cysts and oocysts of protozoa and helminth ova are considered to be of great public health concern since they remain viable for extended periods outside their human host. Viruses have received attention due to low infective doses and difficulties in analysing their presence in waste products (Schönning 2001b).

Many infections, in excess of fifty even if the different numbered types of viruses and serotypes of enteric bacteria are ignored, are transmitted from the excreta of an infected person to the mouth of another. The disease-causing agents (the pathogens) of these infections travel from anus (or rarely, bladder) to mouth by variety of routes sometimes directly on contaminated fingers and sometimes on food, utensils, in water, or by any other route that allows minute amounts of infected excreta to be ingested. Human excreta are the principal vehicle for transmission and spread of a wide range of communicable diseases. Some of these diseases rank among the chief causes of sickness and death in societies where poverty and malnutrition are common (Feachem et al 1983). Diarrhoeas, for instance are, together with malnutrition, respiratory disease and endemic malaria, the main causes of death among small children and infants in developing countries. Cholera, whether endemic or epidemic in form, is accompanied by numerous deaths in all age groups, although under endemic conditions it is children who suffer the most fatalities. Therefore the collection, transport, treatment and disposal of human excreta are of the utmost importance in the protection of community health everywhere (Strauss and Blumenthal 1994).

Discussion

Good personal and food hygiene are of great importance for people who are involved with handling and using excreta in agriculture.

2.6.5 SURVIVAL OF MICROORGANISMS IN THE ENVIRONMENT

(a) Introduction

The ability of a microorganism to survive is defined as its persistence. The persistence of microorganisms in the environment is a field that has been widely investigated (Feachem et al 1983).

As the death (inactivation) and survival of excreted pathogens is an important factor influencing transmission, these organisms should be destroyed or otherwise rendered harmless. In principle, pathogens die off upon excretion, as environmental conditions outside the human host are generally not conducive to their survival. Prominent exceptions are pathogens whose transitional stages multiply in intermediate hosts such as *Schistosoma* (Strauss and Blumenthal 1994). Stenström (2001) states that exposure to faecal material always constitutes a health risk, and that minimisation of direct contact is of prime importance for preventing disease transmission.

Also, some viruses, although they cannot multiply outside a suitable host cell, may survive for many weeks in certain environments, especially where temperatures are cool (less than 15^{o}C). Another important factor is the infective dose of pathogens, i.e. the dose required to create the disease in a human host. For helminths, protozoa and viruses, the infective dose is less than 10^2, while for bacteria it is medium to high (between 10^4 and 10^6) (Feachem et al 1993).

From the time of excretion, the concentration of enteric pathogens usually declines by the death or loss of infectivity of a proportion of the organisms. Protozoa and viruses are unable to grow in the environment, thus numbers will always decrease, whereas bacteria may multiply under favourable environmental conditions (Feachem et al 1983).

Multiplication of bacterial pathogens is generally rare, however, and is unlikely to continue for very long. Intestinal helminths except the trematodes, which have a multiplication phase in their molluscan intermediate hosts, will decrease in numbers following excretion. The natural death of organisms when exposed to a hostile environment is of the utmost importance because it reduces the infectivity of excreta independently of any treatment process. Some treatment processes have little effect on excreted pathogens and simply allow the necessary time for natural die-off to occur. Other treatment processes create conditions that are particularly hostile to excreted pathogens and promote their rapid death. The effects of activated sludge on faecal bacteria, or of thermophilic digestion on all organisms, are of this kind. The essential environmental factors in limiting pathogens' persistence are time and temperature (Feachem et al 1983).

The success of a given treatment process in reducing the pathogenicity of an effluent or sludge thus depends in general upon its retention time and its creation of an environment especially hostile to particular organisms. The sole environmental condition likely found in a nightsoil or sewage treatment system that is most fatal to all pathogens is raised temperature (in the range 55-65^{o}C). The only other low-cost process that causes virtually 100% removal of pathogens is the waste stabilization pond system with its long retention times, exposure to sunlight, and good sedimentation properties. The rate of loss of infectivity of an organism also depends very much on temperature, because most organisms survive well at low temperatures (5^{o}C) and rapidly die at high temperatures (more than 40^{o}C). Except in sludge or nightsoil digestion processes, temperatures approximate environmental temperatures in most developing countries, generally in the range of 15-35^{o}C and commonly 20-30^{o}C. It is therefore useful to know the persistence of pathogens at ambient temperatures in different environments, so that the likely risk of using various faecal products can be predicted (Strauss and Blumenthal 1994).

The influence of the type of dry sanitation system used, and the local climatic conditions experienced, has been examined by Redlinger et al (2001a). In field trials carried out in north-central Mexico, where the climate is hot and dry, they found that urine diverting dehydrating toilets produced faecal material with a lower pathogenic content than non-

urine diverting biodegrading (composting) toilets. The authors pointed out that the environmental setting was a key factor in the dehydration process, since with a year-round dry climate, moisture levels in the faecal pile were lower than what would be expected in, for instance, humid, tropical environments. Also, the composting toilets could not perform well (in terms of pathogen inactivation) since the faecal pile rapidly lost moisture to below the critical level required to support microbiological growth.

Moe and Izurieta (2003) describe a study that was carried out on urine-diverting toilets in El Salvador (118 households with double vault urine-diverting (DVUD) toilets and 38 households with single vault solar-heated urine-diverting toilets in seven rural communities). In both types of toilets, pH was found to be the most important single factor determining the inactivation of bacterial indicators and coliphages, while temperature was the strongest predictor of *Ascaris* die-off. The most rapid inactivation of faecal coliforms, *C. perfringens*, somatic coliphage and *Ascaris* occurred when pH was ≥11 and daytime peak temperature was ≥36^{o}C. Due to the fact that faecal pile peak temperatures in the DVUD toilets were typically only 1 degree higher than the ambient temperature (average 31^{o}C), these toilets were found to have very little impact on *Ascaris* inactivation. In contrast, peak faecal pile temperatures in the solar toilets varied between 37^{o}C and 44^{o}C, which resulted in no viable *Ascaris* being found. However, the DVUD toilets produced better inactivation of faecal coliforms, *C. perfringens* and coliphage, which was thought to be because of the longer average vault storage time compared with the single-vault solar toilets. The authors concluded that, in the humid climate where the study was carried out, pH and peak temperature were the most important factors affecting the microbial quality of biosolids in both types of toilets. However, they stated that double-vault toilets with long storage times (i.e. large vaults) and good solar exposure yielded the best quality (fewer pathogens) biosolids overall. They also recommended that additives to raise pH levels in ecosan toilets should be strongly recommended, and added that improvements in ecosan toilet design and operation should provide a safer biosolids product for agricultural use.

Environmental factors of importance in the die-off rate of pathogens are high temperature, low moisture content and time. A high temperature, especially, is the most important consideration as all living organisms, from the simplest to the most complex, can survive at temperatures only up to a certain level. Above that level they perish. Regarding moisture content, all biological activity comes to a halt at moisture contents of 12% or less, although the process would be disastrously slowed long before that that level was reached. Generally, moisture content begins to be a limiting factor when it drops below 35 to 40%. Also time *per se* does not kill the microorganisms; rather, it is the continued exposure to an unfavourable condition that does the job (Golueke 1976). A further important factor is pH. The pH limits for the survival of *E. coli*, for example, are between 4,4 and 9,0, with the optimum between 6,0 and 7,0. In general, pH values greater than about 9,0 are detrimental to all microbial growth (Prescott, Harley and Klein 1990). In support of these observations, Peasey (2000) notes that the two most influential factors seem to be the pH of the faeces pile and the storage or resting time. The more alkaline the pile and the longer it is stored, the greater the percentage reduction in pathogens.

(b) Physiochemical and biological factors that affect the survival of pathogens in excreta and excreta use systems

Different factors affecting the inactivation of pathogens in the environment include temperature, pH, moisture, and competition from naturally occurring microorganisms. To obtain a fertiliser product from excreta that is safe to use, it is possible to apply treatment methods utilising any of these parameters in combination with time (Schönning 2001b).

Temperature

Most microorganisms survive well at low temperatures (5°C) and rapidly die at high temperatures (more than 40°C). This is the case for different types of media including water, soil, sewage, and crops (Feachem et al 1983).

To ensure inactivation in e.g. composting processes, temperatures around 55-65°C are needed to kill all types of pathogens (except bacterial spores) within hours. The hardiest organisms are cysts of *Entamoebae histolytica*, *Ascaris* eggs and *Mycobacterium tuberculosis*. Viruses such as bovine parvovirus and *Salmonella typhimurium* phage 28B are also considered to be heat resistant. Temperature effects might especially be of concern in temperate regions where the temperatures are quite low during a large part of the year (Schönning 2001b).

For safety reasons it would be preferable if all pathogens were killed. However, it is not possible to secure total die-off, but only to determine a state where no viable organisms can be determined. If the conditions are changed, there is a risk for regrowth of pathogenic bacteria, even if only one single bacterium survives (Vinnerås 2002).

The organic material in faeces can be used to generate heat for thermal treatment. This has the advantage that when the material is degraded it is stabilised, and the risk for regrowth of organisms then decreases (Vinnerås 2002, quoting Sidhu et al 2001). The two most common treatment alternatives are incineration and thermal composting. Under aerobic conditions, microbiological digestion produces an excess of heat energy. If that heat is captured by insulating the process, either with specialised insulation material or a thick layer of organic matter, the temperature of the material may increase up to 80°C (Vinnerås 2002, quoting Haug 1993 and Epstein 1997). The composting can either be dry (approximately 35-55% dry matter content) or liquid (2-10% dry matter content). However, the moisture content of the material affects the efficiency of thermal inactivation, as heat transfer to the organisms, and thus the inactivation, is more efficient when moisture is present (Vinnerås 2002, quoting Stanbury et al 1995 and Turner 2002). Obviously, this has important implications for toilets based on dehydrating principles for storage and treatment of the faecal matter.

To attain temperatures high enough for thermal inactivation of pathogens, the heat has to be kept within the material. Some parts of the material may, however, be at a lower temperature, i.e. the surface of an open heap and, where the vault is ventilated, the area around the incoming air. In such cases the material will not have a homogenous temperature and thermal disinfection will not be complete. To get all the material treated at elevated temperatures, it has to be turned periodically so that the parts in low temperature zones are moved into high temperature zones (Vinnerås 2002).

While adding ash to the faeces is advantageous for pathogen die-off, odour elimination, fly reduction, etc, and is widely practised where urine-diversion systems are used, it also has a negative effect on heat build-up in the faecal pile. The reason is that the concentration of organic matter in the mix is decreased, which leaves less energy available to increase the temperature. To achieve sufficiently high temperatures, a high-energy amendment has to be added to the material, for example, food waste, fruit peelings, etc. The heap also has to be well insulated (Vinnerås 2002, quoting Karlsson and Larsson 2000 and Björklund 2002). When low temperature zones are present in the heap, the pathogens will not be deactivated within all the material, and there will therefore be an increased risk for regrowth in these zones. Care must therefore be exercised when handling the material, in

order to avoid direct contact. Some degree of mechanisation or automation in turning the material is advised (Vinnerås 2002).

pH

Many microorganisms are generally adapted to a neutral pH (7) even though enteric pathogens need to withstand the acidic conditions in the stomach to cause an infection. Highly acidic or alkaline conditions will have an inactivation effect on most microorganisms by the hydrolysation of cell components or denaturation of enzymes. Bacteria survival is shorter in acid soils (pH 3-5) than in alkaline soils (Feachem et al 1983). In a Vietnamese study, Chien et al (2001) found that pH was the major factor influencing pathogen destruction in faecal material. This was confirmed by Moe and Izurieta (2003) in a study carried out in El Salvador.

Moisture

Moisture content is mainly applicable to the survival of pathogens in soil and faeces. A moist soil favours the survival of microorganisms, and drying may be used as a process to sanitise excreta in dry toilets (Esrey et al 1998).

Virus survival is prolonged under moist conditions. Protozoa cysts are highly sensitive to desiccation, which may also affect their survival on plant surfaces. For *Ascaris* eggs to be inactivated, a moisture level below 5% is needed (Feachem et al 1983)

Nutrients

If nutrition is available and other conditions are favourable, bacteria may grow in the environment. Nutrient deficiencies thus only affect bacteria. Enteric bacteria adapted to the gastrointestinal tract are not always capable of competing with indigenous bacteria for the scarce nutrients available, and their ability to reproduce and even survive in the environment therefore tends to be limited (Feachem et al 1983).

(c) Contamination of soils and crops

Desiccation of faeces enhances the rate of destruction of enteric microorganisms. This greatly increases the value and manageability of the faeces as an agricultural resource, as well as reducing pollutant burdens on the aquatic environment and health hazards associated with handling. Experimental data has confirmed that dry storage of faeces for a minimum period of one year usually results in a product of substantially improved microbiological quality (Wheeler and Carroll 1989). The authors assert that even the most persistent eggs, such as *Ascaris*, are usually rendered non-viable by storage for one year at moderate temperatures, e.g. 25^{o}C.

Strauss and Blumenthal (1994) noted that temperature, dryness and UV light were important factors influencing pathogen die-off over time. When faecal sludge is applied to fields, environmental factors such as wind and sunshine come into play. Because the soil is offered a measure of protection against the elements by the leaves of the crops, pathogens tend to survive longer here than in the crops, which are more exposed (Figure 2.40).

It is possible that the product from toilets with short retention times (less than one year) carries some potential risk. The risk in epidemiological terms would depend on the extent

of exposure and susceptibility to the infection. If farmers handle the fertiliser with bare hands then, depending on hygiene practices, there is a potential for transmission of infection by the oral route. This could occur in the case of helminth infections, such as *Ascaris*. Where the fertiliser is used before or at the beginning of the growing cycle of an edible crop, and dug into the soil, there would be no risk to consumers of the crop. However, in cases where the fertiliser is used in a way that brings it into contact with the edible portion of the crop, then a risk of transmission of helminth infections to consumers could occur (Strauss and Blumenthal 1990).

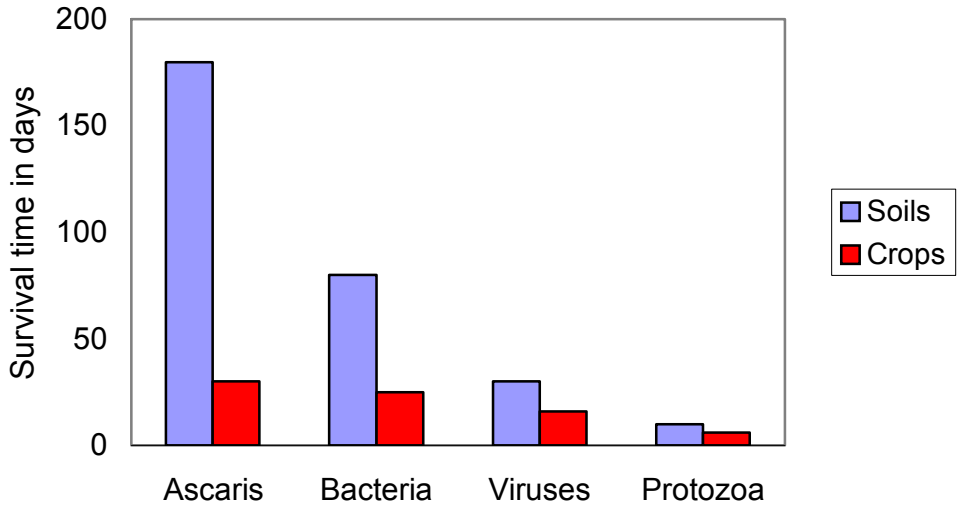


Figure 2.40: Survival times of pathogens in untreated faecal sludges applied to fields in warm climates (Strauss and Blumenthal 1994)

(d) Comparison of treatment efficiencies: dry sanitation technologies vs. conventional wastewater treatment (Stenström 2001)

Investigations were carried out in a number of dry ecosan toilets in various regions of the world in order to assess the efficiency of dry sanitation in relation to the die-off of different representatives of microbial groups. Using a target time of 6 months for storage of the faecal material, analyses were done taking into account time, temperature, pH and, where appropriate, moisture. The results are shown in Table 2.8.

Table 2.8: Reduction efficiency in dry ecosan toilets, with a storage time of 6 months and pH value of 9 or more. Values are expressed as log_{10} reductions.

Parameter	Reduction efficiency	Remarks
Bacteria (coliforms)	> 6 log	Chinese experiments
Bacteria (faecal enterococci)	4-6 log	Mexican extrapolations
Bacteriophages (index virus)	5->6 log	Chinese experiments Vietnamese experiments Mexican extrapolations
Ascaris ova (index parasite)	100%	Chinese experiments Vietnamese experiments

The most important result noted was the 100% reduction of *Ascaris* viability in the 6-month period. The author noted that shorter storage times resulted in partial reductions. Another observation was that viruses seemed to be reduced at a slower rate than the other pathogenic groups. Temperature was seen to be a major governing factor.

It was concluded that, as long as requirements of time, temperature, pH and, in certain circumstances, low moisture, were met, all the tested ecological sanitation treatment alternatives, independent of region, were superior to traditional wastewater treatment. A normally functioning conventional wastewater treatment plant (mechanical, chemical, biological treatment) will produce a reduction of only 1-3 logs of different groups of pathogens, depending on the type of organism. Traditional soil infiltration systems will give a similar result. From the results in Table 2.8, however, it is seen that a 6-month storage of dry faecal material at a pH of 9 will give at least an additional 3 log reduction, up to a total eradication of pathogens. While stabilisation ponds in tropical areas could, under optimal conditions, give a similar reduction, they are obviously heavily water-dependent.

The author cautioned that, despite the good results produced, regrowth of indicator organisms and bacterial pathogens may occur due to partial wetting that starts a degradation or localised composting, thus favouring short periods of growth. He concluded, however, that based on the investigations performed, on-site ecological sanitation treatment is a favourable and partly superior alternative to traditional wastewater treatment.

(e) Composting vs. dehydration

It is important to note the difference between composting and dehydration (these two processes are described in section 2.3.3(a)). In order to compost faeces, addition of bulk material such as wood/bark chips is needed to allow aeration. If ash or lime has been added in the collection chamber, addition of both energy rich materials such as kitchen waste and acidic material is needed for good compost. Drying or alkalifying of material should therefore not be considered as composting processes. It is known that the optimal pH for growth of bacteria and other composting organisms is in the range of 6,0 to 8,0. With alkalifying systems achieving a pH of 9 or more, the composting process is hampered (while still achieving the goal of pathogen reduction, however). Further degradation of the organic material will instead occur when it is applied to the soil (Schönning and Stenström 2004). It should also be noted that the organic content of the faecal mixture in dry urine-diversion toilets is low (~ 8%), which also restricts the composting process. In practice, composting of faeces from urine-diversion toilets can be questioned (Schönning and Stenström 2004). Only slight elevation of temperature has been recorded in some trials, probably because of insufficient insulation and the addition of ash, resulting in reduced biological degradation and heat losses (Karlsson and Larsson 2000; Björklund 2002).

Many toilets are called “composting toilets” without actually achieving a well-functioning composting process; it is rather storage and anaerobic putrefaction, desiccation or alkalisation that occurs. Unless good maintenance can be assured (which is mainly obtained in large and well-insulated composting units receiving faecal and food wastes from a large number of persons) it is questionable if one could rely on domestic-scale “composting” units as an efficient process for pathogen reduction. Composting is therefore not considered to be a first choice for primary treatment, but rather as an option for secondary treatment of faecal material at a municipal scale or level (Schönning and Stenström 2004).

In small-scale systems (household level) the faeces can be used after primary treatment if the criteria in Table 2.9 are fulfilled. These treatments, along with incineration, can be used as secondary treatment (i.e. material removed from vault and treated) at household level. Secondary treatments for larger systems (i.e. municipal level) include alkaline treatments, composting and incineration (Table 2.10) (Schönning and Stenström 2004).

Table 2.9: Suggested alternative recommendations for primary and secondary treatment of dry faeces before use at the household level. No addition of new material (Schönning and Stenström 2004).

Treatment	Criteria	Comment
Storage (only treatment); ambient temperature 2-20°C	1,5 to 2 years	Will eliminate most bacterial pathogens; regrowth of E. coli and Salmonella not considered if re-wetted; will substantially reduce viruses, protozoa and parasites; some soil-borne ova may persist.
Storage (only treatment); ambient temperature 20-35°C	>1 year	As above
Alkaline treatment	pH >9 for >6 months	If temperature >35°C and moisture <25%. Lower pH and wetter material will prolong the time for absolute elimination.

Table 2.10: Alternative secondary treatments suggested for faeces from large-scale systems (municipal level). No addition of new material (Schönning and Stenström 2004).

Treatment	Criteria	Comment
Alkaline treatment	pH>9 for >6 months	If temperature >35°C and moisture <25%. Lower pH and wetter material will prolong the time for absolute elimination.
Composting	Temperature >50°C for > 1 week	Minimum requirement. Longer time needed if temperature requirement cannot be ensured.
Incineration	Fully incinerated (<10% carbon in ash)	
Storage	As above (Table 2.9)	Time modification needed based on local conditions. Large systems need a higher level of protection than for household level. Additional storage adds to safety.

Successful use of ecosan toilets requires the users to understand the basic principles of dehydration or decomposition involved. The toilets are more sensitive to misuse than other forms of sanitation, and incorrect usage and maintenance can result in pathogens surviving the end product from the faeces pile. If storage time of the pile is too short, pathogens may still be viable, while the addition of insufficient ash, soil or lime will negatively affect moisture and pH of the pile and can result in problems with odour, fly breeding and reduced pathogen die-off. Seasonal lows in ambient temperature and increased humidity can also result in reduced temperature and increased moisture in the storage vault and consequently a reduction in pathogen die-off (Peasey 2000).

All the currently used treatment methods, except storage, are based on either temperature or pH. Other factors also affect microbial survival but are less easily controlled or measured. Biological competition with naturally occurring soil bacteria will be effective after application in the soil. However, this is not recommended as a primary treatment process due to difficulties in reproducibility. The recommendations should therefore be related to measurable parameters and conditions that, in theory and practice, are known to achieve an expected result (Schönning and Stenström 2004).

(f) Discussion

Authors agree that raised temperature, raised pH and low moisture content, in combination with time, are the main factors influencing die-off of faecal pathogens. On the other hand, localised areas of wetting or cooling in the faecal pile are seen to slow down the die-off process.

2.6.6 EXISTING GUIDELINES FOR USE OF EXCRETA

(a) Introduction

While extensive research has been carried out on use of composted faeces and sewage sludge, and various guidelines developed over the years, use of dehydrated faeces has not been investigated to the same extent. Various rules of thumb regarding storage periods do exist, but there is a paucity of detailed scientific information on the subject (Austin and Duncker 2002).

The following paragraphs give a brief outline of some existing guidelines in various countries, including South Africa.

(b) Wastewater and sludge use

In 1989, the World Health Organization published guidelines for the use of treated wastewater in agriculture (WHO 1989). For unrestricted irrigation, the recommendations were as follows:

Intestinal nematode, e.g. *Ascaris* and *Trichuris* species
and hookworms (arithmetic mean number of eggs per litre): ≤ 1

Faecal coliforms (geometric mean number per 100ml): $\leq 10^3$

These recommendations were also supported at the time by an IRCWD report (Strauss and Blumenthal 1990). The authors additionally interpreted these guidelines as including wastewater sludges, i.e.

Intestinal nematode
(arithmetic mean number of eggs per kg wet weight): ≤ 1

Faecal coliforms
(geometric mean number per 100g wet weight): ≤ 10^3

However, Heinss, Larmie and Strauss (1998) suggested that wet weight was not a good basis of measurement due to the varying quantities of solids present in sludges and slurries, and stated that permissible solids loading rates should be used instead. Consequently, these authors recommended that the guideline for nematode eggs should rather be

3–8 eggs per gram total solids (TS) based on a solids loading rate of 2–3 t/ha/yr.

A more recent study published by WELL (Blumenthal et al 2000) suggested that the WHO faecal coliform (FC) value of 10^3 per 100 ml was applicable to both unrestricted and restricted irrigation, and could be relaxed to 10^4 per 100 ml where insufficient resources existed to achieve this, as long as additional protective measures were taken. The WELL study further suggested that the nematode egg guideline of ≤1 egg per litre was still adequate to protect consumers of cultivated vegetables spray-irrigated with effluent of consistent quality and at high temperatures, but not necessarily consumers of vegetables surface-irrigated with effluent at lower temperatures. It was concluded that a guideline of 1 nematode egg per litre may be adequate where crops with a short shelf life are grown (e.g. salad crops), but that a stricter guideline of 0,1 eggs per litre should be adopted to prevent transmission of *Ascaris* infection.

In South Africa, guidelines for unrestricted use of sewage sludge are as follows (Water Research Commission 2006):

Helminth ova (viable ova per g dry sludge): < 0,25 (or 1 ovum per 4g)
Faecal coliform (CFU per g dry sludge): < 10^3 (5 log reduction)

Further restrictions are that the maximum dry application rate should not exceed 10t/ha/yr (1kg/m^2/yr), and that the application rate does not exceed the plant nutrient requirements (agronomic rate).

Latest WHO guidelines

The latest WHO guidelines for wastewater use in agriculture (WHO 2006a) employ a different approach: the guidelines are based on a tolerable burden of disease and health-based targets, rather than a number of allowable organisms as for the above guidelines. The measurement used is the Disability Adjusted Life Year (DALY).[2] The approach adopted in these guidelines focuses on risks from the consumption of food crops eaten

[2] DALYs are a measure of the health of a population or burden of disease due to a specific disease or risk factor. DALYs attempt to measure the time lost because of disability or death from a disease compared with a long life free of disability in the absence of the disease. DALYs are calculated by adding the years of life lost to premature death to the years lived with a disability. Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population (WHO 2006a).

uncooked and risks to fieldworkers from direct contact with treated wastewater, for unrestricted and restricted wastewater irrigation, respectively. The tolerable burden adopted was $\leq 10^{-6}$ DALY (1 micro-DALY) per person per year, as set out in Table 2.11 below.

Table 2.11: Health-based targets for treated wastewater use in agriculture (WHO 2006a)

Exposure scenario	Health-based target (DALY per person per year)	Log_{10} pathogen reduction needed	Number of helminth eggs per litre
Unrestricted irrigation	$\leq 10^{-6}$		
Leaf crops (e.g. lettuce)		6	≤1
Root crops (e.g. onion)		7	≤1
Restricted irrigation	$\leq 10^{-6}$		
Highly mechanised		3	≤1
Labour intensive		4	≤1
Localised (drip) irrigation	$\leq 10^{-6}$		
High-growing crops		2	No recommendation
Low-growing crops		4	≤1

(c) Faeces use

Strauss and Blumenthal (1990) report some observations made from limited data obtained from double vault urine-diversion toilets in Guatemala. While die-off of bacterial pathogens was found to be high at elevated pH, it was seen that *Ascaris* eggs were very resistant – even after storage for one year at temperatures of 17-20°C they were still found to average about 300 eggs per gram. The authors inferred that a one-year storage period was not enough to achieve low or zero egg viability within the vault at these temperatures, even though the toilet contents were dry and pH was high relative to the contents in other types of toilets.

In contrast to minimum storage periods of as little as six months that are actually implemented in some countries, Strauss and Blumenthal (1990) consequently suggested the following (Table 2.12):

Table 2.12: Recommended storage periods for dry faeces (Strauss and Blumenthal 1990)

Storage condition	Vault storage period required	
	Without subsequent sun-drying	With subsequent sun-drying
At 17-20°C average (highland, sub-tropical)	18 months	12 months
At 28-30°C average (lowland, tropical)	10-12 months	8-10 months

The authors further concluded that there is no single best strategy for health protection and that each situation requires its own specific approach. Other health protection measures, e.g. crop restriction or human exposure control, should also be considered.

Latest WHO guidelines

The latest WHO guidelines for the use of excreta in agriculture (WHO 2006b) employ a DALY approach similar to the method used for wastewater, as described earlier. Account is taken of the consumption of crops eaten raw and of risks from direct contact with treated excreta (involving involuntary soil ingestion). The health-based target is again 10^{-6} DALYs per person per year and a total faecal pathogen reduction of 8 to 9 log units for the consumption of leaf crops (e.g. lettuce) and 7 log units for the consumption of root crops (e.g. onions) is required.

2.6.7 CONCLUSIONS

Using the products of ecological sanitation toilets in agriculture can lead to a significant cost saving, as chemical fertilisers do not have to be purchased. Compared with other sewage products, source-separated urine has hygienic advantages because few pathogens are excreted through urine.

The primary aim of sanitation is to prevent the transmission of excreta-related diseases. However, with all sanitation systems there is a risk of disease transmission related to the handling of the end product. Therefore, even a well functioning system could enhance pathogen survival and lead to an increased risk of disease transmission for those handling the end products or consuming crops fertilised with them. A greater understanding of pathogen die-off in dry toilets is required where handling and/or use of excreta is expected.

Relying on treatments recommended for excreta is a simpler method of ensuring hygienic safety than monitoring by the analysis of microbiological parameters. Urine should be stored before use as fertiliser. The recommended period of storage is dependent on the temperature and on the crops to be fertilised. For faeces, different treatment options are possible for ensuring a hygienically safe fertiliser product.

Further research, especially concerning inactivation of microorganisms in faeces during different conditions, and risk assessments of sanitary systems, would be valuable for establishing guidelines on handling and using faeces in a safe manner. Urine may, however, be generally considered to be a more hygienic fertiliser than faeces, and considering its larger content of nutrients, it may be recommended for use in most settings.

2.7 OVERALL CONCLUSIONS FROM THE LITERATURE REVIEW

There is a vast amount of literature on pollution of water resources, particularly on problems caused by inadequate sanitation provision or, where sanitation exists, by poor implementation practices, operation and maintenance. All kinds of traditional sanitation technologies are subject to misuse, breakdown, blockage, leakage, stormwater damage, etc, and, as such, have been the cause of widespread environmental damage in many countries. While on-site technologies have been blamed for much of this damage, the problem is not confined to these situations only, or to any one particular type of sanitation system. Full waterborne systems are usually considered to be “top of the range” and the automatic choice for most people, yet they are possibly the most fragile sanitation technology, requiring adherence to strict design, operation and maintenance procedures, from the toilets up to the treatment plants. For various financial, technical and social reasons, as well as lack of capacity in many local authorities, these systems have had many adverse environmental impacts. However, where implementation practices have been deficient, even robust on-site systems have failed. The problem is often exacerbated where sanitation systems depend on water for their operation. The difficulties are usually related to socio-cultural, educational and institutional issues.

An increasing awareness worldwide of the environmental issues associated with sanitation has led to the development of ecological sanitation technology. This technology is not really new, being rather a refinement of an ancient practice. It has been promoted for environmental reasons, as well as for issues such as water conservation, recycling of nutrients to arable land, easy operation, negligible maintenance costs, dignity and convenience. It represents a conceptual shift in the relationship between people and nature. The toilets are dry (meaning that no water is required for their operation) and may work by either dehydration or decomposition, and may be single- or double-vault. Dehydrating toilets make use of the principle of urine diversion. In its broadest sense, ecological sanitation can include all organic material generated in households, such as kitchen and food wastes, as well as greywater treatment and rainwater harvesting. Ecological sanitation (ecosan) has been implemented successfully in many countries and regions in various stages of development, and among communities of different socio-economic strata, religions, cultures and practices.

While the management of urine-diversion systems requires a higher level of commitment from users than do other forms of dry sanitation, such as VIP toilets, the requirements are not particularly onerous. Some handling, at household level, of urine and faeces is, however, required. With good design and construction, and also proper operation of the toilets, these duties can be minimised. The people that plan, design and build the toilets need to fully understand the basic principles involved and how they relate to local conditions, otherwise inappropriate selection of options may be made. Appropriate social interventions in the form of promotion, support, education and training are also prerequisites for successful implementation.

Human excreta are usually easier to handle when urine and faeces are kept separate, as in urine-diversion toilets. Urine may be handled in various ways. If its use is not desired, it may simply be led into a shallow soakpit. Alternatively, if collection is required, it may be done either by each household individually or by means of a communal system. Guidelines exist for hygienic storage and agricultural use of urine.

Faeces need to be sanitised as far as possible within the toilet vaults in order to facilitate safe removal and further handling, especially where their use as a soil conditioner is required. Various methods can be employed to ensure this, including the use of additives

such as ash, lime, sawdust, dry soil, etc, as well as the judicious use of heat-absorbent building materials, ventilation, moisture control and storage. Further treatment, e.g. by secondary composting, may still be required, depending on the particular circumstances. Good operation and management is, however, the most important obligation.

Human excreta, especially urine, are excellent fertilisers and soil amendments, and their efficacy has been proved in many countries, under a variety of climatic conditions. Many researchers and practitioners view ecosan as a means of returning essential nutrients such as nitrogen, phosphorus, potassium, etc. to the fields where the consumed crops were grown and harvested. As such, excreta should be regarded as a valuable resource, not simply as a waste product destined merely for disposal. In this way, both sanitation and agricultural practices can be made more sustainable. However, it is recognised that excreta contain both valuable nutrients and pathogenic organisms, and that a measure of diligence is required in their treatment and subsequent use in order to avoid disease transmission and environmental damage.

In ecological sanitation, various environmental factors play a role in the treatment of excreta. In urine-diversion toilets, the urine is generally regarded as sterile if it has not been contaminated by faecal pathogens. If contamination has occurred, six months of storage at 20^{o}C is regarded as sufficient to render the pathogens inactive. Faeces, however, require the application of other treatment protocols in addition to storage, as the inactivation of faecal pathogens is a far more complex issue. It is necessary to create conditions inside the storage vault that are hostile to the continuing survival of pathogens, e.g. heat, dehydration and increased pH. To obtain a fertiliser product that is safe to use, it is necessary to apply treatment methods utilising any of these parameters (or a combination) together with storage time. The design and operation of the toilets are of cardinal importance in attaining the required hostile conditions inside the vaults.

Poor handling practices may also result in infection from faeces, and it is therefore essential that persons emptying the vaults and disposing of the products exercise the necessary caution. Good agricultural practices are also encouraged, in order to ensure that faeces do not come into contact with the edible portions of crops. Adequate education and hygiene awareness campaigns in communities receiving ecosan toilets are therefore a prerequisite for the maintenance of public health.

Despite much research having been carried out on inactivation of faecal pathogens in ecosan toilets, differences of opinion still remain on the minimum storage periods and storage conditions required to ensure safety for handling and use of faecal material. Further research is required in order to establish practical guidelines on the best designs and management methods for achieving these conditions in the vaults, which can be used with confidence in all types of settings.

CHAPTER 3
PROBLEM STATEMENT

3.1 CONCLUSIONS FROM THE LITERATURE REVIEW (CHAPTER 2) RELEVANT TO THIS THESIS

From the literature review in chapter 2, a number of important points are of relevance to the further development of this thesis. These are summarised in the following paragraphs.

The primary aim of sanitation is to prevent the transmission of excreta-related diseases. However, with all sanitation systems there is a risk of disease transmission related to the handling or use of the end product. Therefore, even a well functioning system could enhance pathogen survival and lead to an increased risk of disease transmission for those handling the end products or consuming crops fertilised with them. A greater understanding of pathogen die-off in dry sanitation systems is required where handling and/or use of excreta are expected.

Relying on treatments recommended for faeces is a simpler method of ensuring hygienic safety than monitoring by the analysis of microbiological parameters. Different treatment options are possible for ensuring a hygienically safe fertiliser product. Further research, especially concerning inactivation of microorganisms in faeces under different environmental conditions, would be valuable for establishing guidelines on handling and using faeces in a safe manner.

The discussion in the literature review showed that pathogen destruction in dry sanitation systems, particularly in the vaults of urine-diversion (UD) toilets, is mainly dependent on storage time, pH, temperature, humidity, moisture content, organic content of the faecal material, and type of bulking agent added. With these types of systems, some handling of faecal material will always be necessary, not just to empty the vaults and dispose of the material, but also in cases where it will be used for agricultural purposes. It is thus of utmost importance to ensure that the material is safe to handle. This implies that the primary treatment in the vault should, as far as possible, ensure the required level of safety.

While much research has been carried out internationally into pathogen destruction in the vaults of UD toilets, the same cannot be said of South Africa. There is also a wide range of results and conclusions, with recommended storage times varying from six months to two years. There is currently a variety of design and construction methods in this country, and also a number of different types of prefabricated commercial systems on the market. Many of these have been seen to be deficient in various respects, and very often communities are not sufficiently instructed in the proper operation of the toilets. The result is that the country is littered with thousands of poorly conceived and implemented UD toilets. It is also evident that safety aspects of excreta handling have not been given sufficient thought, with vault designs that do not allow sufficient storage space or where the faecal material is very difficult to remove, for example. Design and operational

guidelines are required in order to assist practitioners in these and other respects. Proper regulation of project implementation, which is currently lacking, is also necessary to ensure a uniform (high) standard of toilet design and construction, as well as safe management of excreta, especially faeces. The lesson that has been learned with the proliferation of the prefabricated commercial UD toilets is that there has been too much emphasis on a “quick solution” rather than quality.

While the current (July 2007) number of UD toilets in South Africa is estimated to be more than 60 000, the technology is yet to be generally recognized and accepted by many local authorities and communities. With various examples of poor implementation in evidence, a single outbreak of gastro-intestinal illness in an area served by these toilets will be sufficient to tarnish the image of a basically good sanitation technology. It is essential to gather more information concerning the safety of handling faecal material collected from the toilet vaults, so that sound recommendations can be made concerning optimum vault size, storage period, etc. in order to ensure that the material is safe to handle and either dispose of or use for agricultural purposes.

Sound management practices could play an important role in reducing the health risks involved in emptying the vaults of UD toilets and the disposal or further use of faecal material. From the public health viewpoint, it is necessary to reduce, as far as possible, the risk of handling faecal material. To do this, a better understanding of the factors influencing pathogen die-off in the vaults is required.

Ecological sanitation faces specific challenges to counteract pathogen transmission in the handling of faecal material and in its use on agricultural land for food production. With dry handling of the faeces, as in UD systems for example, primary treatment has moved to the household instead of being part of a centralised system. This is an important difference from a barrier perspective. To ensure the necessary safety against pathogen transmission, therefore, it is essential to have simple installation, handling and management guidelines (Jenssen et al 2004).

However, there is still very little agreement on the actual storage period required in order to achieve the reduced pathogen limits required by e.g. the South African guidelines. No research at all has been carried out in South Africa on this subject. Implementing agencies engaged in UD sanitation projects, and in particular the technical and social staff involved, need to be aware of the specific design and operation criteria for UD toilets, not only where use of faecal material for crop growing is proposed but also for routine handling and disposal of the material. There is currently a lack of awareness of the important issues in South Africa, and information and guidelines on UD toilet design and operation are urgently needed by practitioners.

3.2 FOCUS OF THIS THESIS

The focus of this thesis, therefore, is to investigate the efficacy of various methods aimed at enhancing pathogen destruction in the vaults of UD toilets, with the aim of (a) establishing the best combination of factors/methods, in particular the vault storage period required, and (b) producing guidelines for the construction, operation and regulation of these systems. The various factors influencing pathogen die-off have been set out earlier in this thesis and these will be examined in more detail using actual faecal material extracted from working UD toilets. The overall purpose of the research is to establish safety criteria for handling of faecal material from UD toilets. Urine will not be considered any further as its relative safety for handling and agricultural use has been established.

The above investigation into pathogen die-off in UD toilet vaults is fully detailed in chapter 5. It is preceded, in chapter 4, by a description of an agricultural field trial carried out with the purpose of establishing the pathogen uptake by spinach and carrots grown in soil amended with ecosan biosolids. This trial was carried out to establish whether there is a risk of contamination of certain food crops when using unstabilised faecal material. The guidelines referred to are contained in chapter 6.

CHAPTER 4
FIELD TRIALS: MICROBIOLOGICAL EFFECTS ON FOOD CROPS FERTILISED WITH FAECAL MATERIAL FROM URINE-DIVERSION TOILETS

4.1 INTRODUCTION

One of the advantages of ecological sanitation is that faecal material can be advantageously applied to soils (Esrey et al 1998). At present, however, faecal material from urine-diversion (UD) toilets in South Africa has not been classified in the current South African norms (WRC 2006). Considering the widespread use of urine-diversion technology in South Africa, it has become important to assess the possible uses or acceptable disposal methods of the faecal material produced, and for that reason information concerning the quality of this material and of its effects under different management options is important.

This chapter is based largely on chapter 3 of the Water Research Commission (WRC) publication entitled "*Use of human excreta from urine-diversion toilets in food gardens: agronomic and health aspects*" (Mnkeni et al 2006). This publication emanated from the WRC project number K5/1439 entitled "*Strategy for the furtherance of knowledge and good practice of ecological sanitation (ecosan) technology in South Africa*." The writer was the overall project leader and also co-author/editor of this particular chapter.

4.2 BACKGROUND AND PURPOSE OF INVESTIGATION

Urine-diversion sanitation technology involves the storage of faeces in dry conditions that inactivate the microorganisms to such an extent that a safe soil conditioner is produced (Esrey et al 1998). When applied to land, this material increases agricultural yields (Esrey et al 1998; Austin and Duncker 2002, Kouraa et al 2002), because human excreta contain organic matter, phosphorus and nitrogen compounds that are essential plant nutrients. The use of dry human excreta is not new. It was documented in the 12th century in China (Schönning 2001c) and until the second half of the 19th century in Finland (Olsson 2001). Because this material originates in toilets based on the principle of separating urine from faeces, it dehydrates quite rapidly. Compared to traditional latrine sludge (and even to sludge produced in conventional wastewater treatment systems) faecal material from urine-diversion toilets displays a lower moisture content that contributes to microorganism inactivation (Esrey et al 1998; Schönning 2001b).

Recycling excreta to soils reduces the need for chemical fertilisers; however, pathogens are recycled to humans if improper agricultural practices are followed (Höglund 2002). Concerns about using faecal material include higher pathogenic content in developing countries compared to that in developed countries (Jimenez et al 2002 & 2004). This material, as well as that from other sanitation alternatives in small-scale systems, demands more personal involvement from the users (including handling of the waste),

which constitutes a higher human exposure level compared to that from conventional piped systems. Nevertheless, it is considered that where the material can improve agricultural productivity, it can contribute to improving the nutritional status of the population, thus improving public health (Höglund 2001; IWMI 2003). According to Peasey (2002), although ecosan technology is spreading all over the world, and with it the recycling of excreta to soils, only a few researchers have addressed the problems associated with the revalorization practice or documented the pathogen die-off. Moreover, little data about the microbial quality of ecosan faecal material from developing countries (where the health risks are the highest) are available. The objective of this research was thus to investigate the potential health risks of using faecal material in agriculture by determining the pathogen uptake on the surfaces of the edible portions of the crops.

4.3 METHODOLOGY

A 25kg composite sample of dry faecal material mixed with some topsoil was collected from the main heap of UD faecal material in eThekwini (described in chapter 5 of this thesis). This material had been extracted from UD toilets and left in a heap exposed to the elements for four months. For microbial characterisation, four bacteria, one fungus as well as helminth ova were measured. Total coliforms were measured due to their presence in faeces, faecal coliforms and faecal *streptococci* because they are considered as good indicators of faecal pollution by most authors (e.g. Feachem et al 1983) and S*almonella spp* because they are often considered in sludge regulations. For fungi there is not a universal indicator; *Aspergillus spp.* were used because they are opportunistic pathogens belonging to a group of moulds that is found worldwide. Finally, helminth ova were monitored due to their high persistence in the environment and because they are considered as quality indicators for most faeces use practices. The most important health effects associated with helminth infections are anaemia (hookworm), rectal prolapse (*Trichuris*) and intestinal obstruction and malnutrition (*Ascaris*). *Ascaris* and *Trichuris* alone infect over one third of the population in developing countries (WHO/UNICEF 2000). Helminths are commonly associated with sanitary risks when sludge is used as an agricultural fertilizer (Asaolu and Ofoezie 2003).

To analyse total coliform, faecal coliform, faecal *streptoccoci*, *Aspergillus spp.*, *Salmonella spp* and helminth ova, serial dilution techniques as described below (4.3.1 – 4.3.4) were used (Islam et al 2004 & 2005):

4.3.1 Total coliform, faecal coliform and faecal *streptococci*

1g of faecal material was added to 9ml of sterile buffered peptone water solution and vortexed for 10s using an aseptic technique. 10^{-1} to 10^{-10} dilutions were made. 0,1mℓ aliquots were plated on three selective media, i.e. m-Endo agar, m-Enterococcus agar (37°C) and m-Fc agar (44°C) in triplicate. The plates were incubated at 37°C and 44°C for 24h. After 24h the numbers of typical colonies were recorded; the colonies were identified by form and colour.

4.3.2 *Aspergillus spp*

Fungi were enumerated by serial dilution in sterilised ¼ strength Ringer's solution. 1g of faecal material was added to 9mℓ of the solution and 10^{-1} to 10^{-10} dilutions made. Rose-

bengal agar amended with 0,1mg streptomycin-sulphate per mℓ was used to enumerate the fungi. The plates were inoculated with 100µℓ of each dilution (three plates per suspension) and incubated at 25°C for 2 to 4 days.

4.3.3 *Salmonella spp*

1g of faecal material was added to 9mℓ buffered peptone water and vortexed for 10s. 10^{-1} to 10^{-5} serial dilutions were prepared and incubated at 37°C for 18 to 24h. 0,1mℓ of the mixture was transferred to 10mℓ Rappaport-Vassiliadis (RV) enrichment broth and incubated at 37°C for 24h. The broth was sub-cultured by spreading 0,1mℓ onto plates of Xylose-Lysine-Desoxycholate XLD) agar and incubated at 37°C for 24h. Occurrence of black colonies suggested the presence of *Salmonella*.

The technique used for *Salmonella* was replaced during the second phase of the study with a standard technique (APHA, AWWA, WEF 1995). TS (total solids), pH, and nitrogen were also determined using standard techniques (APHA, AWWA, WEF 1995).

4.3.4 Helminth ova

For helminth ova (HO) detection the Ayres technique modified by Maya, Jiménez and Schwartzbrod (2006 – in press at the time the experiment was performed) was used. This was preceded by adding 200mℓ of 0,01% tween solution (a mild detergent) to 30g spinach and carrot samples in a sterile bag and pummelling in a stomacher lab-blender 400 for 1h. Once the helminth ova were enumerated the viability was determined by incubating the sample at 26°C for 3-4 weeks. The viability (larva formation) was observed under a microscope.

4.3.5 Procedure

Analyses were performed to characterize the following:

- the faecal material prior to its application;
- the soil before sowing and after harvesting;
- the irrigation water during the study; and
- the crops after harvesting.

These analyses were performed for the purpose of establishing the measurable microbial effects of the faecal material and irrigation water on the natural soil, as well as the microbial effects on the crops themselves.

To assess the microbial effects of the faecal material in agriculture, two kinds of crops were selected, namely spinach and carrots. These crops were considered because they are eaten everywhere in South Africa, are often consumed raw, and for spinach the edible parts grow above the ground, while for carrots they grow below the ground. 2m x 9m plots at the experimental farm of the University of Pretoria were used (Figure 4.1). Each crop was planted in two plots, one being used as control while the other was divided into three sections. Each plot was treated with a different application rate of faecal material, except for the control plot where no faecal material was added (negative control).

Figure 4.1: Spinach and carrot crops at the University of Pretoria's experimental farm, January 2005

To determine the amount of faecal material to be added, the following criteria were taken into account:

- the nitrogen demand of crops (50kg N/ha for carrots and 100kg N/ha for spinach);
- application rates above and below 8t/ha, which is the maximum permissible value in South Africa; and
- three different helminth ova rates.

Following these criteria, the material was applied on carrots at 0; 7; 12,5 and 35t/ha (tons per hectare) corresponding to 0; 1; 1,7 and 4,8 HO (helminth ova)/cm^2, while for spinach 0; 1,3; 19,0 and 37,5t/ha equivalent to 0; 0,18; 2,6 and 5,1 HO/cm^2 were used.The helminth rate was defined as the quantity of total helminth ova applied per square centimetre. The material was mixed to a depth of 100mm. Seeds were planted to a depth of 50mm in the second week of November 2004 (summer). The pattern within the blocks was in rows 300mm apart and the seeds were spaced 50mm apart within the rows. Spinach was harvested in January 2005 (after 7 weeks) and carrots in March 2005 (after 12 weeks). In each case, the whole plant was pulled from the soil and cut to collect roots and leaves separately. For faecal material and soil analyses 1g samples were used. To analyse bacteria and fungi, 5g of crop samples were taken, while for helminth analyses the sample size was 30g.

4.4 RESULTS AND DISCUSSION

4.4.1 Characterisation of faecal material (Table 4.1)

While the TS content was high (43 ± 2%) and hence the moisture content low, the N content (0,2 - 0,34%) was within the common range for domestic sludges (0,2 - 0,6%) if the N contribution that would have been due to urea was subtracted (90% of the value according to Metcalf and Eddy 2003). The N content was low compared with other sludges, however, and this implied that higher quantities of material needed to be added

to fulfil the nutrient demand of the crops. This would not have been important if the material had no microbial content, but this was not the case.

Regarding helminths, the value found (29,8 ± 2,9 total helminths/gTS) indicated that the concentrations were not as high as could be expected for sludges from developing countries (ranging from 67 to 735 ova/gTS according to Jiménez and Wang 2005) and were even comparable to those obtained from anaerobic digester sludges in South Africa (2 to 40 *Ascaris*/gTS according to Snyman and van der Walt 2003). However, the faecal material had already been stored in a heap exposed to the weather for about four months, which accounted for much of the pathogen die-off that had already taken place.

Table 4.1: Faecal material characterisation

Parameter	Mean value (n=3)
N content, %	0,2 - 0,34
Total coliforms, CFU/gTS	$2{,}2x10^{6}$
Aspergillus spp, CFU/gTS	$3{,}9x10^{3}$
Faecal *streptococci*, CFU/gTS	$2{,}1x10^{6}$
Faecal coliforms, CFU/g TS	$1{,}8x10^{6}$
Salmonella spp, CFU/gTS	$2{,}2x10^{5}$
Total *Ascaris*, ova/gTS	25,3 ± 4,4
Total helminths, ova/gTS	29,8 ± 2,9
Viability of helminths, %	88,8 ± 0,5

Table 4.2: Original soil characteristics

Parameter	Mean value (n=3)
pH	7,7 ± 0,21
TS content (moisture)	86% ± 2 (14 ± 2)
Total coliforms	$8{,}1x10^{3}$ - $2{,}7x10^{5}$
Faecal *streptococci*	0, absent
Faecal coliforms	$2{,}6\ x10^{3}$ - $1{,}1x10^{4}$
Salmonella spp	0, absent
Aspergillus spp	0 - $7\ x\ 10^{1}$
Total helminths, ova/gTS	1,4 ± 0,5
Viability of helminths, %	0 - 10%

4.4.2 Irrigation water

Water used for irrigation came from a borehole and was stored in open tanks. The water was not disinfected and birds were often observed drinking water from the tanks. This is possibly the reason why some microbial pollution was found, although at very low concentrations. Total coliforms ranged from 0,1 to 0,3 CFU/100ml, faecal coliforms from 0,2 to 0,9 CFU/100ml, faecal *streptococci* from 0 to 0,1 CFU/100ml, while *Salmonella spp* and helminth ova were not detected in any of the five samples analysed. 5 litre samples were used for the analysis.

4.4.3 Original soil characteristics (Table 4.2)

Soils were slightly alkaline (pH 7,7) and contained microorganisms such as total and faecal coliforms. The first are commonly considered to be native in soils, while the second have been reported as native in water in high-temperature countries and therefore could be present in soils (Hazen and Toranzos 1990). Faecal *streptococci* and *Salmonella* (using the APHA, AWWA, WEF method) were not found in the soil while helminth ova were present in low concentrations (1,4 ± 0,5 HO/gTS) and with very low viability (0 to 10%). According to the records of the farm, the plots had not received any manure application (which can contain helminth ova) for at least 1,5 years. Regarding the genus, almost all the eggs found were *Ascaris* although *Toxocara* was sometimes also found.

4.4.4 Crop results

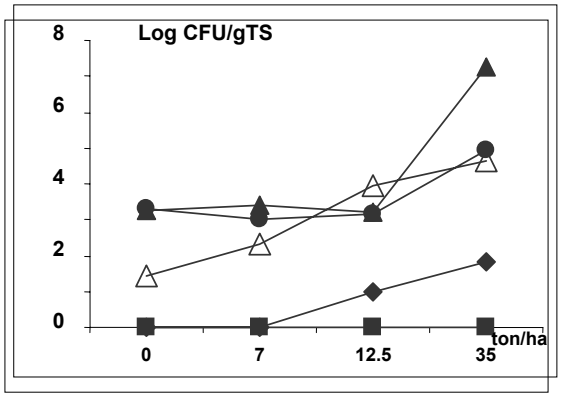


Figure 4.2(a): ▲Total Coliform; ●Faecal Coliform; ΔFaecal *Streptococci*; ■*Salmonella spp.*; and ♦*Aspergillus spp* in carrot soil after harvesting

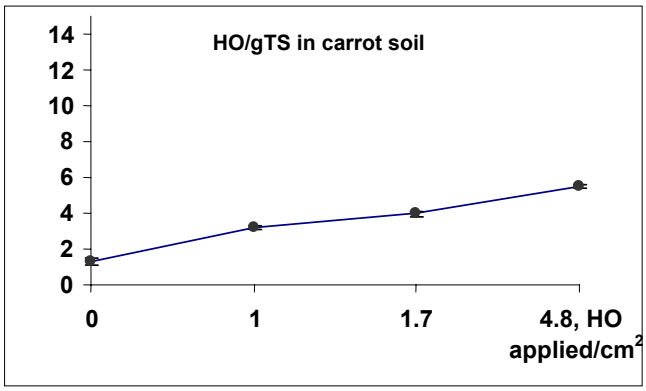


Figure 4.2(b): Helminth ova content in carrot soil after harvesting

The quantities of faecal material applied were equivalent in terms of the actual **viable** helminth eggs to application rates of 0,9; 1,5 and 4,3 HO/cm^2 for carrots and 0,2; 2,3 and 4,5 HO/cm^2 for spinach. Figure 4.2 shows the microbial effects of the application of faecal material on carrot soil. Total coliforms and faecal coliforms (Figure 4.2(a)) were present in the soil in similar concentrations for all the application rates, and only for the highest value a noticeable increase can be seen, while faecal *streptococci* increased correspondingly with increasing faecal material. Similar results were obtained for spinach soil, although the increase for the highest sludge application rate was less noticeable. In the case of *Salmonella*, the results in spinach soil were erratic, indicating that the Islam et al (2004) analytical technique was not appropriate. For carrots using the APHA, AWWA, WEF (1995) technique, *Salmonella* results were negative in all cases. Helminth ova in soils for both carrots and spinach (Figure 4.2(b), only for carrots) show a clear correlation with the rate of faecal material applied: the larger the sludge application rate the greater the number of helminth ova found in soils.

There was a diminishing helminth ova viability from the original value of 88,8% to 52 ± 3% for spinach soil and to 39 ± 7% in carrot soil. The greater decrease of viability in carrot soil was likely due to the longer time taken to monitor carrot soil (12 weeks) than for spinach soil (7 weeks). The decrease in viability can be explained, although not conclusively, by the high temperature registered during the summer time in Pretoria (ranging from 27-38^{o}C during the day) but also to possible prior damage suffered by the eggs during their earlier dehydration in the UD toilets as well as during further exposure to the elements in the heap, as mentioned above and as described in chapter 5. *Ascaris* have been reported to die rapidly at temperatures over 40^{o}C in different types of media including water, soil, sewage and crops (Feachem et al 1983). The temperature limit could be less if high temperatures are combined with other negative environmental conditions such as high ammonia content or low moisture (Heinonen-Tanski and Van Wijk-Sijbesma 2004).

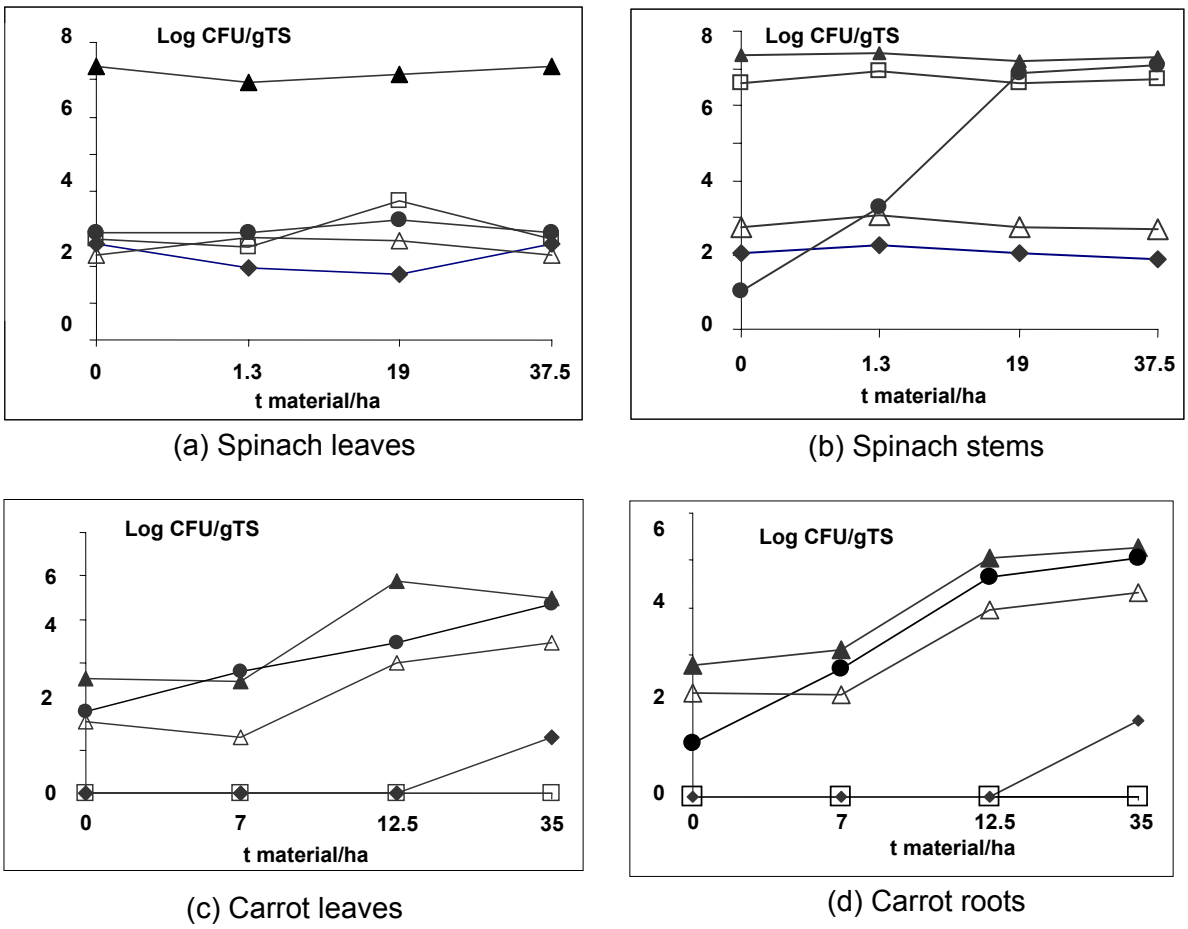


Figure 4.3: ▲Total Coliform; ●Faecal Coliform; ΔFaecal Streptococci; ■*Salmonella spp.*; ♦*Aspergillus spp.* on crops after harvesting

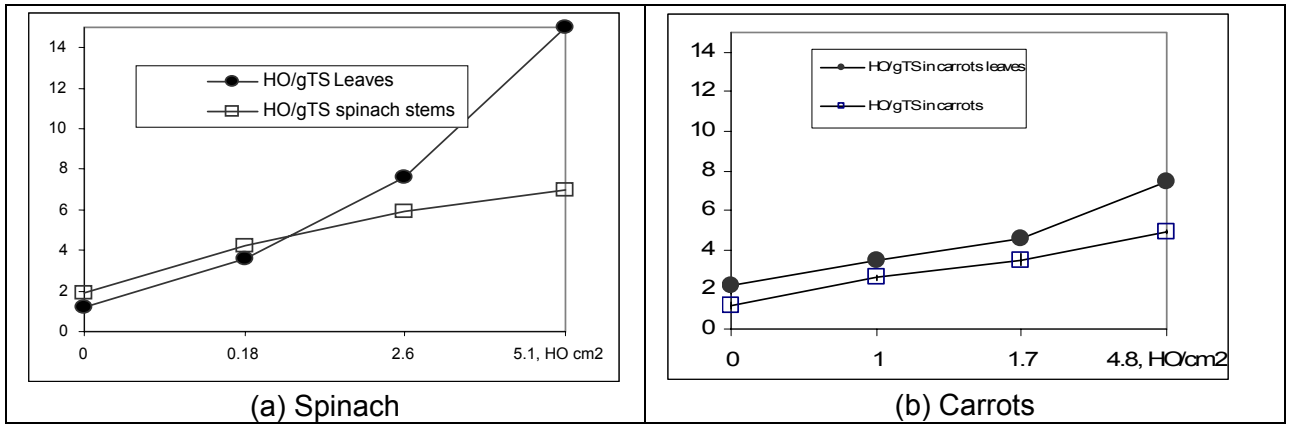


Figure 4.4: Helminth ova content in crops

Figure 4.3 shows the results of the bacteria numbers in spinach leaves (a) and stems (b). There was not a clear relationship between the quantity of faecal material applied and the total microbial number in leaves or stems. For faecal coliforms in stems, the results seem to indicate that bacteria can survive underground but not on top of the soil where UV sunlight is available to kill the organisms. In carrot leaves (c) and roots (d), total and faecal

coliforms as well as faecal *streptococci* increased as the faecal material application rate increased. *Aspergillus spp* and *Salmonella spp* were present in low numbers at all the different treatments, although the *Salmonella* results in spinach are suspect due to the testing technique used during the first phase of the experiment, as described in section 4.3.3. Regarding helminth ova, increasing concentrations were found in both stems and leaves (Figure 4.4(a) and (b)) as the quantity of material applied (and hence that of helminths) increased. Contamination is seen to be more important in leaves than in stems (roots), seeming to indicate that helminth ova are preferentially attached to parts of the plants above ground rather than to soil.

Although these results show that crops were polluted even using the smallest application rate, understanding the health significance would require proper epidemiological or toxicological studies that consider the probability of microorganisms, especially helminth ova, actually infecting the host. This would depend on the viability of eggs, the quantity of microorganisms consumed by a person through conventional daily diets in the region and the infective dose. Concerning the viability of helminth ova, for spinach crops the data were not obtained, but in carrot leaves it was 25 ± 5% while in carrot roots it was 20 ± 8%. This indicated that although present, they were mainly in an inactive state, thus reducing the risk of spreading the disease through consumption.

4.5 CONCLUSIONS FROM THIS EXPERIMENT

Faecal material was extracted from urine-diversion toilets in the eThekwini region of South Africa and left in a heap exposed to the weather for four months. Applying different rates of material to spinach and carrots, two common edible crops, it was found that the bacteria and fungi content were only noticeable for the higher rates (>35 t/ha), while the helminth ova content varied, both in leaves and stems, depending on the quantity of material applied. Helminth ova content was, for both crops, more prevalent in leaves, suggesting that the ova adhere preferentially to plants rather than soil.

To assess the actual health risk of helminth ova consumption, the final viability on crops needs to be considered as well as the infective dose for farmers and consumers and the daily diet of vegetables in the region. The actual age and storage conditions of the faecal material used are also important considerations.

It is clear, however, that there is a health risk involved in growing edible crops in soils amended with ecosan biosolids. Even if in this case the spinach and carrots were cooked before consumption, normal handling of the crops during harvesting and preparation could have caused infection if personal hygiene was unsatisfactory. It is thus of utmost importance that crop growers and consumers, as well as proponents of biosolids use, are aware of the storage and treatment requirements for ecosan biosolids before these are applied to soils where crops are grown. These aspects are investigated further in chapter 5.

CHAPTER 5
DETAILED INVESTIGATION INTO VAULT PROCESSES

ABSTRACT

It is hypothesised that the most advantageous approach to pathogen destruction in a urine-diversion (UD) toilet vault is to maximise the effects of various environmental factors, e.g. pH, temperature, low moisture, type of bulking agent and storage time. In order to quantify these effects a field experiment was set up consisting of 12 UD toilet vaults, each with a different combination of faeces and bulking agent (soil, ash, wood shavings, NaOH or straw), ventilation (ventpipe / no ventpipe) and vault lid material (concrete, metal or perspex). Temperature probes, which were connected to a data logger, were inserted in the heaps and the logger monitored over a period of nearly 10 months. This enabled a number of graphs to be drawn illustrating the effect of the above parameters on heap temperature over the experimental period. In addition, samples were taken at various intervals from each vault as well as from the main heap of faecal material that was left exposed to the elements. The samples were subjected to microbiological testing in order to quantify the pathogen die-off over time for each vault as well as for the main heap.

The conclusions drawn from the experimentation were the following:

- *Influence of ventpipe*
  Ventilation of the vault did not result in any meaningful difference in either the vault temperature or rate of pathogen die-off.

- *Influence of vault lid material*
  The lid material, and by inference also the material of the vault walls, has no significant effect on the temperature of the heap or the associated pathogen die-off.

- *Type of bulking agent*
  While the type of bulking agent used does not significantly influence the temperature of the faecal material, it does have an effect on the rate of pathogen die-off. The ordinary soil mix was seen to give the best results, and this was ascribed to the effect of competing microorganisms in the soil itself.

- *Influence of sunshine and rain*
  The main heap of material (faeces/soil mix) that was exposed to the elements performed among the best in terms of pathogen die-off. Apart from the influence of competing microorganisms in the soil on the pathogens as described above, this good performance was also ascribed to the effect of UV radiation as well as alternating wetting/drying and heating/cooling cycles, which suggests that open-air exposure is likely to provide the best treatment.

Comparing the results of this research with other local and international research, it appears that there is a great deal of convergence in the results. It is concluded that vaults of UD toilets should be sized for a storage period of 12 months from last use.

5.1 BACKGROUND AND HYPOTHESIS

In chapter 2 the following factors or environmental conditions were identified as playing the most important roles in the process of pathogen destruction within the faecal pile in urine-diversion (UD) toilets:

- Storage time
- pH
- temperature
- humidity
- moisture content
- organic content
- type of bulking agent

Moe et al (2001) suggested that no single factor can predict microbial indicator concentration and that microbial quality is a function of multiple factors. It is hypothesised, therefore, that the most advantageous approach to pathogen destruction in a UD toilet vault would be to maximise the effects of pH, temperature and low moisture content, while storing the material in the vault for an optimum time. There are various ways of raising the pH, while increased temperature and dehydration could possibly be facilitated by good aeration (ventilation) of the vault and suitable building materials, particularly in hot climates. If these factors could be combined in such a way that their individual effects are maximised, then it should be possible to reduce the vault storage time required to achieve a level of pathogen destruction commensurate with safety for handling. This in turn will decrease the size of toilet vault required and hence the construction cost.

5.2 OBJECTIVES OF STUDY

In an attempt to test the validity of the above hypothesis, it was decided to conduct field tests on toilet vaults operating under various conditions of ventilation, pH, bulking agent, etc. As it would not be possible to obtain controlled conditions in toilets that were actually in use, the approach was taken to rather build new toilet vaults and insert faecal material extracted from working toilets into them. eThekwini Water Services (EWS) was requested to assist by constructing vaults similar to those built in various villages in the municipal area (Figure 5.1). An agreement was concluded to build the required number of vaults in the grounds of the Northern Wastewater Treatment Works (NWWTW) where a measure of security was available for the equipment that would be installed. Only the toilet vaults would be constructed and not the toilet superstructures, as it was not the intention that these would be “live” (i.e. working) toilets.

Bearing in mind the various factors affecting pathogen destruction in UD toilet vaults, as already discussed, it was considered necessary to carry out tests allowing for the following variables:

- Aeration (i.e. ventpipe) or no aeration. A high ambient temperature could be transferred to the inside of the vault by movement of warm air. Dehydration of the material could also be facilitated.
- Type of bulking agent. Various agents, such as NaOH and ash for example, will normally increase the pH, while others may assist heat transfer and aeration through the faecal contents by increasing the porosity of the pile, e.g. straw, leaves

or wood shavings. Adding biomass would in this case, however, probably not promote composting due to the generally dry conditions in the vault.

- Type of vault lid (i.e. absorbing or encouraging heat transfer to the vault or not). Conventional wisdom in this case is to use a black-painted metal lid, while materials such as PVC and perspex are also known to allow the passage of heat.

The experimental protocol is described in the following section.

5.3 METHODS AND MATERIALS

5.3.1 General

The experimental setup, as originally proposed, is shown in Figure 5.2. Six double vault base structures, i.e. twelve vaults in all, were constructed by EWS. The standard vault size used by EWS is 735mm wide x 1310mm long x 800mm deep (internal dimensions). An exploded view of the toilet is shown in Figure 5.3, which illustrates the shape of the vaults. Figure 5.4 shows the completed experimental layout.

Figure 5.1: Typical double vault UD toilets built in the eThekwini municipal area. Vaults similar to these, without the superstructures, were constructed for the experimental work at NWWTW
(Photographs: F. Stevens, eThekwini Water Services).

Block A: Test ventpipe	
Vault A1	**Vault A2**
Vault lid Concrete **Bulking agent** Soil **Ventpipe** Yes	**Vault lid** Concrete **Bulking agent** Soil **Ventpipe** No

Block B: Test metal lid	
Vault B1	**Vault B2**
Vault lid Metal **Bulking agent** Ash **Ventpipe** No	**Vault lid** Metal **Bulking agent** Wood shavings **Ventpipe** No

Block C: Test PVC lid	
Vault C1	**Vault C2**
Vault lid PVC **Bulking agent** Ash **Ventpipe** No	**Vault lid** PVC **Bulking agent** Wood shavings **Ventpipe** No

Block D: Test concrete lid	
Vault D1	**Vault D2**
Vault lid Concrete **Bulking agent** Ash **Ventpipe** No	**Vault lid** Concrete **Bulking agent** Wood shavings **Ventpipe** No

Block E: Test NaOH	
Vault E1	**Vault E2**
Vault lid Concrete **Bulking agent** NaOH **Ventpipe** Yes	**Vault lid** Concrete **Bulking agent** NaOH **Ventpipe** No

Block F: Test porous agent	
Vault F1	**Vault F2**
Vault lid Concrete **Bulking agent** Grass, leaves, etc **Ventpipe** Yes	**Vault lid** Concrete **Bulking agent** Grass, leaves, etc **Ventpipe** No

Figure 5.2: The vault layout as originally proposed. Some parameters were revised for the final layout (see Figure 5.8).

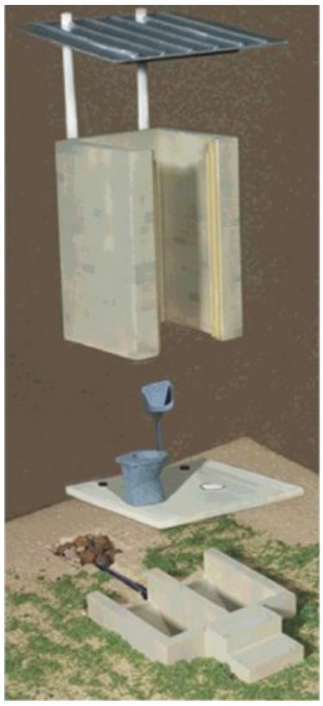


Figure 5.3: Exploded view of the eThekwini urine-diversion toilet
(Photograph: eThekwini Water Services)

Figure 5.4: Completed vault layout

Vent pipes, where installed, were fitted with umbrella-type caps in an attempt to prevent rainwater from entering the vaults. In order to ensure proper ventilation, a small brick structure with a lid was added over the pedestal hole in the slab to simulate a toilet lid with air gap. See Figure 5.5.

Figure 5.5: Ventilation of vault

Once the vault construction process was complete, the faecal material was inserted. The material was obtained by EWS, who extracted it from working UD toilets in various villages in the municipal area. This was then brought to the site in bags. Due to the difficulty of working with fresh faeces these were discarded, leaving material generally between one and three months old. As there was a limit on the amount of material available, it was not possible to insert more than a certain amount into the vaults. However, this was not considered to be a problem, as the amount of material inserted was roughly equivalent to what would be found in many types of UD toilets in the country (eThekwini's toilet vaults are actually very large when compared with others).

The bags were emptied onto a concrete slab and the material thoroughly mixed (Figure 5.6). The various additives (bulking agents) were obtained as follows:

- NaOH was purchased at a local pharmaceutical supply store;
- coal ash was obtained from a nearby industrial laundry that used coal for the boilers;
- wood shavings were obtained at a nearby lumber yard; and
- grass cuttings were fetched from a work team engaged in roadside maintenance.

All faecal material was already mixed with some soil instead of ash. The latter was not generally available because householders had access to electrical energy so did not often use fires.

The various bulking agents were mixed with the faecal material in the proportions indicated in Figure 5.8 before being inserted into the vaults. The mix proportions were such that the eventual heap sizes were more or less the same in each vault. The remainder of the original heap was left exposed to the weather on the concrete slab as a control (Figure 5.7).

It could be argued that this setup did not represent toilets in actual use, as in a “live” toilet the bulking agent is added after each defecation. However, as fresh faeces can contaminate the older pile beneath, recommendations on storage times are usually based on time from the last addition to the pile. As it was the intention to derive recommendations for bulking agents and minimum storage times, and because of the necessity for bringing each vault to a common “starting point” for experimental reasons, it was felt that this method would result in acceptable indications of the relative efficacy of each type of bulking agent.

Figure 5.6: Mixing and weighing the faecal material prior to addition of bulking agents

Figure 5.7: Remainder of original heap of faecal material used as a control

Block A: Test ventpipe	
Vault A1	**Vault A2**
Vault lid Concrete **Bulking agent** Soil **Ventpipe** Yes **80kg loaded**	**Vault lid** Concrete **Bulking agent** Soil **Ventpipe** No **80kg loaded**

Block B: Test metal lid	
Vault B1	**Vault B2**
Vault lid Metal **Bulking agent** Soil + ash **Ventpipe** No **80kg loaded** **40 faeces / 40 ash**	**Vault lid** Metal **Bulking agent** Soil + wood shavings **Ventpipe** No **64kg loaded** **40 faeces / 24 wood**

Block C: Test perspex lid	
Vault C1	**Vault C2**
Vault lid Perspex **Bulking agent** Soil + ash **Ventpipe** No **80kg loaded** **40 faeces / 40 ash**	**Vault lid** Perspex **Bulking agent** Soil + wood shavings **Ventpipe** No **64kg loaded** **40 faeces / 24 wood**

Block D: Test concrete lid	
Vault D1	**Vault D2**
Vault lid Concrete **Bulking agent** Soil + ash **Ventpipe** No **80kg loaded** **40 faeces / 40 ash**	**Vault lid** Concrete **Bulking agent** Soil + wood shavings **Ventpipe** No **64kg loaded** **40 faeces / 24 wood**

Block E: Test NaOH	
Vault E1	**Vault E2**
Vault lid Concrete **Bulking agent** Soil + NaOH **Ventpipe** Yes **55kg loaded** **40 faeces / 15 NaOH**	**Vault lid** Concrete **Bulking agent** Soil + NaOH **Ventpipe** No **55kg loaded** **40 faeces / 15 NaOH**

Block F: Test porous agent	
Vault F1	**Vault F2**
Vault lid Concrete **Bulking agent** Soil + dry grass (straw) **Ventpipe** Yes **60 kg loaded** **55 faeces / 5 grass**	**Vault lid** Concrete **Bulking agent** Soil + dry grass (straw) **Ventpipe** No **60kg loaded** **55 faeces / 5 grass**

Figure 5.8: Details of actual vault setup on 3 June 2004

The temperature probes were subsequently installed. These consisted of 450mm long stainless steel tubes containing sensors with 25mm long copper points connected by cables to a data logger. The voltage output was linearly proportional to the Centigrade temperature, thus enabling direct temperature measurements to take place. They were calibrated before connection. The logger took a temperature reading every three hours on a continuous basis. A car battery was used as a power source and the equipment designed in such a way that a notebook computer could be connected to the logger and the data downloaded to an Excel spreadsheet at intervals of up to six weeks.

The process of installing the probes is illustrated in Figure 5.9 below. The photograph on the left depicts the cables being pulled through the protective conduits. The top right photograph shows the probes being calibrated against a standard probe in a bucket of water, while the bottom right photograph illustrates the lockable box with battery and logger.

With the exception of vaults A1 and A2, one probe was inserted in each heap, to a depth of approximately 200mm. In order to obtain a temperature profile in the heaps, three probes were installed in each of the heaps of vaults A1 and A2 at depths of 100mm, 200mm and 300mm respectively. A final probe measured outside ambient temperature.

Figure 5.9: Calibrating and installing the temperature probes and data logger

Temperature and microbiological monitoring was carried out over a period of almost 10 months, after which time trends had become clear and there was no point in continuing the process. There were intermittent problems with the logging equipment that resulted in

short periods with no temperature data, but this did not detract from the overall value of the data as there was sufficient information available for analysis purposes.

A problem was also experienced in keeping the vaults dry. It was found that, due to some heavy rainstorms that were accompanied by strong winds, rainwater was often driven under the ventpipe umbrella and down the pipe, causing wetting of the material underneath. This caused the moisture content of the material to fluctuate and also prevented some of the heaps from drying out beyond their initial moisture content. A further problem was experienced in block E where both vaults were flooded at one stage, with the heaps (faeces + NaOH) being completely waterlogged for a long period. This negatively influenced the effect of the high pH of the NaOH, as will be seen from the microbiological results. It had the advantage, however, of illustrating the necessity for keeping the vaults dry in practice.

Sampling for microbiological testing was carried out at the following intervals, where t represents the time in days from when the vaults were loaded: t=0; t=44; t=97; t=174; and t=278.

5.3.2 Sampling

Sampling was done using a specially fabricated cylindrical coring device (Figure 5.10). The device was inserted into the heap while being simultaneously rotated, thus cutting a core of material 35mm wide and approximately 200mm long. The core was then expressed into a sterilised sample bottle (Figure 5.11). The equipment was cleaned with 70% ethanol before the following sample was cored.

Figure 5.10: Coring device and sample bottles

Figure 5.11: Expressing the cored material into the sample bottle

5.3.3 Microbiological parameters

Indicator organisms
It is impossible to test for all the possible organisms that could present a health risk, therefore indicator organisms are used to give a general indication of water quality. The "coliform group" of organisms has been found to be the most useful. This group comprises organisms such as *Escherichia coli*, *Klebsiella pneumoniae* and *Enterobacter aerogenes*. *Escherichia coli* is commonly found in the human intestine and most strains are normally not pathogenic. The "coliform group" is defined as all aerobic and facultative anaerobic gram-negative, non-sporeforming, rod-shaped bacteria that ferment lactose with the formation of gas within 48h at 35°C. The presence of these bacteria indicates that pollution has occurred that can be associated with faecal contamination from man or other warm-blooded animals.

Total coliform bacteria
As applied to the membrane filter technique, this term refers to a group of gram-negative, non-sporeforming bacteria that develop a dark red colony with a green metallic sheen within 24h at 35 ± 1°C on an Endo-type medium containing lactose.

Faecal coliform bacteria
This refers to the thermo-tolerant forms of the total coliform group that ferment lactose at 44,5 ± 0,5°C in 18 to 24h. Within the group, *E. coli* and *Klebsiella* species are the organisms of interest since, when present, they indicate that recent faecal contamination has occurred with the possibility of accompanying enteric pathogens. For the purpose of this test, faecal coliforms are defined as bacteria that produce various shades of blue colonies on m-FC medium within 24h when incubated at 44,5°C. Non-faecal coliform colonies are grey to cream-coloured.

Escherichia coli
E. coli are a member of the faecal coliform group of bacteria that yield a positive indole reaction at 44,5°C. Bacteria that conform to this definition generally consist exclusively of *E. coli* of almost definite faecal origin. They are more specific than faecal coliforms. This method is applicable to the confirmation of faecal coliform bacteria isolated on m-Fc media.

Faecal streptococci bacteria
These indicate faecal pollution and refer to those streptococci commonly found in human and animal faeces. They are used as a supplementary bacterial indicator. For the purpose of this test, faecal streptococci are defined as those bacteria that produce deep red or maroon colonies on m-Enterococcus agar after incubation at 35°C.

Coliphage
A coliphage is a virus hosting on the coliform bacteria. They have similar survival patterns as enteric viruses. Although they do not provide an absolute indication of the presence of enteric viruses in all conditions, they may provide an acceptable indication of the presence of viruses in general. They are present whenever total and faecal coliforms are found in high numbers. The presence of coliphages is demonstrated by the ability of the virus to infect its host and cause lysis of the bacterial cells. The lysis is evident by appearance of plaques (clear zones) on the agar plates with host cells (*E. coli*) background or lawn.

Faecal clostridia
Clostridium species are Gram-positive, rod-shaped spore-formers and are part of our normal flora. The spores are found in human and animal faecal matter and the presence of *Clostridium perfringens* is taken as conclusive proof of faecal contamination. For the purpose of this test, faecal *clostridia* are defined as sulphite reducing anaerobic bacteria that produce typical black colonies when incubated on tryptose-sulphite-cycloserine agar under anaerobic conditions for 24h at 45°C.

Heterotrophic plate count
This test quantifies viable aerobic bacteria. These bacteria do not represent the total number of microorganisms in the sample but only those that are able to form visible colonies in nutrient media under specific culture conditions. The test for the heterotrophic plate count is used together with total and faecal coliforms as an indication of sanitary quality.

Salmonella
These are rod-shaped, motile (except *S. gallinarum* and *S. Pullorum*) non-sporeforming, Gram-negative bacteria. The test method, described in section 5.3.5 below, is applicable to the examination of all kinds of water, soil, sewage and sludge samples for the presence or absence of *Salmonella* species.

Parasites
Giardia, *Cryptosporidium* and *Entamoeba* are protozoan parasites. *Taenia* (known as tapeworms) are cestodes (ribbon-like intestinal worms), while *Ascaris* are intestinal nematodes (roundworms).

5.3.4 Sample preparation

For the bacterial determinations, 20g of sample material were weighed off in duplicate. One was used for analysis and the other to determine moisture content. The bacteria

were extracted from the samples by adding sterile saline, the samples were sonicated for 10 minutes and then left overnight. Extracts (supernatant) were analysed the following day using the standard procedures described below.

For the *Ascaris, Entamoeba* and *Taenia* enumerations, as well as for Cryptosporidium oocysts and Giardia cysts, the sample was prepared according to the method of Franck (1988). This involved diluting the samples with physiological salt solution until they were just liquid enough to be ground in a homogeniser, after the addition of a few drops of anionic washing agent. Thereafter 100g of the sample was used to determine the moisture content, while the remaining material was weighed off in 10g portions and 100ml of physiological salt solution added to prevent them from drying out.

5.3.5 Test methods

All sample preparation and testing were carried out in the microbiological laboratory of the CSIR in Pretoria, which is a SANAS accredited laboratory. Due to cost considerations only one sample from each heap was taken and analysed each time, thus making a statistical analysis inappropriate.

Heterotrophic plate count
The pour plate method was performed in a biological safety cabinet. The extracts were mixed with a non-selective nutrient-enriched agar medium. The agar plates were then incubated at 35°C for 48h after which all visible colonies were counted.

Total coliform bacteria
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on m-Endo growth medium and incubated at 35°C for 24h. The bacteria produced colonies with a golden-green metallic sheen.

Faecal coliform bacteria
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on m-FC growth medium and incubated at 44,5°C for 18 to 24h. The bacteria produced various shades of blue colonies.

Faecal streptococci bacteria
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on m-Enterococcus agar medium and incubated at 35°C for 48h. The bacteria produced deep red or maroon colonies.

Salmonella
The detection of *Salmonella* involved four successive stages:

- Concentration of the sample by membrane filtration;
- pre-enrichment of the sample into a non-selective medium to ensure that injured organisms were resuscitated;
- enrichment of the sample in a selective medium to eliminate the growth of interfering organisms; and
- selection by plating the sample on selective media followed by incubation at 35°C for 48h.

Faecal Clostridia
The extracts were filtered through a membrane filter upon which the bacteria were trapped. The filter was then placed on tryptose-sulphite-cycloserine agar and incubated at 45°C for 24h. The bacteria produced typical black colonies.

Coliphage
- Coliphage agar plates were inoculated with the *E. coli* WG4 bacterial host and extract, for somatic coliphage detection;
- the plates were incubated at 35 ± 1°C for 18h;
- the presence of coliphages was demonstrated by the ability of the virus to infect its host and cause lysis of the bacterial cells. The lysis was evident by appearance of plaques (clear zones) on the agar plates with host cells (*E. coli*) background or lawn; and
- the plaques were counted and expressed as plaque forming units per g.

For the coliform, streptococci and clostridia assays, 100ml, 10ml and 1ml solutions, as well as dilutions of 1ml, were filtered and a plate with between 20 and 60 colonies chosen for the count. The *salmonella*, coliphage and heterotrophic plate count samples were not filtered, however.

pH
10g of the extraction was mixed with 500ml sterile water, shaken and left overnight. A pH probe with meter was used for the measurement.

Moisture content (MC)
10g of the sample was dried in an oven at 50°C for one week and weighed again.

$$MC = \frac{(\text{weight of moist sample} - \text{weight of dry sample}) \times 100}{\text{Weight of moist sample}}$$

Ascaris Lumbricoides, Entamoeba and Taenia
Enumeration of eggs, and the viability thereof, was carried out according to the method of Franck (1988) using a modified Visser filter. The sample was poured into the Visser filter and washed through with a strong jet of water. The remaining material was collected in a tube and centrifuged for 2 minutes at 1 680G, whereafter the supernatant was extracted. The tube was then filled with 40% zinc sulphate solution while being thoroughly mixed and centrifuged for 1,5 minutes at 420G, whereupon the supernatant was poured through a membrane filter. The sides of the filter container were washed with a strong jet of water and the process repeated until the zinc sulphate was removed and the eggs evenly distributed. The membrane filter was then put into an incubator for 30 minutes, after which the eggs were enumerated under a microscope.

Giardia and Cryptosporidium

Determination of the cysts and oocysts, and the viability thereof, was carried out in the same manner as for the helminths, except that there was a further step in the process. Because the organisms are much smaller, they were washed through all three of the filters in the Visser apparatus but were trapped on an additional filter of 1,2 micron, whereafter they were enumerated under a microscope.

5.4 EXPERIMENTAL RESULTS

The experimental results are grouped under three headings, namely, initial material characteristics, temperature results and microbiological results. The results are given according to the various vaults where they occurred. Temperature and microbiological results are also shown graphically in order to illustrate trends or occurrences.

The temperature and microbiological results are discussed separately at first and then seen together.

5.4.1 Initial material characteristics

The initial analysis of the vault contents is shown in Table 5.1. It should be noted that vaults A1 and A2 are the same material (faeces mixed with soil) as the main heap and the latter is thus not shown separately.

Heterotrophic plate counts varied between 3,9 x 10^7 and 3,0 x 10^8 cfu/g of material. Total coliform bacteria ranged from 1,5 x 10^4 to 3,3 x 10^6 cfu/g, and faecal coliform bacteria from 1,5 x 10^4 to 9,1 x 10^5 cfu/g. Faecal streptococci varied between 2,5 x 10^4 and 3,0 x 10^5 cfu/g. *Salmonellae* were detected in every vault. Coliphage counts ranged from 1,7 x 10^3 to 1,3 x 10^4 pfu/g and clostridium from 3,0 x 10^2 to 8,8 x 10^3 cfu/g. *Cryptosporidium* was present in five vaults, numbering between 0,9 and 2,4 per 10g, while *Giardia* was found in only two of the vaults, varying from 12 to 32 per 10g respectively. *Ascaris* was found in every vault, ranging from 201 to 305 per 10g respectively.

pH measurements of the heap samples varied between 6,37 and 10,09 while moisture content was between 8,6 and 59,6. The latter measurement, in vaults F1 and F2 (faeces + grass), was due to the grass being very wet from rain.

The pH of the coal ash was found to be only 6,20, which also affected the faeces/ash mixture (pH 6,90). This was contrary to expectations, as it was (wrongly) assumed that the value would be in the region of 10, as for wood ash. After consideration it was decided to leave the material in the vaults, as there was insufficient left in the original heap to mix with another source of ash, and using other faecal material would mean that the initial characteristics would be different. As the pH of the mixture was almost neutral and the ash was extremely coarse, it was considered useful to be used as a further example of a porous (aerated) mixture.

Table 5.1: Initial analysis of vault contents at start of experiment (t=0)

Organisms	Vault A1 (faeces + soil)	Vault A2 (faeces + soil)	Ash only	NaOH only	Wood shavings only	Grass only	Vaults B1, C1, D1 (faeces + ash)	Vaults B2, C2, D2 (faeces + wood shavings)	Vaults E1, E2 (faeces + NaOH)	Vaults F1, F2 (faeces + grass)
Heterotrophic plate count cfu/g	$2,9 \times 10^8$	$3,0 \times 10^8$	-	-	-	-	$2,1 \times 10^8$	$6,1 \times 10^7$	$3,9 \times 10^7$	$2,1 \times 10^8$
Total coliform bacteria cfu/g	$1,7 \times 10^6$	$3,3 \times 10^6$	-	-	-	-	$8,0 \times 10^4$	$6,6 \times 10^4$	$1,5 \times 10^4$	$2,8 \times 10^5$
Faecal coliform bacteria cfu/g	$9,1 \times 10^5$	$2,0 \times 10^5$	-	-	-	-	$2,5 \times 10^4$	$3,1 \times 10^4$	$1,5 \times 10^4$	$5,4 \times 10^4$
Faecal strepto-cocci bacteria cfu/g	$3,0 \times 10^5$	$2,9 \times 10^5$	-	-	-	-	$3,7 \times 10^4$	$6,0 \times 10^4$	$2,5 \times 10^4$	$1,8 \times 10^5$
Salmonella spp /g	Present	Present	-	-	-	-	Present	Present	Present	Present
Coliphage count pfu/g	$1,3 \times 10^4$	$1,7 \times 10^3$	-	-	-	-	$6,6 \times 10^3$	$4,9 \times 10^3$	$5,2 \times 10^3$	$2,0 \times 10^3$
Clostridium count cfu/g	$8,0 \times 10^3$	$6,0 \times 10^2$	-	-	-	-	$2,6 \times 10^3$	$1,1 \times 10^3$	$3,0 \times 10^2$	$8,8 \times 10^3$
pH	7,06	7,18	6,20	9,92	6,14	6,37	6,90	6,37	10,09	6,80
Moisture %	12,5	16,4	0,6	-	24,6	76,4	12,8	12,9	8,6	59,6
Cryptosporidium oocysts /10g	0,9	2,4					2,2	ND	ND	ND
Giardia cysts /10g	12	32					ND	ND	ND	ND
Ascaris eggs /10g *	201	237					218	305	272	237

Notes:
ND = not detected.
* Represents total no of eggs, i.e. viable plus non-viable.
cfu = colony forming units.
pfu = plaque forming units.

5.4.2 Temperature results

An example of some results from the data logger for a typical period is illustrated in Appendix A. The format of the information as an Excel spreadsheet made it possible to analyse any of the variables, or a combination thereof, for any selected period of time.

A number of graphs illustrating typical temperature trends in the vaults are now shown. The graphs represent the following:

- Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for all vaults (Figures 5.12 to 5.17);
- top, middle and bottom heap temperatures for the warmest week in January 2005 (summer) for vaults A1 and A2 (Figure 5.18);
- influence of ventpipe on heap temperatures in July 2004 (winter) and January 2005 (summer) for vaults A1 and A2 (Figure 5.19);
- influence of vault lid material on heap temperatures in July 2004 (winter) and January 2005 (summer) for vaults B2, C2 and D2 (Figure 5.20); and
- influence of various bulking agents on heap temperatures in July 2004 (winter) and January 2005 (summer) for vaults A2, D1, D2 and F2 (Figure 5.21).

Summary tables of the mean, minimum and maximum heap temperatures for the coldest week in July 2004 (winter) and the warmest week in January 2005 (summer) follow hereunder:

Table 5.2: Mean, minimum and maximum heap temperatures for the coldest week in July 2004 (winter)

Vault	Conditions	Mean temp °C	Min temp °C	Max temp °C
A1	Soil, concrete lid, ventpipe	17,2	16,1	18,6
A2	Soil, concrete lid, no ventpipe	17,5	16,4	19,0
B1	Ash, metal lid, no ventpipe	16,2	13,9	18,3
B2	Wood shavings, metal lid, no ventpipe	17,3	15,3	19,4
C1	Ash, perspex lid, no ventpipe	16,6	13,9	18,8
C2	Wood shavings, perspex lid, no ventpipe	17,5	15,4	19,6
D1	Ash, concrete lid, no ventpipe	15,9	13,3	18,2
D2	Wood shavings, concrete lid, no ventpipe	16,9	15,2	18,9
E1	NaOH, concrete lid, ventpipe	15,8	13,3	17,7
E2	NaOH, concrete lid no ventpipe	14,9	12,1	17,6
F1	Straw, concrete lid, ventpipe	17,2	15,0	19,0
F2	Straw, concrete lid, no ventpipe	18,4	17,4	19,9

Table 5.3: Mean, minimum and maximum heap temperatures for the warmest week in January 2005 (summer)

Vault	Conditions	Mean temp °C	Min temp °C	Max temp °C
A1	Soil, concrete lid, ventpipe	27,6	26,2	30,6
A2	Soil, concrete lid, no ventpipe	27,0	24,7	28,1
B1	Ash, metal lid, no ventpipe	27,6	25,6	29,2
B2	Wood shavings, metal lid, no ventpipe	28,7	26,7	30,1
C1	Ash, perspex lid, no ventpipe	27,5	25,4	29,0
C2	Wood shavings, perspex lid, no ventpipe	27,8	26,0	29,0
D1	Ash, concrete lid, no ventpipe	27,3	24,6	29,7
D2	Wood shavings, concrete lid, no ventpipe	28,2	26,3	29,6
E1	NaOH, concrete lid, ventpipe	27,7	25,5	29,4
E2	NaOH, concrete lid no ventpipe	ND	ND	ND
F1	Straw, concrete lid, ventpipe	ND	ND	ND
F2	Straw, concrete lid, no ventpipe	26,7	24,7	28,1

ND = no data

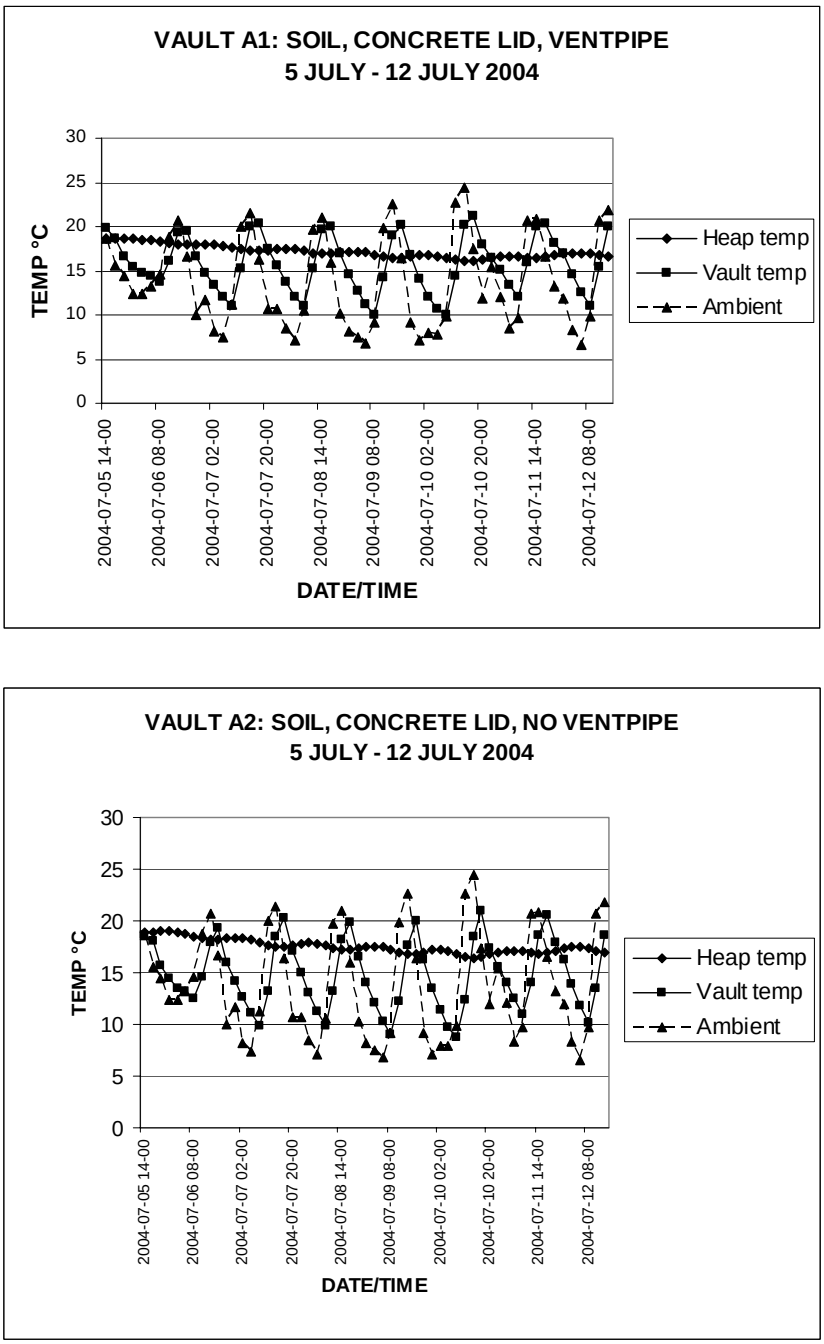
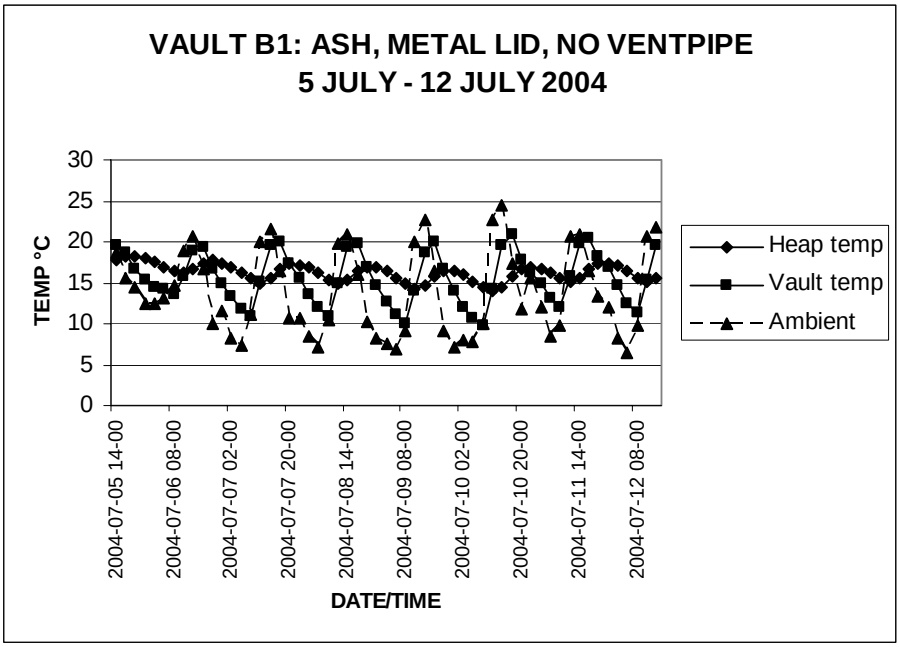


Figure 5.12: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults A1 and A2.

In vault A1 (soil, concrete lid, ventpipe) and vault A2 (soil, concrete lid, no ventpipe) the heap temperatures remain almost constant, fluctuating in a narrow band (about 1°C diurnally and 2°C over the full week) even while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter.

It appears as if the presence or absence of a ventpipe has no discernable effect on the heap or vault temperatures.



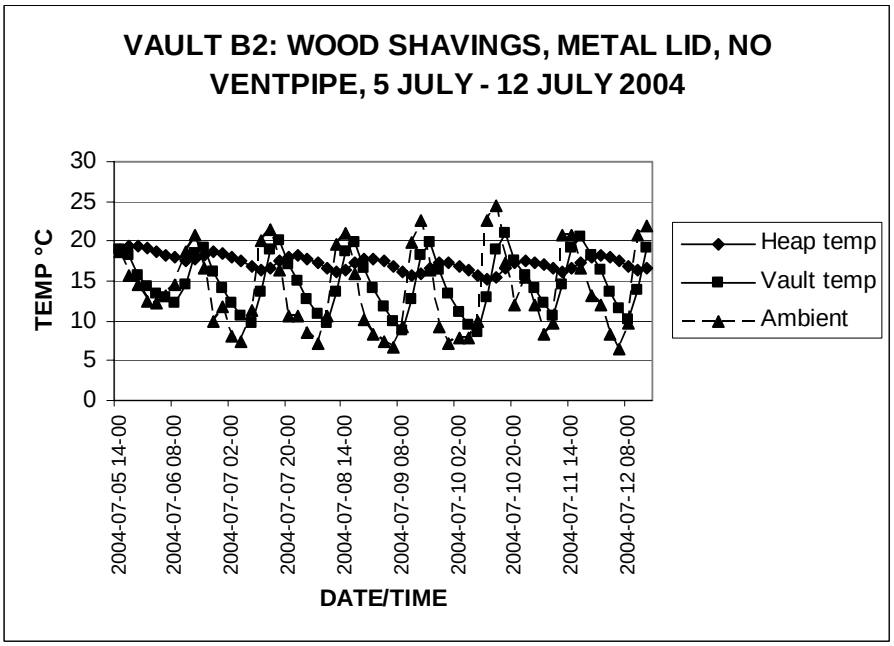
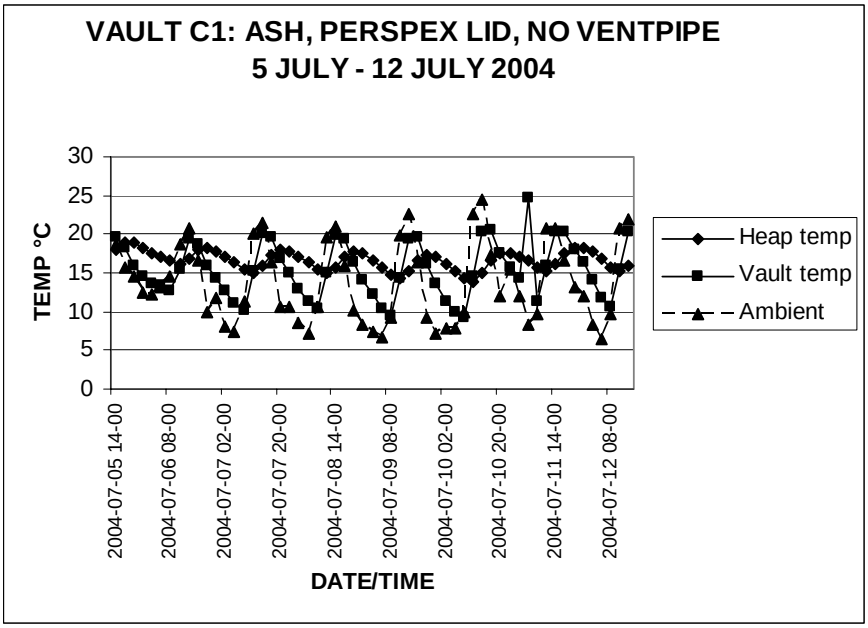


Figure 5.13: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults B1 and B2.

In vault B1 (ash, metal lid, no ventpipe) and vault B2 (wood shavings, metal lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter. The diurnal fluctuations in heap temperatures are greater than in vaults A1 and A2 (soil mix) even though the vault temperatures are about the same. It is thought that the ash and wood shavings in vaults B1 and B2 respectively gain and lose heat quicker than the soil in vaults A1 and A2.



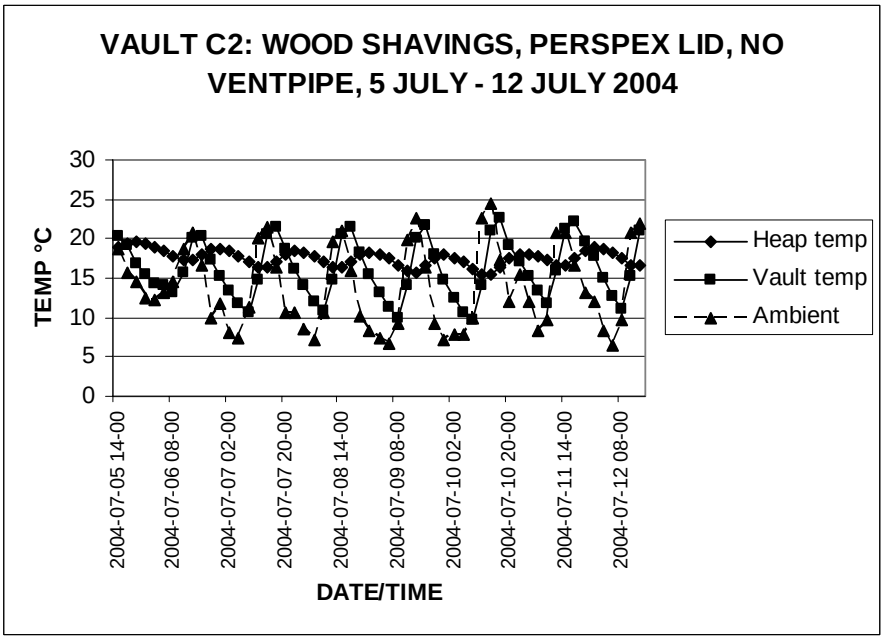
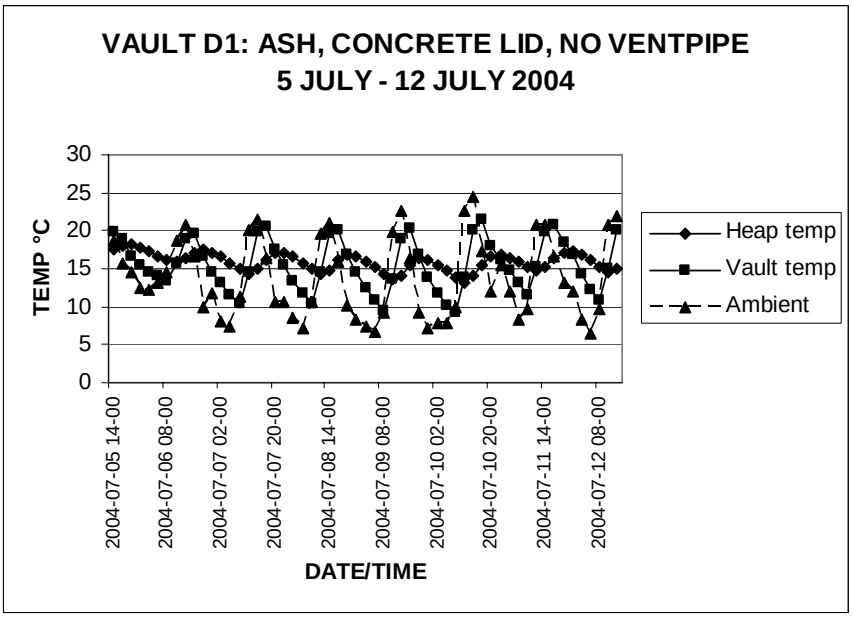


Figure 5.14: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults C1 and C2.

In vault C1 (ash, perspex lid, no ventpipe) and vault C2 (wood shavings, perspex lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter. The diurnal fluctuations in heap temperatures are greater than in vaults A1 and A2 (soil mix) even though the vault temperatures are about the same. It is thought that the ash and wood shavings in vaults C1 and C2 respectively gain and lose heat quicker than the soil in vaults A1 and A2.



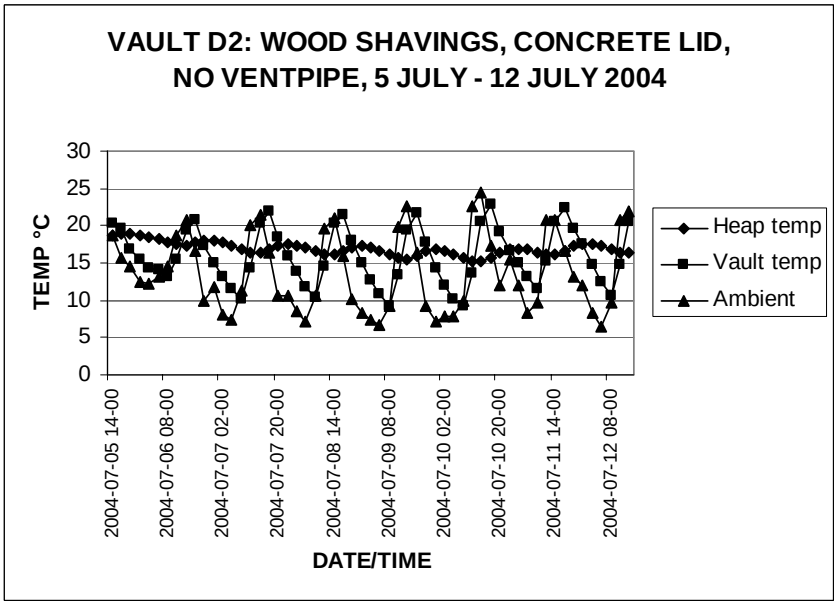


Figure 5.15: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults D1 and D2.

In vault D1 (ash, concrete lid, no ventpipe) and vault D2 (wood shavings, concrete lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The vault temperatures, however, fluctuate more widely and follow the pattern of the outside temperature, differing generally less than 5°C from the latter. The diurnal fluctuations in heap temperatures are greater than in vaults A1 and A2 (soil mix) even though the vault temperatures are about the same. It is thought that the ash and wood shavings in vaults D1 and D2 respectively gain and lose heat quicker than the soil in vaults A1 and A2.

The heap in vault D1 shows bigger temperature fluctuations than the heap in vault D2. It is thought that the ash, being very coarse, made the heap more porous and thus subject to greater air exchange within the vault.

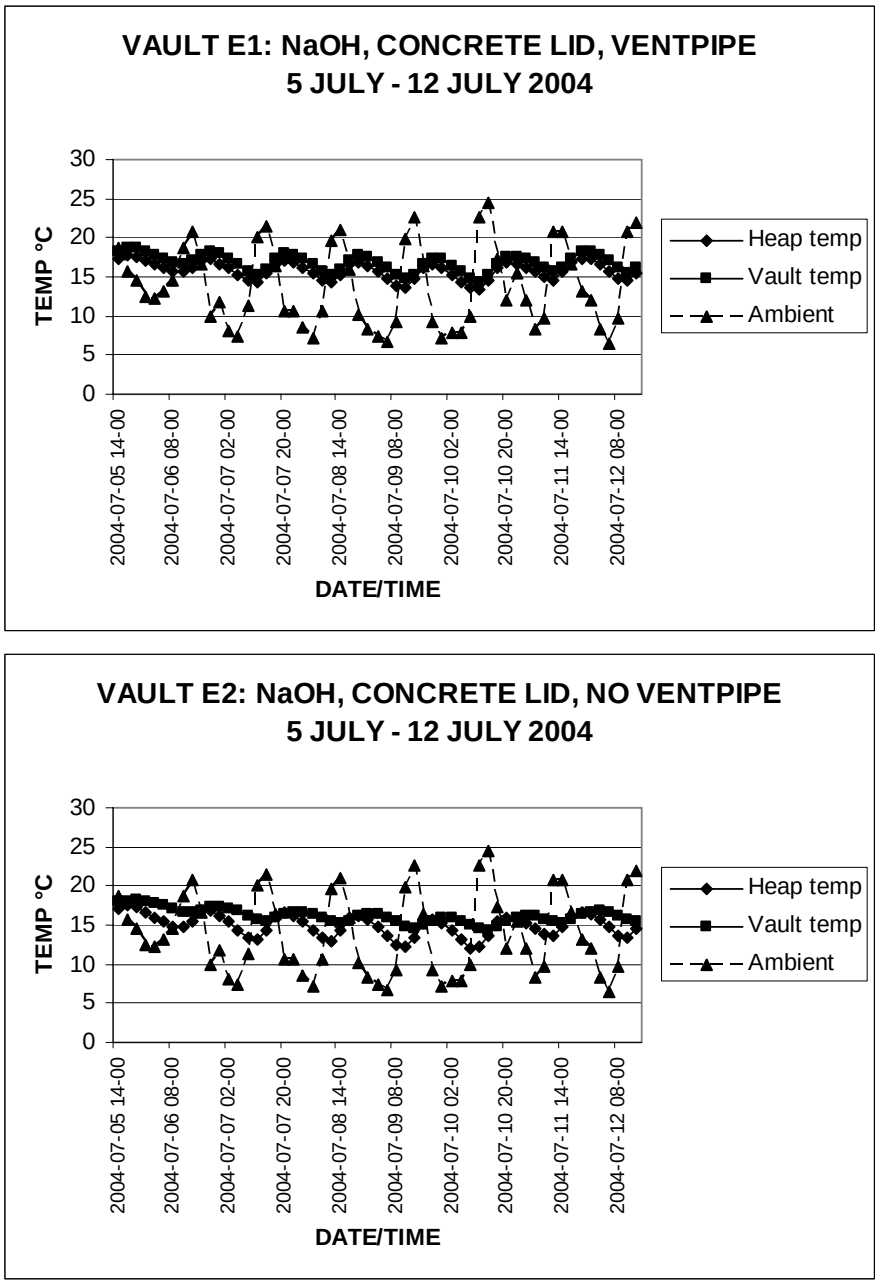
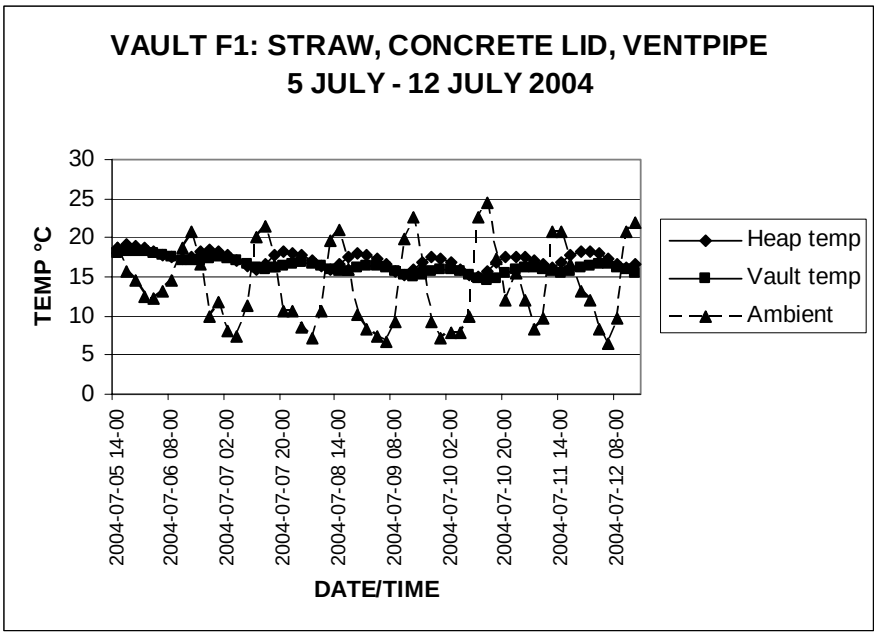


Figure 5.16: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults E1 and E2.

In vault E1 (NaOH, concrete lid, ventpipe) and vault E2 (NaOH, concrete lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The diurnal fluctuations in heap temperatures in vaults E1 and E2 are greater than in vaults A1 and A2 (soil mix). It is possible that the NaOH gains and loses heat quicker than the soil in vaults A1 and A2. The vault temperatures, in this case, remain slightly higher than, and closely follow, the heap temperatures.

It does not appear as if the presence or absence of a ventpipe has any noteworthy effect on the heap or vault temperatures.



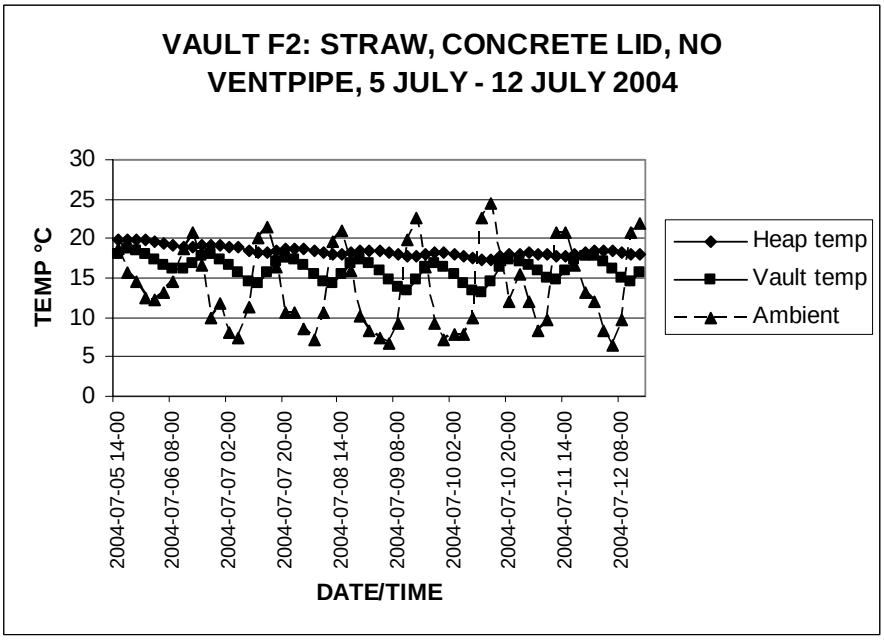


Figure 5.17: Heap, vault and ambient temperatures for the coldest week in July 2004 (winter) for vaults F1 and F2.

In vault F1 (dry grass, concrete lid, ventpipe) and vault F2 (dry grass, concrete lid, no ventpipe) the heap temperatures fluctuate in a narrow band (about 1-3°C diurnally and 4°C over the full week) while the outside temperature shows diurnal differences of up to 18°C. The overall heat gains in the heaps, while not constant, are therefore sustained. The diurnal fluctuations in heap temperatures in vault F1 are greater than in both vaults A1 and A2 (soil mix), while the fluctuations in vault F2 are about the same. The vault temperatures are, in this case, slightly lower than the heap temperatures.

It does not appear as if the presence or absence of a ventpipe has any noteworthy effect on the heap or vault temperatures.

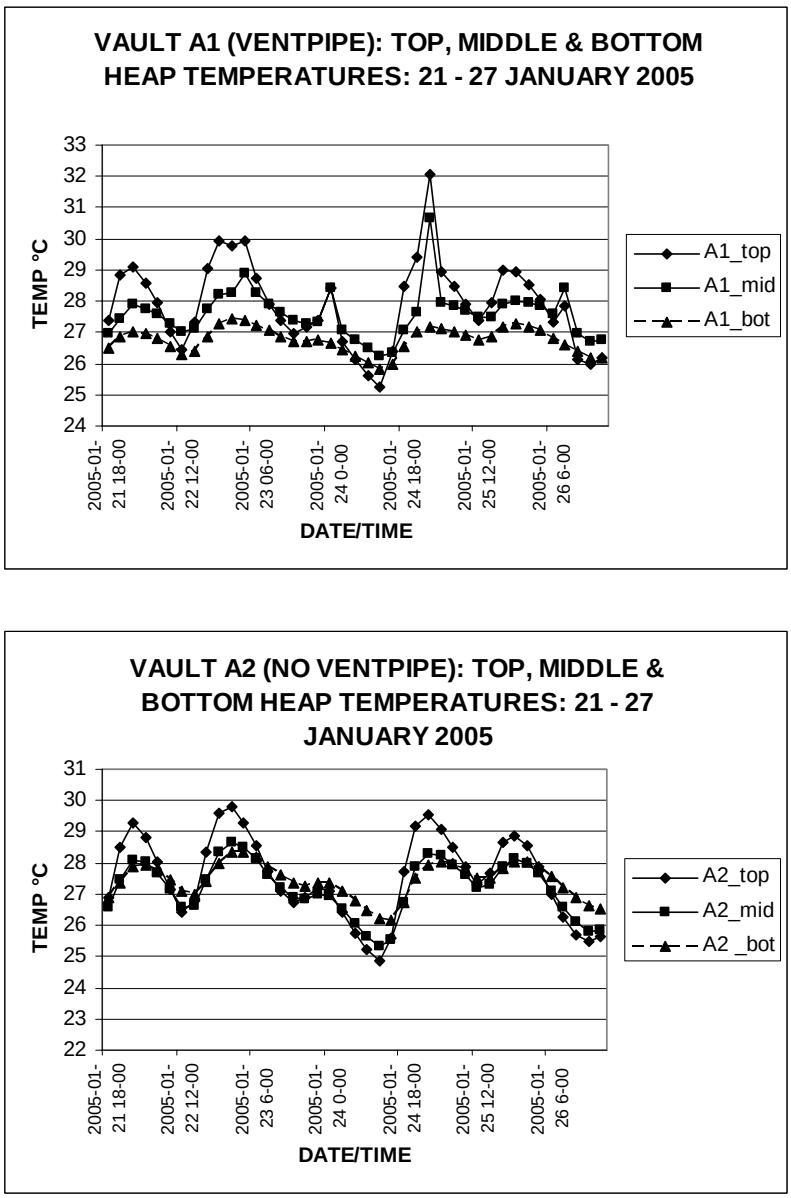


Figure 5.18: Top, middle and bottom heap temperatures for the warmest week in January 2005 (summer) for vaults A1 (top graph) and A2 (bottom graph).

The surface of the heap is the warmest for most of the time, followed by the middle of the heap, while the inside layer is usually the coldest. The surface temperature also shows the greatest fluctuations, occasionally becoming the coldest during pronounced drops in temperature.

The temperature difference between the top and bottom layers of the heap varies generally between 1-5°C, with the greatest difference coinciding with the highest temperature peak.

Vault A1 has a ventpipe which appears to play a small role only when the greatest temperature peak occurs, when the heap surface temperature in vault A1 rises to about 3°C higher than that in vault A2.

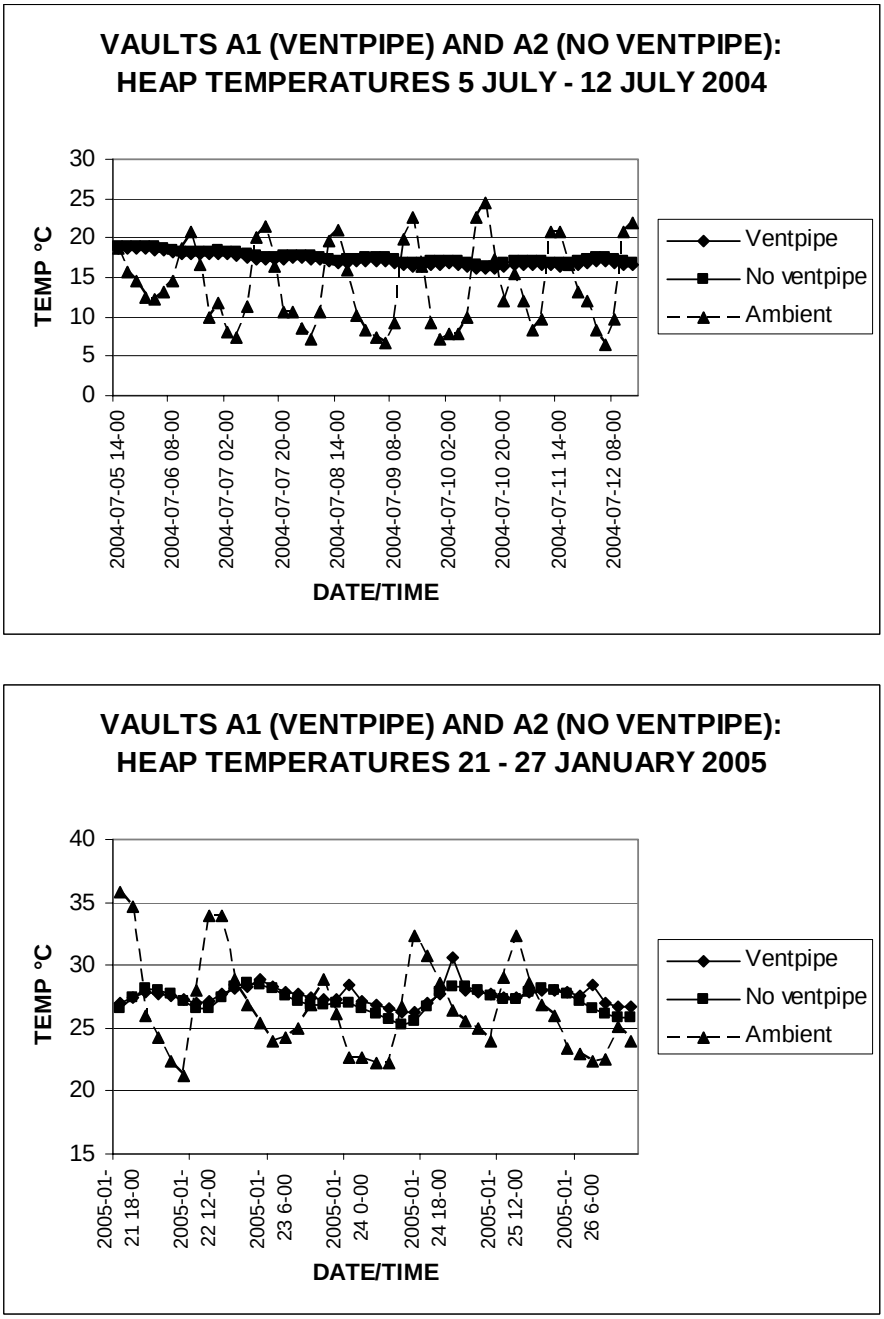
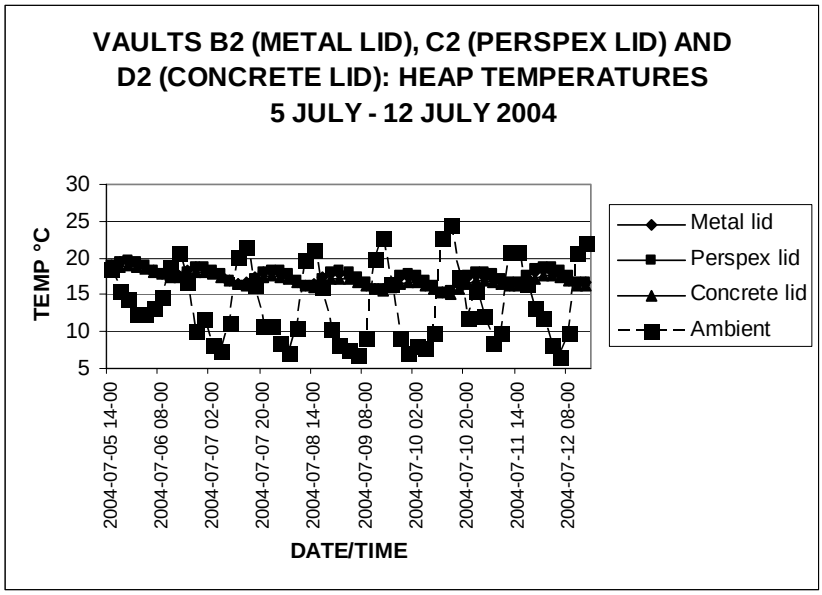


Figure 5.19: Influence of ventpipe on heap temperatures in July 2004 (winter) (top graph) and January 2005 (summer) (bottom graph) for vaults A1 and A2.

The heap temperatures in vaults A1 (ventpipe) and A2 (no ventpipe), for both the winter and summer periods, remain almost identical, although greater diurnal fluctuations are evident in summer. The heaps in both vaults consist of faeces plus soil only. Because there is no discernable difference between the two vaults in each case, it can be concluded that a ventpipe does not facilitate heat transfer to the faecal pile to any extent.

The reason for the greater diurnal temperature fluctuations in summer is not known, as the ambient temperature fluctuations are actually of smaller magnitude.



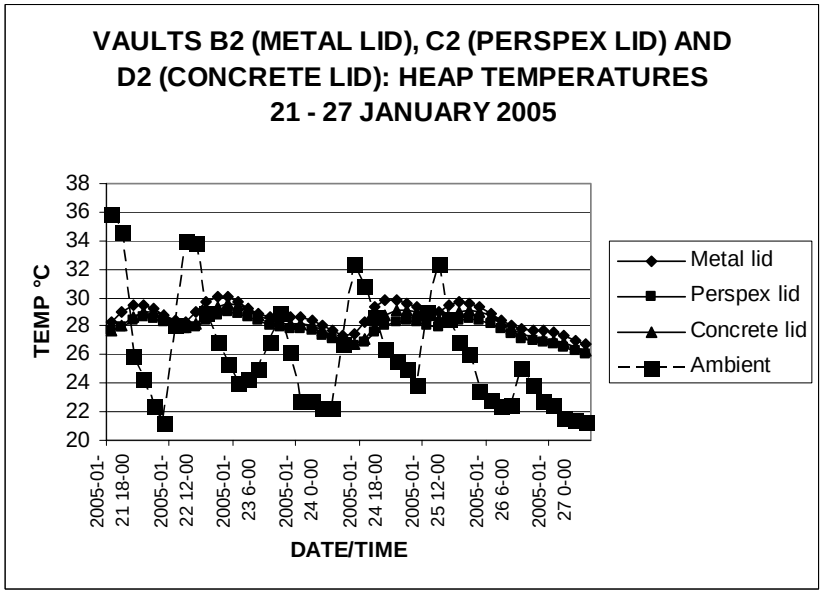


Figure 5.20: Influence of vault lid material on heap temperatures in July 2004 (winter) (top graph) and January 2005 (summer) (bottom graph) for vaults B2, C2 and D2.

The heap temperatures in vaults B2 (metal lid), C2 (perspex lid) and D2 (concrete lid), for both the winter and summer periods, remain almost identical, with a maximum difference of only about 2°C. The bulking agent in all three vaults is soil and wood shavings and none have ventpipes. In winter the perspex lid produces the highest temperature, followed by the metal lid, with the concrete lid producing the lowest. In summer the metal lid produces the highest temperature, followed by the concrete lid, while the perspex lid produces the lowest.

If the vertical scale effect is eliminated, there is virtually no difference between the magnitude of the diurnal temperature fluctuations between summer and winter.

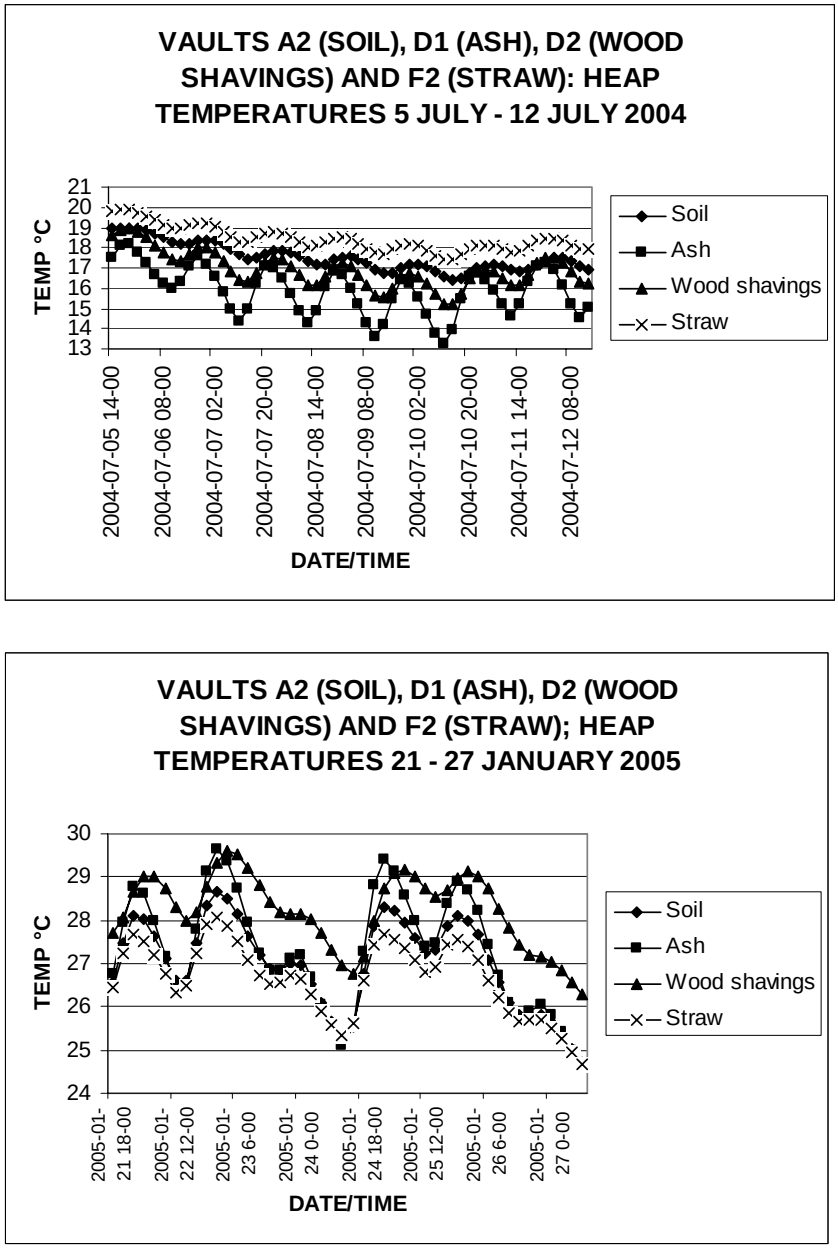


Figure 5.21: Influence of various bulking agents on heap temperatures in July 2004 (winter) (top graph) and January 2005 (summer) (bottom graph) for vaults A2, D1, D2 and F2.

The heap temperatures in vaults A2 (soil), D1 (ash), D2 (wood shavings) and F2 (straw) show clear differences during both the winter and summer periods. None of the vaults have ventpipes. The heap with straw shows the highest temperature in winter but the lowest in summer. The heap with ash shows the lowest temperature in winter but the second highest in summer. The heap with wood shavings has the second lowest temperature in winter but the highest in summer. The heap with soil varies between second highest and third highest in winter and summer respectively.

In winter the temperature differences vary between 2°C and 4°C and in summer between 1°C and 2°C. The reason for the reversal in trends between winter and summer is not known.

5.4.3 Discussion of temperature results

The following discussion should be seen in the light of the local climate in eThekwini – sub-tropical, mild to cool winters and warm summers with high humidity.

Influence of ventpipe:

There is very little difference in either the heap or the vault temperatures between vaults with ventpipes and those without. Ventilation should therefore not be considered to affect heat transfer to or from the faecal pile to any notable extent.

Residual warmth of heap:

Once the heap has developed a certain amount of warmth, the temperature fluctuates in a narrow band (1-3 degrees C) around that level even while the ambient temperature shows diurnal peak/trough differences of up to 18 degrees. This is an important observation as it implies that, should it be possible to raise the heap temperature to a satisfactory level for pathogen destruction, the temperature should remain high and not be subject to large daily fluctuations. This will obviously expedite pathogen die-off.

The fluctuations in heap temperature lag behind those of the ambient temperature, with highs and lows occurring at different times.

Temperature gradient in heap:

The surface of the heap is the warmest for most of the time, followed by the middle of the heap, while the inside layer is usually the coldest. The surface also shows the greatest fluctuations, occasionally becoming the coldest during pronounced drops in temperature. This is to be expected.

The temperature gradient in the heap is the opposite of what is found during a composting process, where the inside of the heap is generally the warmest.

Influence of vault lid material:

During summer the metal lid produces the highest heap temperature, followed by the concrete lid, with the perspex lid producing the lowest temperature. In winter the situation is different, with the perspex lid producing the highest heap temperature, followed by the metal lid with the concrete lid producing the lowest. These temperature differences should not be seen as significant, however, as the differences between them vary by less than 0,5°C to about 2°C.

Type of bulking agent:

In summer, wood shavings appear to allow the most heat transfer to the heap, with temperatures being almost consistently higher than heaps with other materials. In contrast to expectations, however, straw had the opposite effect and showed the lowest heat gain. It appears that wood shavings retain heat better than straw in this case. Even so, the difference was less than 2°C. Temperatures in the heap with only soil mixed with the faeces were roughly between the heaps with wood shavings and straw respectively. The coarse ash was second best.

In winter the situation was completely different, with straw showing the highest heat gain and ash the least, with soil and wood shavings in between. Once again, however, the total difference was small, being for the most part less than 3°C. The reason for the reversal in trends is not known.

Due to the relatively small temperature variation between bulking agents, the different treatments are not considered to have any significant effect compared with the basic mixture of faeces and soil. They should therefore not be considered to facilitate heat transfer in the heap to any notable extent.

In general, these additives tend to reduce the concentration of faecal matter in the mix, and less heat build-up can therefore be expected – it is not a composting process (which produces heat) that takes place. In an ignition test conducted on the faeces/soil mix, the content of organic material was found to be only 7,98%. If high-energy amendments, e.g. fruit peelings, food waste, etc. are added instead, then a higher heap temperature can be expected to occur.

The relatively low moisture content in the heaps also played a role in preventing a higher heat build-up than would be expected under e.g. composting conditions.

5.4.4 Microbiological results

Results are presented in tabular format in Appendix B. Graphical representations of selected parameters follow hereunder. The graphs shown are the following:

- All vaults: total coliform, faecal coliform and faecal streptococci (Figures 5.22 to 5.33).
- Main heap: total coliform, faecal coliform and faecal streptococci (Figure 5.34).
- Main heap rehydrated: total coliform, faecal coliform and clostridium (Figure 5.35).
- Main heap spiked: E.coli (Figure 5.36).
- Main heap spiked: Coliphage (Figure 5.37).
- Main heap: *Ascaris* eggs (Figure 5.38).
- Influence of type of bulking agent on *Ascaris* eggs (Figure 5.39).
- Influence of ventpipe on *Ascaris* eggs (Figure 5.40).

As mentioned previously, only one sample from each heap was taken and analysed each time, due to cost considerations. Further, not all parameters were analysed each time. It can be seen from the tables of results in Appendix C that the analyses of the different heaps, although each was taken from the same original heap, show varying results at the start of the experimentation, i.e. at t=0. This can be attributed to the fact that the results are reported for a certain weight of combined material (1g or 10g) and each vault had a different mix. Moreover, an inherent variability in sampling and testing is always present, particularly when only one sample is analysed each time, and there is considerable evidence of this in the results.

Comments on wood shavings and straw bulking agents:

The results show variability especially for the vaults where wood shavings and straw were used as bulking agents. These materials are well-known substrates for the growth or persistence of coliforms. Potentially also faecal streptococci will grow, and may also be a part of the decomposition flora of straw. This should be taken into account.

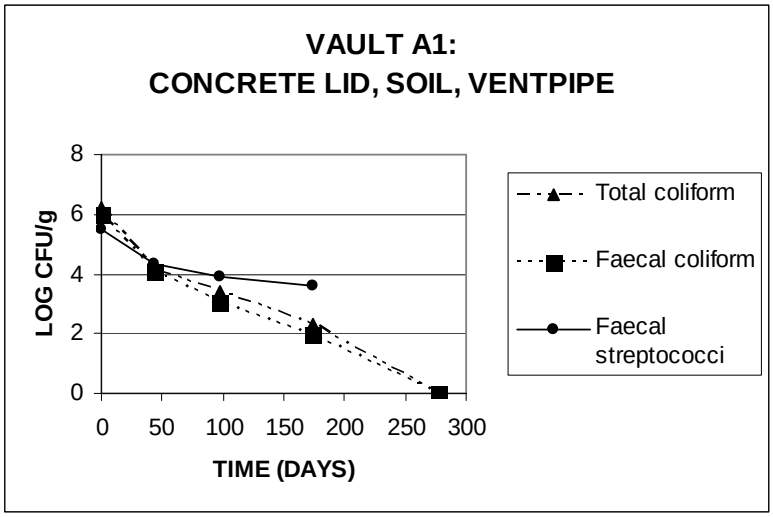


Figure 5.22: Vault A1 – total coliform, faecal coliform and faecal streptococci

In vault A1, total and faecal coliform numbers were reduced by approximately 6 $\log_{10}$ cfu/g over the 278 day experimental period, while faecal streptococci were reduced by 2 $\log_{10}$ cfu/g over 174 days. The $t_{99,9}$ value, i.e. time for 3 $\log_{10}$ die-off, for total coliforms was 135 days and for faecal coliforms 100 days, while faecal streptococci were not tested over a long enough period to determine this.

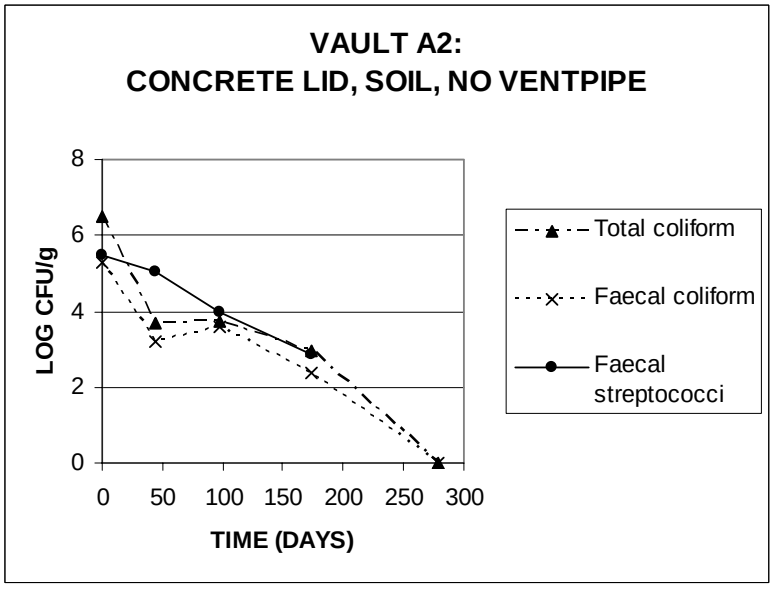


Figure 5.23: Vault A2 – total coliform, faecal coliform and faecal streptococci

In vault A2, total and faecal coliform numbers were reduced by approximately 6 $\log_{10}$ cfu/g over the 278 day experimental period, while faecal streptococci were reduced by approximately 2 $\log_{10}$ cfu/g over 174 days. The $t_{99,9}$ value for total coliforms was 140 days, for faecal coliforms 195 days and for faecal streptococci 140 days.

There appears to be no discernable difference that could be ascribed to the presence of a ventpipe in vault A1.

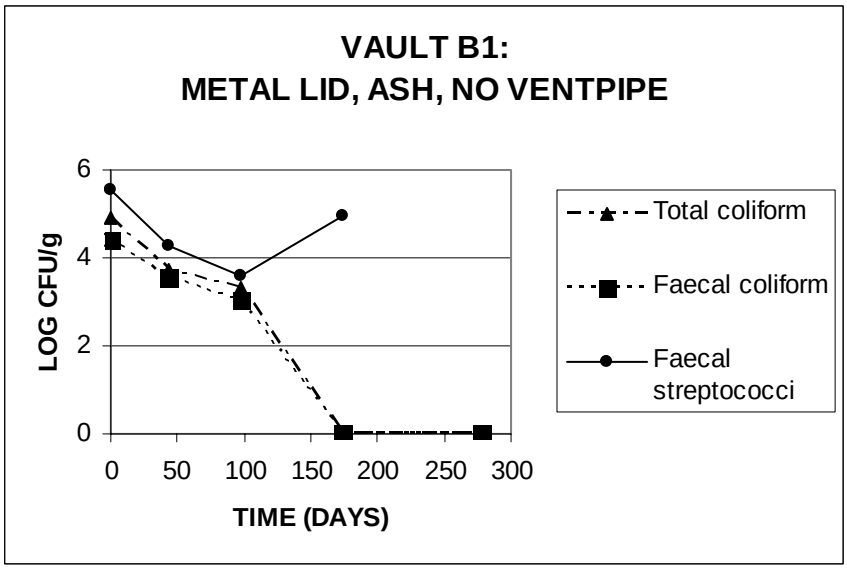


Figure 5.24: Vault B1 – total coliform, faecal coliform and faecal streptococci

In vault B1, total and faecal coliform numbers were reduced by approximately 5 $\log_{10}$ cfu/g over 174 days, while faecal streptococci were reduced by approximately 2 $\log_{10}$ cfu/g over 97 days before showing an upward trend again. This phenomenon is most likely due to sample variability and should not be seen as significant. The $t_{99,9}$ value for total coliforms was about 130 days, for faecal coliform about 140 days, while faecal streptococci were not tested over a long enough period to determine this.

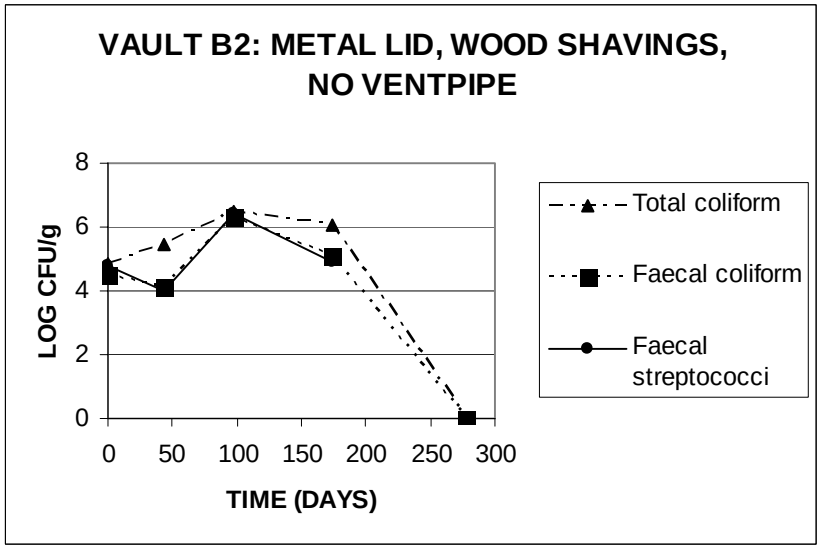


Figure 5.25: Vault B2 – total coliform, faecal coliform and faecal streptococci

In vault B2, total and faecal coliform numbers were reduced by approximately 5 $\log_{10}$ cfu/g over 278 days, while first showing an upward trend over the first 97 days due to reasons discussed earlier. Faecal streptococci exhibited large fluctuations over a period of 174 days. These fluctuations should not be seen as significant. Due to the variability, the $t_{99,9}$ value for total and faecal coliforms increased to about 250 days, while faecal streptococci were not tested over a long enough period to determine this.

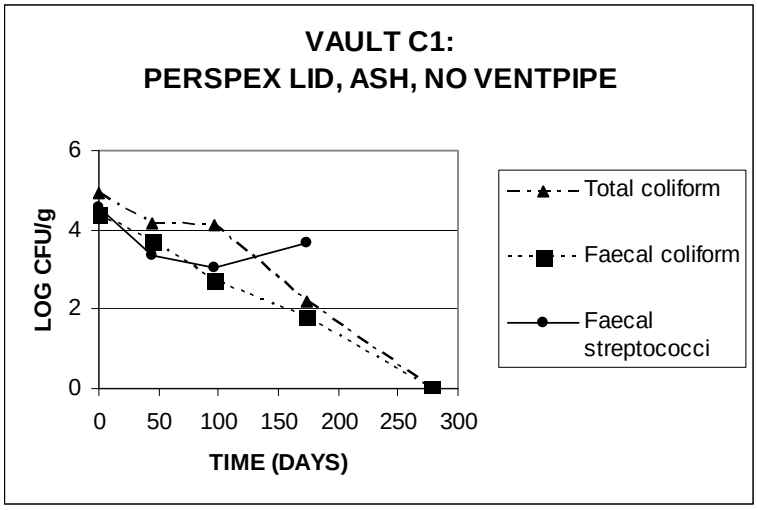


Figure 5.26: Vault C1 – total coliform, faecal coliform and faecal streptococci

In vault C1, total and faecal coliform numbers were reduced by approximately 5 $\log_{10}$ cfu/g over 278 days, while faecal streptococci were reduced by approximately 2 $\log_{10}$ cfu/g over 97 days before showing an upward trend again. This is most likely due to sample variability, as the sample at 174 days exhibited a much higher moisture content than the previous sample at 97 days – 21,8% as opposed to 7,1%. The $t_{99,9}$ value for total coliforms was about 135 days, for faecal coliform about 200 days, while faecal streptococci were not tested over a long enough period to determine this.

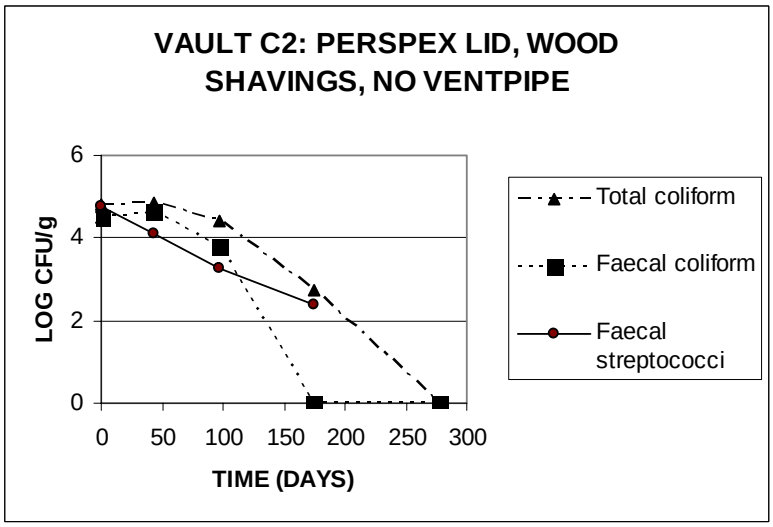


Figure 5.27: Vault C2 – total coliform, faecal coliform and faecal streptococci

In vault C2, total coliform numbers decreased by approximately 5 $\log_{10}$ cfu/g over 174 days, while faecal coliform reduced by 5 $\log_{10}$ cfu/g over 278 days. Faecal streptococci reduced by approximately 2 $\log_{10}$ over 174 days. The $t_{99,9}$ value for total coliform was about 210 days, for faecal coliform about 145 days, while faecal streptococci were not tested over a long enough period to determine this.

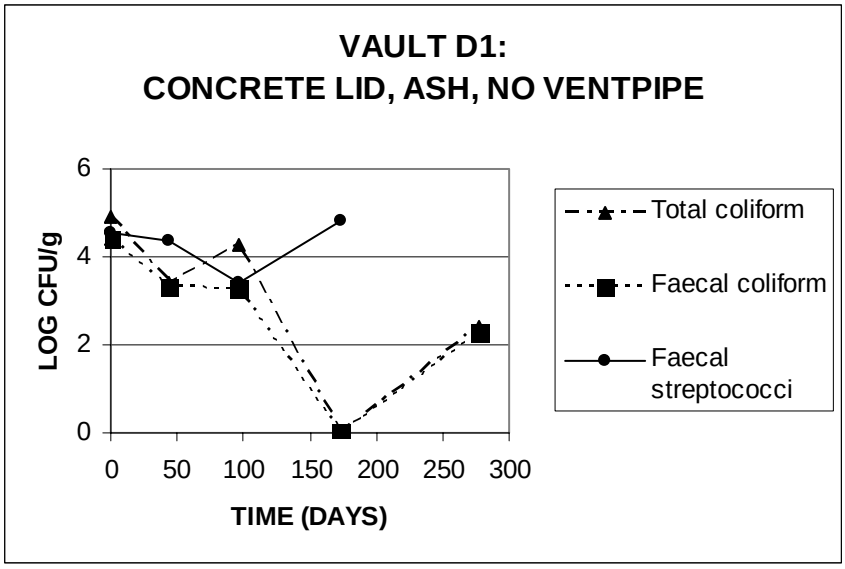


Figure 5.28: Vault D1 – total coliform, faecal coliform and faecal streptococci

In vault D1, all parameters exhibited large fluctuations. Total and faecal coliforms reduced by approximately 5 $\log_{10}$ cfu/g over 174 days, with total coliform showing a temporary increase of about 1 $\log_{10}$ cfu/g at 97 days. Total and faecal coliforms both show an increase again of 2 $\log_{10}$ cfu/g at 278 days, while faecal streptococci display an increase of approximately 2 $\log_{10}$ cfu/g at 174 days. Although sample variability played a noteworthy role in the fluctuating values of all the parameters, it can be seen that $t_{99,9}$ for total and faecal coliform was about 135 days, while faecal streptococci did not achieve this reduction.

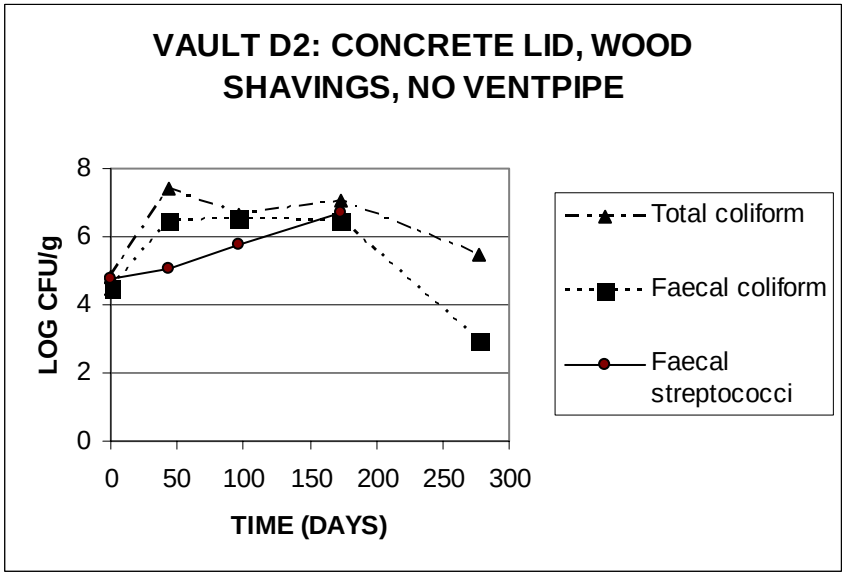


Figure 5.29: Vault D2 – total coliform, faecal coliform and faecal streptococci

In vault D2 only faecal coliform show an overall decrease in numbers – amounting to approximately 2 $\log_{10}$ cfu/g over 278 days. Total coliforms display an overall increase of approximately 1 $\log_{10}$ cfu/g over 278 days, while faecal streptococci exhibit a continuous increase amounting to approximately 2 $\log_{10}$ over 174 days. None of the parameters reached a 3 $\log_{10}$ reduction.

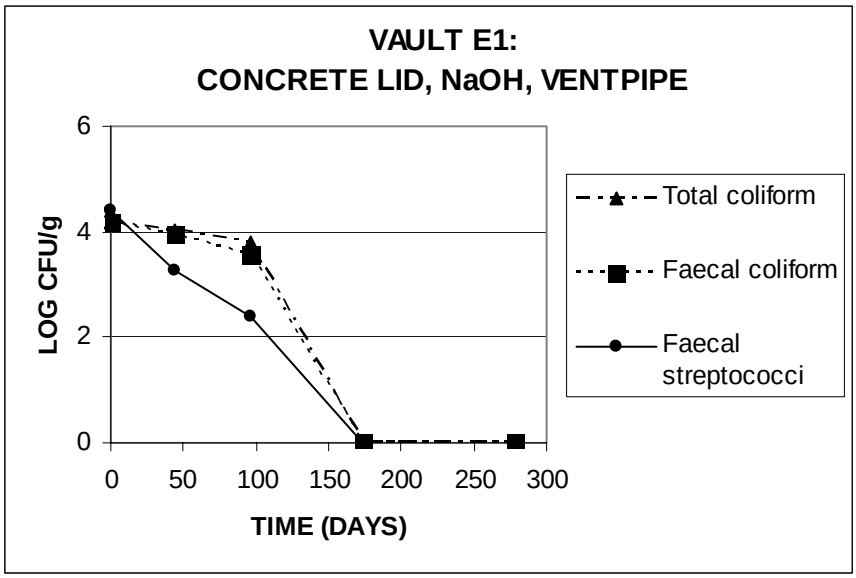


Figure 5.30: Vault E1 – total coliform, faecal coliform and faecal streptococci

In vault E1, all parameters exhibit strong decreasing tendencies, reducing by approximately 4 $\log_{10}$ cfu/g over 174 days. Faecal streptococci show the fastest rate of die-off, with a $t_{99,9}$ value of about 125 days, while total and faecal coliforms display a $t_{99,9}$ value of about 150 days.

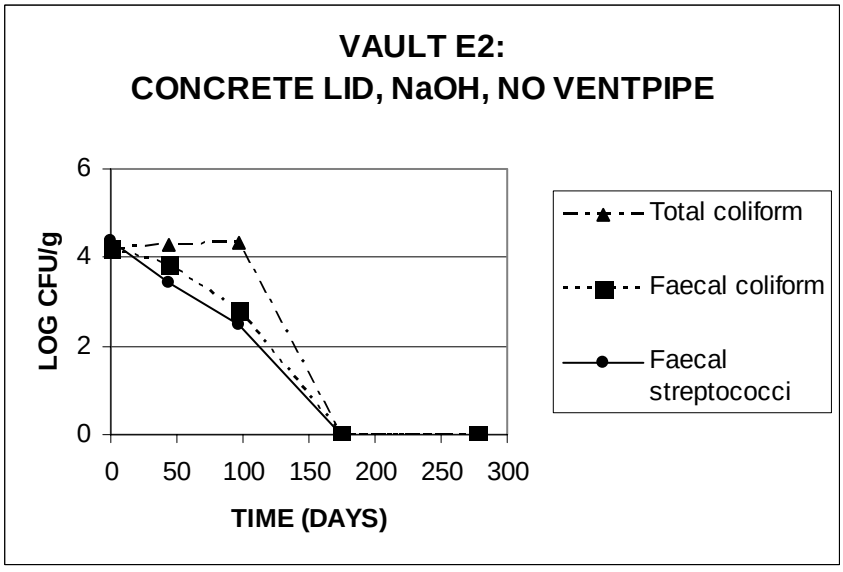


Figure 5.31: Vault E2 – total coliform, faecal coliform and faecal streptococci

In vault E2, all parameters show a decrease of approximately 4 $\log_{10}$ cfu/g over 174 days. Faecal streptococci numbers once again show the fastest rate of die-off, with a $t_{99,9}$ value of about 125 days, followed by faecal coliform at about 150 days. Total coliform numbers exhibit an increase until 97 days (possibly due to an increase in moisture content from 8,6% to 21,4%) and the $t_{99,9}$ value is about 155 days.

There appears to be no discernable difference that could be ascribed to the presence or absence of a ventpipe in vaults E1 and E2 respectively.

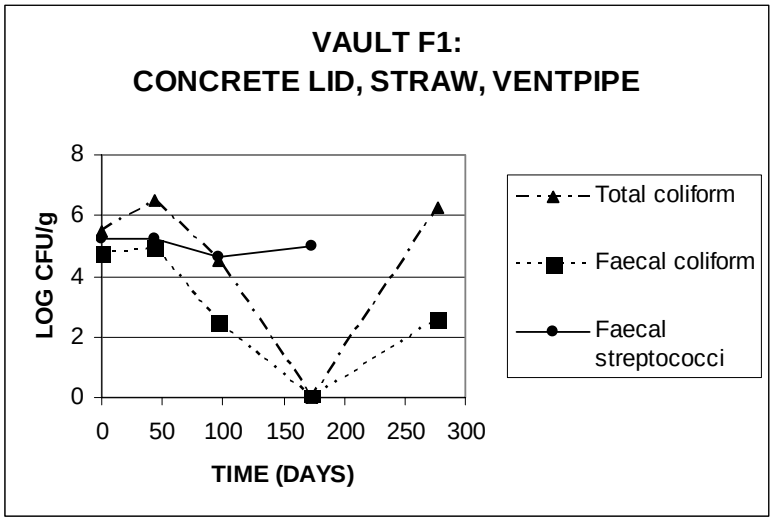


Figure 5.32: Vault F1 – total coliform, faecal coliform and faecal streptococci

In vault F1, faecal streptococci numbers remain virtually constant while both total and faecal coliform numbers show an increase initially before dropping approximately 5 $\log_{10}$ cfu/g by 174 days. Thereafter large increases are evident at 278 days. These fluctuations are most likely due to the reasons discussed earlier and should not be regarded as significant. The $t_{99,9}$ values for total and faecal coliforms are about 130 days and 125 days respectively, while faecal streptococci were not tested over a long enough period to determine this.

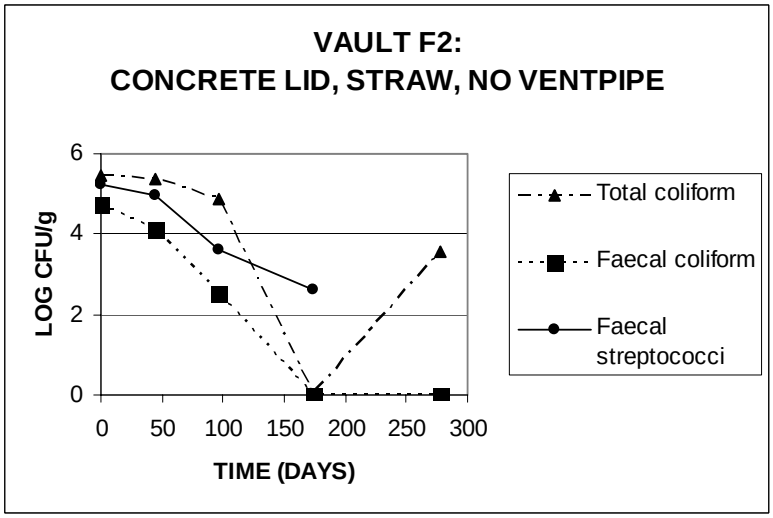


Figure 5.33: Vault F2 – total coliform, faecal coliform and faecal streptococci

In vault F2, all parameters show a decline in numbers: both total and faecal coliforms are reduced by approximately 5 $\log_{10}$ cfu/g after 174 days and faecal streptococci by approximately 3 $\log_{10}$ cfu/g in the same period. Once again there is a large increase in total coliform numbers at 278 days for reasons described earlier. The $t_{99,9}$ value of total coliform is about 130 days, faecal coliform about 120 days and faecal streptococci about 174 days.

There appears to be no discernable difference that could be ascribed to the presence or absence of a ventpipe in vaults F1 and F2 respectively.

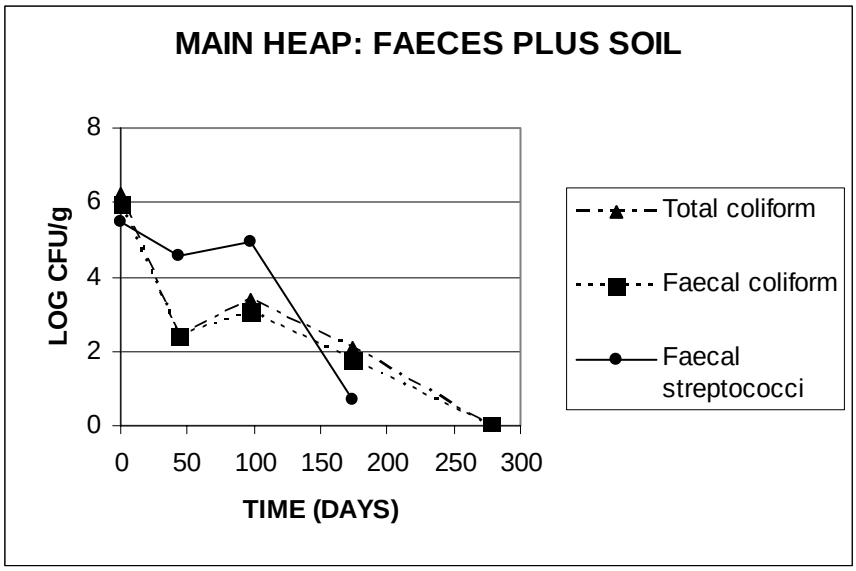


Figure 5.34: Main heap: total coliform, faecal coliform and faecal streptococci

In the main heap of material (faeces plus soil), total and faecal coliform numbers reduce in an almost identical fashion by 6 $\log_{10}$ cfu/g after 278 days, while faecal streptococci reduce by approximately 5 $\log_{10}$ cfu/g after 174 days. There are small increases for all parameters at 97 days, most probably due to sample variability. The $t_{99,9}$ value of both total and faecal coliforms is about 115 days and of faecal streptococci about 140 days.

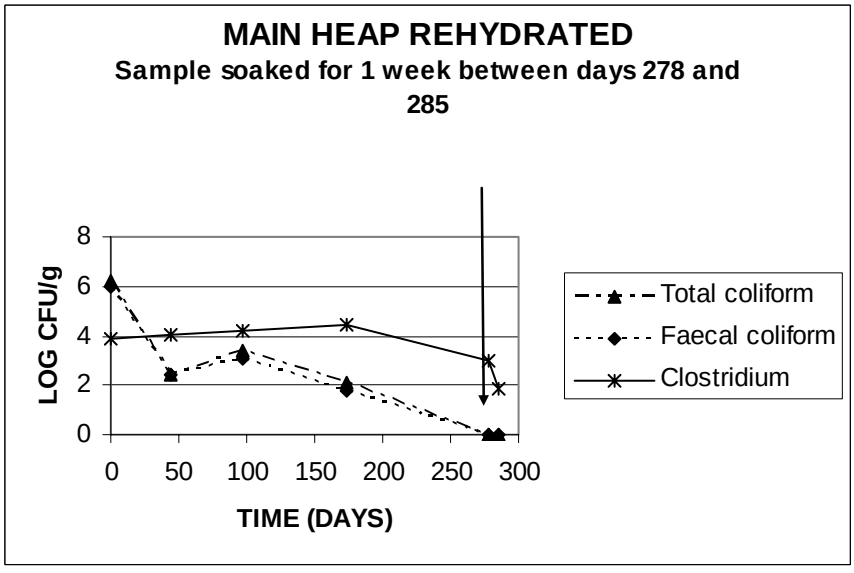


Figure 5.35: Main heap rehydrated: total coliform, faecal coliform and clostridium

The sample taken at 278 days was rehydrated with distilled water for one week, after which the organisms were enumerated again. For the coliforms the count was less than 3 on both occasions, showing that there had been no growth in these organisms, while clostridium decreased further by 1 $\log_{10}$ cfu/g. This indicates that the sample was probably microbiologically stable by this time.

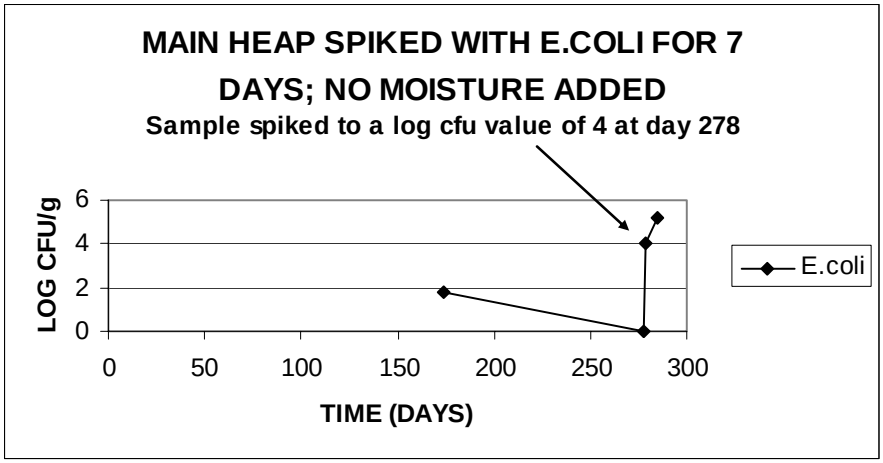


Figure 5.36: Main heap spiked: *E.coli*

The sample taken at 278 days was spiked with *E.coli* to a $\log_{10}$ cfu value of 4,0 (i.e. $1{,}0 \times 10^4$ cfu/g) following which the organism was enumerated again after one week. After this time the count had risen by 1 $\log_{10}$ to $1{,}6 \times 10^5$ cfu/g. Comparing this graph with the previous one (Figure 5.35), this phenomenon probably implies that there were not enough bacteria left in the sample to be able to compete with the *E.coli* for nutrients, thus allowing the latter organism to grow further.

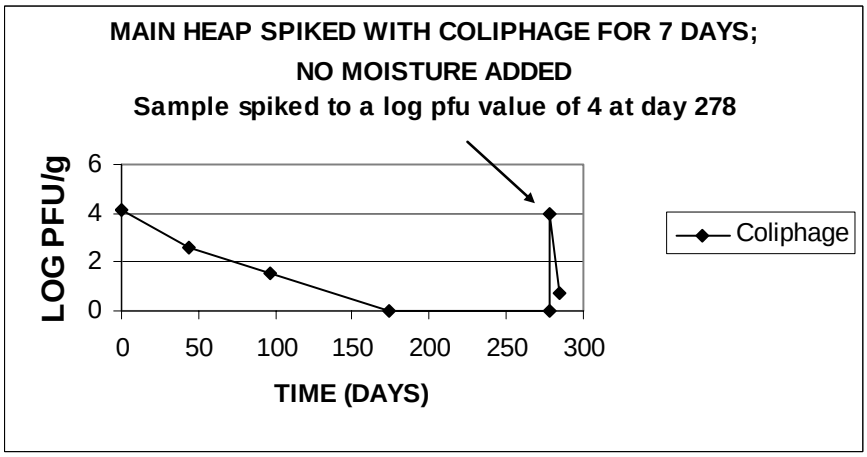


Figure 5.37: Main heap spiked: Coliphage

The sample taken at 278 days was spiked with coliphage virus to a $\log_{10}$ pfu value of 4,0 (i.e. $1{,}0 \times 10^4$ pfu/g) following which the organism was enumerated again after one week. After this time the count had reduced to 5. Comparing this graph with Figure 5.35, this phenomenon probably implies that there were not enough *E. coli* and other bacteria left in the sample for the virus to host on.

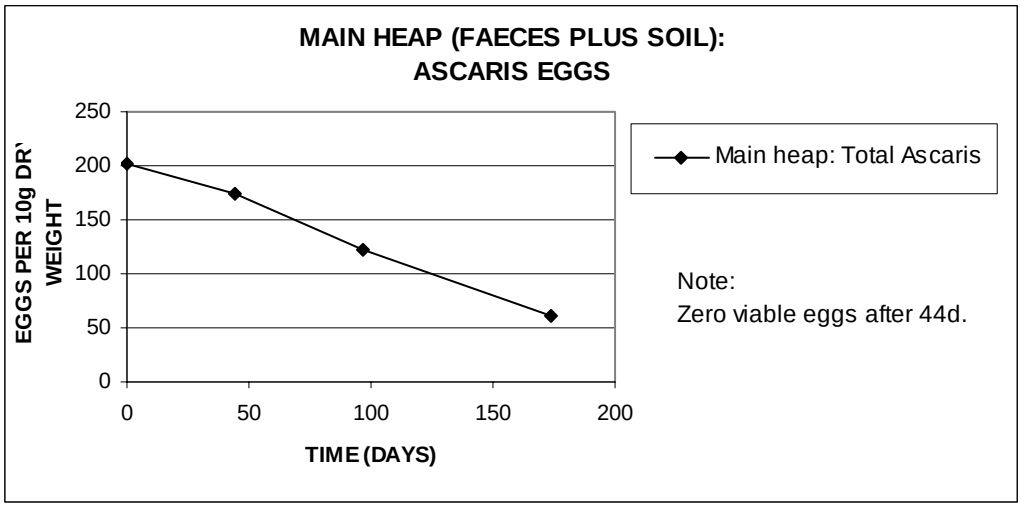


Figure 5.38: Main heap: *Ascaris* eggs

In the main heap (faeces plus soil), the number of total *Ascaris* eggs reduced consistently from an initial 201 to 62 over a period of 174 days. However, the actual viable eggs were reduced to zero by 44 days.

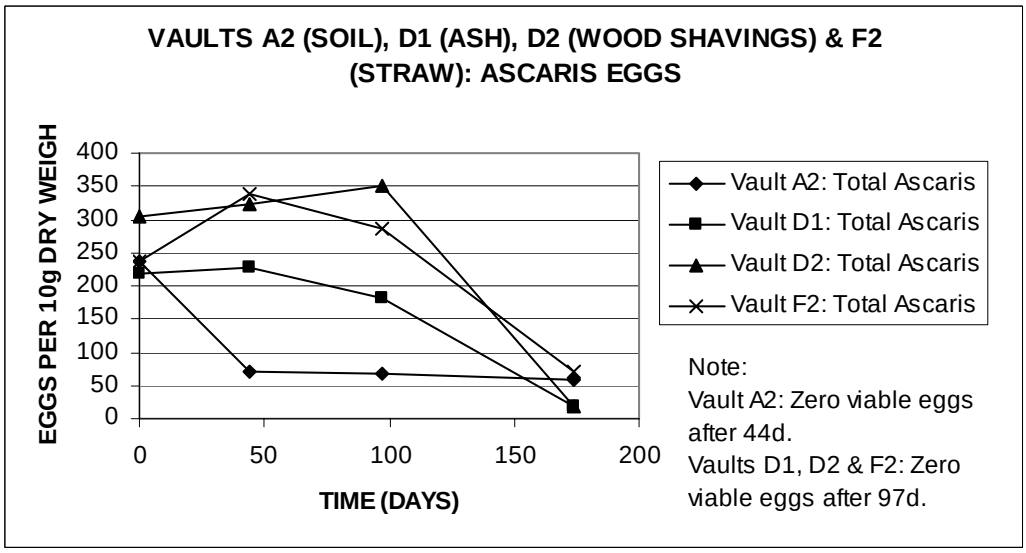


Figure 5.39: Influence of type of bulking agent on *Ascaris* eggs

In vault A2 (soil) the number of total *Ascaris* eggs reduced from an initial 237 to 60 in 174 days, with the actual viable eggs being zero by 44 days. In vault D1 (ash), the numbers of total eggs reduced from 218 to 20 by 174 days; in vault D2 (wood shavings) from 305 to 17 by 174 days; and in vault F2 (straw) from 237 to 72 by 174 days. In the latter three vaults the actual viable eggs were reduced to zero by 97 days. None of the vaults were fitted with ventpipes. The counts in the latter three vaults showed increases initially, but these were probably the result of sample variability.

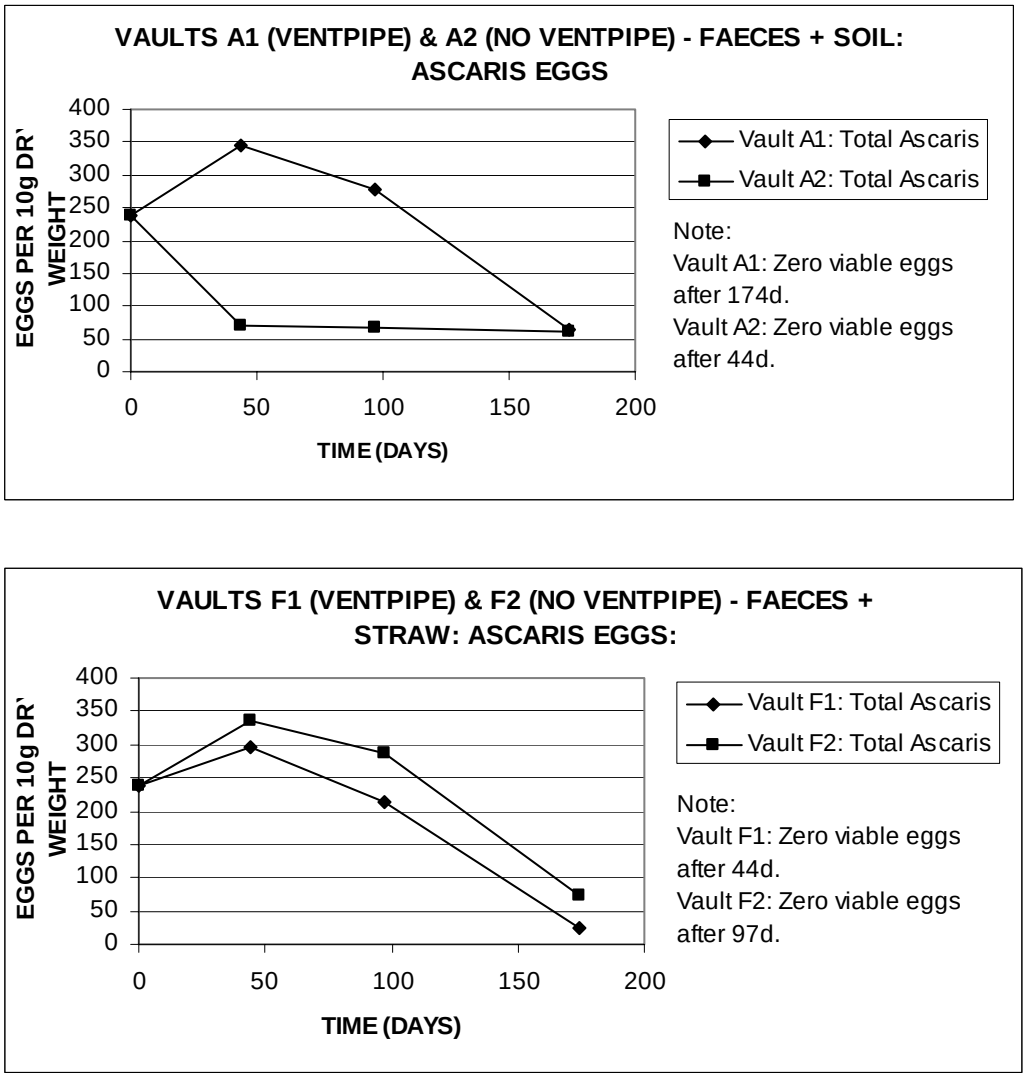


Figure 5.40: Influence of ventpipe on *Ascaris* eggs

In vaults A1 and A2 (faeces plus soil), the numbers of total *Ascaris* eggs reduced from an initial 237 to 64 and 60 after 174 days respectively, with the actual viable eggs being reduced to zero by 174 days and 44 days respectively. It appears, however, that the results of vault A1, because of the increase in numbers at day 44, were subject to sample variability. It cannot therefore be construed that the presence or absence of a ventpipe has any discernable effect. It is nevertheless clear that the eggs do not survive longer than six months in this type of environment.

In vaults F1 and F2 (faeces plus straw), the numbers of total *Ascaris* eggs reduced from an initial 237 to 23 and 72 after 174 days respectively, with the actual viable eggs being reduced to zero by 44 days and 97 days respectively. Once again it appears that the results of both vaults, because of the increase in numbers at 44 days, were subject to sample variability. It cannot therefore be construed that the presence or absence of a ventpipe has any discernable effect. It is nevertheless clear that the eggs do not survive longer than about three months in this type of environment.

5.4.5 Discussion of microbiological results

The various combinations of bulking agent, vault lid and ventpipe are summarised in Table 5.4 below.

Table 5.4: Treatments applied to each heap or vault

Heap/vault	Treatment		
	Bulking agent	**Lid type**	**Ventpipe**
Main Heap	Soil	None	–
Vault A1	Soil	Concrete	Yes
Vault A2	Soil	Concrete	No
Vault B1	Ash	Metal	No
Vault B2	Wood	Metal	No
Vault C1	Ash	Perspex	No
Vault C2	Wood	Perspex	No
Vault D1	Ash	Concrete	No
Vault D2	Wood	Concrete	No
Vault E1	NaOH	Concrete	Yes
Vault E2	NaOH	Concrete	No
Vault F1	Straw	Concrete	Yes
Vault F2	Straw	Concrete	No

For cost reasons, only one sample from each heap was taken at the various time intervals (t=0, t=44, t=97, t=174 and t=278, where t represents the number of days from the time the vaults were loaded). A summary of the tests undertaken is shown in Table 5.5. Due to the single samples, a statistical analysis was considered inappropriate.

In Table 5.6 the times for 3 $\log_{10}$ (i.e. 99,9% reduction) are indicated for total coliform, faecal coliform and faecal streptococci in the various vaults as well as in the main heap. These are seen to vary as follows:

Vaults:
130 to 250 days for total coliform, 100 to 250 days for faecal coliform, and 125 days and longer for faecal streptococci.

Main heap:
115 days for total and faecal coliform, and 140 days for faecal streptococci.

In addition, viable *Ascaris* ova were reduced to zero between 44 and 174 days in the vaults and by 44 days in the main heap.

Table 5.5: Parameters tested in each sample

Parameter
Heterotrophic plate count per g
Total coliform bacteria count per g
Faecal coliform bacteria count per g
Faecal streptococci bacteria count per g
Coliphage count per g
Clostridium count per g
Ascaris eggs per 10g dry weight
Moisture content %
E coli bacteria count per g
Salmonella spp per g (present/absent)
pH
Cryptosporidium oocysts count per 10g dry weight
Giardia cysts count per 10g dry weight
Entamoeba spp eggs per 10g dry weight
Taenia eggs per 10g dry weight

Table 5.6: Time for 3 $\log_{10}$ (99,9%) reduction for some parameters

Vault	Time for 3 $\log_{10}$ reduction - days		
	Total coliform	Faecal coliform	Faecal streptococci
A1	135	100	-
A2	140	195	140
B1	130	140	-
B2	250	250	-
C1	135	200	-
C2	210	145	-
D1	135	135	-
D2	-	-	-
E1	150	150	125
E2	155	150	125
F1	130	125	-
F2	130	120	-
Main	115	115	140

Figure 5.41 shows the trends in heterotrophic plate count, total coliform bacteria and coliphage for the various vaults in combined graphs.

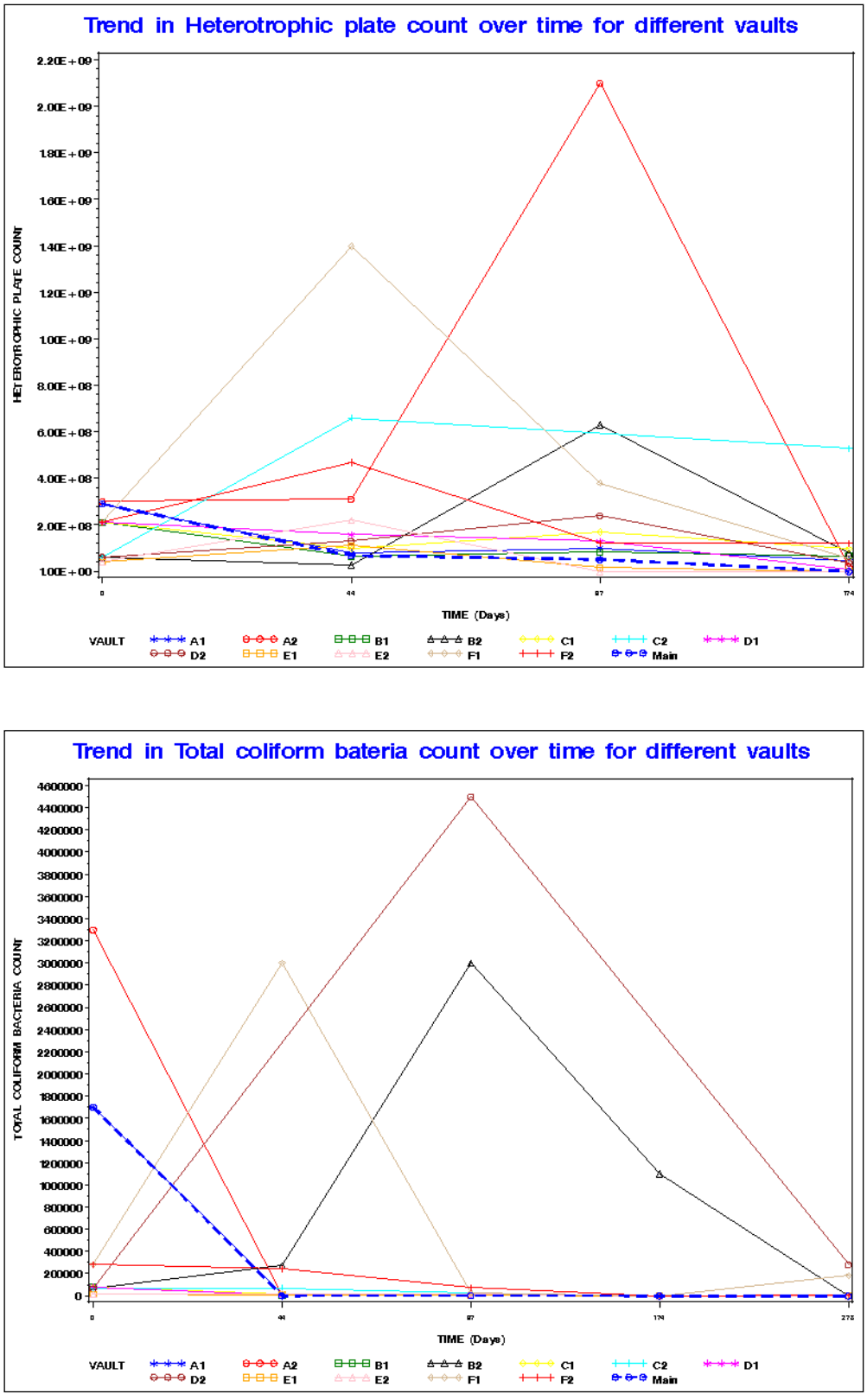


Figure 5.41: Trend in indicator counts over time for different vaults

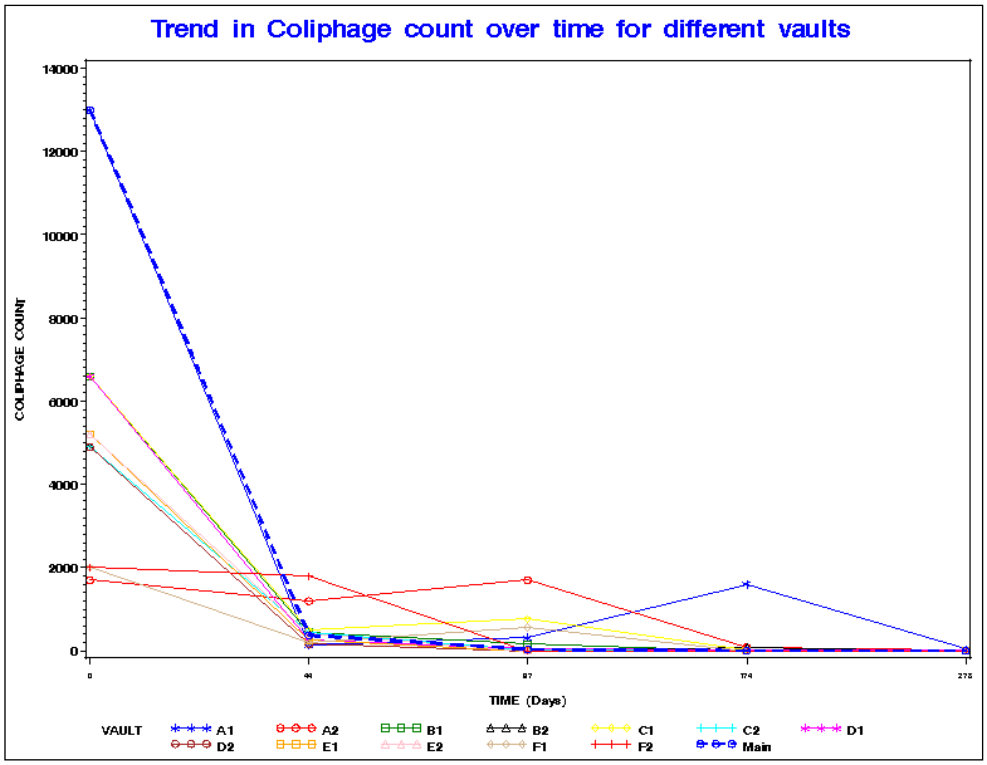


Figure 5.41 (cont): Trend in indicator counts over time for different vaults

Conclusions:

Overall, no effect of lid type and the absence or presence of a ventpipe can be seen in the results, but there is evidence that the type of bulking agent plays a role. Generally the soil mix shows a much better performance than the other mixes with regard to the objective (i.e. rate of pathogen die-off) irrespective of whether the soil mix is closed in a vault (vault A1) or on the open heap exposed to the elements. The ash and soil mixes appear to have the second best rate of pathogen die-off, while the NaOH and wood mixes appear to perform the worst of all the mixes in terms of pathogen die-off rate.

The importance of keeping the vaults dry is evidenced by the relatively poor performance of the NaOH mix with regard to the rate of pathogen destruction compared with most of the other vaults. From a study of the literature, the addition of a pH elevating agent should be one of the most effective treatments for the destruction of pathogens in faecal material. The beneficial effect of the additive was in this case, however, countered by the ingress of a large quantity of water into the particular vaults, as mentioned earlier in the chapter. The moist conditions favoured continued pathogen survival. Care should therefore be taken during design and construction of urine-diversion toilets to divert storm- or groundwater away from the vaults, and toilet users need to be made aware that no wastewater or other liquids should be poured into the vaults.

The selection of the type of ash for use as a bulking agent is important. In this particular case the pH of the faeces/coal ash mixture was virtually neutral and the result in terms of pathogen destruction was not as good as the best performing faeces/soil mixture,

although better than the wood shavings mixture with the lower pH. It is possible that a wood ash with a higher pH (±10) would have performed the best in this case. Ashes from different sources are seen to have different pH values, and this needs to be recognised during the project planning process. Local sources of ash (e.g. cooking fires) should be analysed for pH value and suitable recommendations made to the toilet users.

The material is likely to be microbiologically stable at the end of the recommended storage period, as evidenced by Figures 5.35 to 5.37. Should the material be used for agricultural purposes after this period, it is therefore unlikely that watering of crops grown in the faecally amended soil will pose any danger to crop handlers or consumers, or that any pollution of water resources will take place.

5.5 OVERALL DISCUSSION OF TEMPERATURE AND MICROBIOLOGICAL RESULTS AND CORRELATION WITH OTHER RESEARCH

As before, the following discussion should be seen in the light of the local climate in eThekwini – sub-tropical, mild to cool winters and warm summers with high humidity. It is likely that different results would be obtained in another climatic zone, for example a dry and hot area.

Influence of ventpipe:

Although there appears to be some correlation between moisture content and the presence of a ventpipe in vaults A1 and F1, ventilation of the vault did not result in any meaningful difference in either the vault temperature or the rate of pathogen die-off. Conventional ventilation (i.e. a ventpipe) should therefore not be considered to contribute anything other than a reduction of odours and flies in the toilet superstructure.

Influence of vault lid material;

The lid material, and by inference also the material of the vault walls, has no significant effect on the temperature of the heap or the associated rate of pathogen die-off. This implies that any suitable locally available building material may be used, which has favourable cost implications.

Type of bulking agent:

While the type of bulking agent used does not significantly influence the temperature of the faecal material, it does have an effect on the rate of pathogen die-off. Although the data obtained from the field experimentation implies that the ordinary soil mix gives the best results, it cannot (in this case) be ascribed to pH effects and is more likely to be the result of competing microorganisms in the soil itself. Furthermore, the (relatively) poor performance of the ash and NaOH mixes can be ascribed to external influences in this case – the pH of the ash was not as high as expected while the effects of the high pH of NaOH were negated by the presence of water in the particular vaults. Normally these are considered good additives and should be used wherever possible. While the use of NaOH is probably not economically justifiable, and will in any case not be readily available in rural areas, the use of ash from domestic cooking fires has proven to be effective in many

countries (Austin 2000; Austin 2001; Esrey and Andersson 2001; Gough 1997; Guzha 2004; Moe et al 2001; Proudfoot et al 2002; Winblad 1996).

Perhaps the most important observation regarding bulking agents is that where other suitable materials are not available (e.g. where households have access to electricity and may thus not have any ash) the addition of soil will promote satisfactory pathogen die-off.

Influence of sunshine and rain:

The main heap performed among the best in terms of pathogen die-off. While the heap was subject to frequent soaking by rain, it always appeared to dry out fairly rapidly and the moisture content at times of sampling was generally low compared with the vaults. It is surmised that the relatively good pathogen reduction evidenced here is as a result of the alternate wetting/drying and heating/cooling cycles, as well as UV light on the surface of the heap. This suggests that the best treatment, especially in hot, dry areas, could be obtained simply by open-air exposure. This has important implications for entrepreneurs involved in collection and further treatment (e.g. compost manufacturing) of faecal material from urine-diversion toilets, as expensive sheds or covered areas may not be required. Eco-villages using urine-diversion toilets could also beneficially use an open-air space for storage and further treatment (e.g. co-composting) of faecal material.

Rate of pathogen destruction:

The faecal material was, as previously noted, between one and three months old when collected from the UD toilets, after which the various samples were mixed together to produce a homogenous product. While it is not known what the relative “age” of the final, mixed, product was at the start of experimentation, initial pathogen counts were high enough to suggest a comparatively “fresh” product. However, some time (say three months) should, for safety, be added to the time for achieving the pathogen die-off indicated by the results of the experimentation. In the majority of cases, faecal coliform bacteria were reduced to below 10^3 per g (the South African limit for use of sewage sludge in agriculture (WRC 2006) which is also the USEPA limit) within 6 months from the start of experimentation, while viable *Ascaris* eggs were seen to be reduced to zero within 3 months, thus also fulfilling the South African requirement of <0,25/g. Cryptosporidium oocysts, Giardia cysts, as well as *Entamoeba* and *Taenia* eggs were also seen to be reduced significantly within six months. A total storage period of 9 to 12 months is thus considered sufficient.

Arnbjerg-Nielsen et al (2004) conducted a study in Denmark where scenarios associated with faeces use, such as emptying of the faecal container and distribution of the material in the garden, gardening itself as well as recreational activities in the garden were considered. They concluded that 12 months of storage of faeces without additional treatment (such as addition of pH elevating compounds) were not sufficient for inactivation of pathogens to acceptable levels (yearly risk of infection $<10^4$). Ascaris were seen to constitute the highest risk. In the eThekwini experimentation, however, even the addition of soil only and storage for a shorter time proved to be acceptable.

Moe and Izurieta (2003), in a study conducted on double-vault urine-diversion toilets in El Salvador, found that 81% of biosolids sampled met the USEPA faecal coliform standard of 10^3 per g within 12 months of storage, thus supporting the eThekwini research results.

However, only 59% of their samples met the USEPA *Ascaris* standard of 1 ovum per 4g in this time.

Stenström (2001) reported that Vietnamese and Chinese experiments on urine-diversion toilets showed a 100% reduction of viability in *Ascaris* ova after a storage period of six months. Further research showed reductions of 4 to 6 $\log_{10}$ in faecal enterococci within six months and 5 to >6 $\log_{10}$ in bacteriophage virus. These results therefore support the eThekwini observations.

Redlinger et al (2001b) report on research carried out in Chihuahua, Northern Mexico, where the climate is dry and sunny all year round, with hot summers and cool winters. According to these authors, solar exposure of the toilets was important for raising the temperature of the faecal material, with 95% of the samples complying with a USEPA class A rating being from toilets with good solar exposure. They maintained that class A biosolids were 10,2 times likelier to occur in these toilets than in toilets without good solar exposure. The low moisture content that resulted from the solar heat was found to promote pathogen destruction. This was not found to be the case in eThekwini. The authors noted that the year-round dry climate was an important factor in desiccation of the faecal material. Finally, the authors recommended that the faecal material not be used before six months of storage and that no six-month material should be disposed of on edible plants or in areas where persons could be exposed via dust or direct contact. This also supports the eThekwini observations.

Proudfoot et al (2002), in research conducted in informal settlements around Harare, Zimbabwe, found a complete reduction of *E. coli* in urine-diversion toilets within 8 weeks. They also found that Streptococci and Clostridium organisms were in most cases eliminated in 16 weeks and suggested that the faecal material would be safe to use within 4 to 6 months of storage. This is about half the period suggested above.

From the temperature data, particularly Figure 5.18, as well as the microbiological results, it is evident that certain areas of the heaps are colder than others, which may delay pathogen inactivation in these localised “pockets” of material. In order to obviate this problem the heaps would have to be turned regularly so that a homogenous temperature, as far as possible, is obtained throughout the heap.

Taking all the above into consideration it would appear that there is a great deal of convergence in the research results, both locally and abroad. Vaults of UD toilets should therefore be sized for a storage period of 12 months from last use. Further design guidelines are presented in chapter 6.

CHAPTER 6
RECOMMENDATIONS FOR CONSTRUCTION, OPERATION AND REGULATION OF URINE-DIVERSION TOILETS

6.1 INTRODUCTION

6.1.1 What this research has shown

The standard of urine-diversion (UD) toilets in South Africa varies greatly. While there are many good examples of the technology, there are also many that have been ill-conceived and that are badly built and poorly operated. Project implementers are responsible for the quality of sanitation schemes and should be equipped with the necessary information to oversee the process. Of course, successful implementation also requires that sufficient funds are made available to allow good project supervision to take place. This is a crucial aspect and one that is often overlooked to the detriment of the project.

These guidelines are aimed at providing implementers with, firstly, the necessary technical information to build good quality urine-diversion toilets and, secondly, the basic operation and maintenance tasks that should be conveyed to the toilet owners. The guidelines are intended to be a stand-alone document and some repetition of information from earlier chapters is thus unavoidable.

6.1.2 Scope of guidelines

The technology of urine diversion is introduced, followed by basic design and construction guidelines, including drawings, for the superstructure and vault of a UD toilet. Both single- and double-vault toilets are discussed. A number of photographs are also provided, illustrating good and bad building practices. Further aspects discussed are requirements for urine pipes and ventilation.

Operation and maintenance of UD toilets are subsequently covered. Topics discussed are dehydration, odour, fly control, cleaning of the pedestal, disposal of anal cleansing material, urine collection and disposal, clearing of blockages in urine pipes, and faeces management.

The above guidelines are aimed at designers and toilet users. However, organisations responsible for administering public and environmental health, such as Departments of Health, Environmental Affairs, etc, as well as the local and regional authorities that actually implement the sanitation schemes, should become actively involved in regulating the operation of UD toilets, particularly the removal and disposal of faecal material. Some regulatory guidelines are therefore also included to assist these organisations to set uniform (high) standards in their respective jurisdictions.

6.2 DESIGN AND CONSTRUCTION GUIDELINES

6.2.1 Introduction

Urine-diversion (UD) toilets have been used successfully for many years in a number of developing countries, e.g. Vietnam, China, Mexico, El Salvador, Ecuador, Guatemala and Ethiopia, and recently also in Zimbabwe and South Africa. The technology is not restricted to developing countries, however; some highly developed countries, such as Sweden for example, have incorporated these sanitation systems into various housing estates in both single and multi-storey houses and apartment blocks. The most important difference between UD and composting toilets is the moisture content in the faeces receptacle. Urine is diverted at source by a specially designed pedestal and is not mixed with the faeces. A pit is not necessary as the entire structure may be constructed above ground; alternatively, only a shallow excavation (maximum 500mm) may be required. The toilet may even be inside the dwelling. Material such as ash, dry soil or sawdust is sprinkled over the faeces after using the toilet. These agents absorb the moisture and also control odours and flies. The dry conditions facilitate rapid desiccation of the faeces. The desiccated faeces make a good soil conditioner, while urine is an excellent source of fertiliser, being rich in nitrogen, phosphorus and potassium.

A schematic representation of a UD toilet is given in Figure 6.1, while Figure 6.2 depicts a typical UD pedestal. Figure 6.3 shows some examples of easy to build toilet structures.

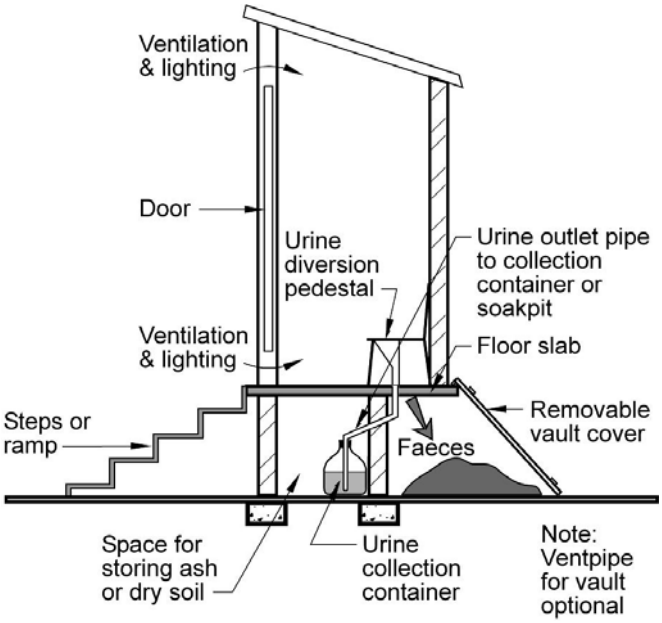


Figure 6.1
Schematic representation of a UD toilet.

Figure 6.2
Typical UD pedestal.
(Photograph: CSIR)

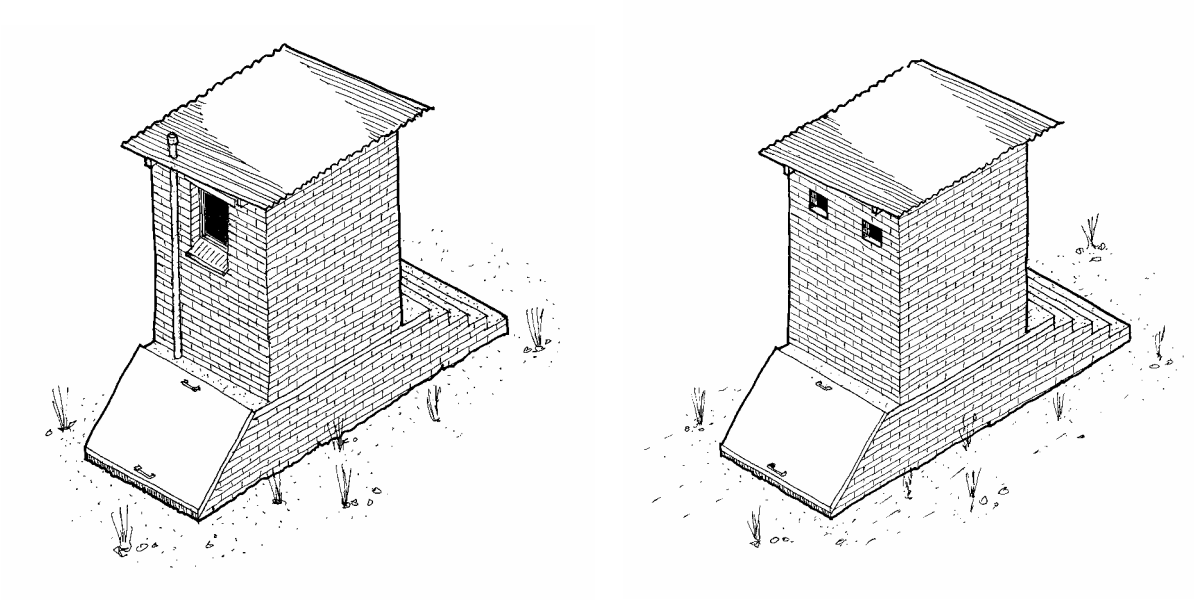


Figure 6.3: Typical examples of simple, easy to build UD toilet structures. As an alternative to conventionally built brick structures, some commercially available toilets are built with thin prefabricated concrete panels that are assembled on site (Drawing: MC Bolton).

6.2.2 Constructing a UD toilet

(a) General

UD toilets require careful operation, but are inherently simple systems. For successful implementation, this feature should be maximised as far as possible, particularly in low-income communities. As proper operation and maintenance of the toilets are crucial factors in the success of any sanitation scheme, particular attention should be paid during the planning and design process to making these tasks as easy as possible. This will help to ensure sustainability.

UD toilets can be based on either the single vault or double vault principle. Many thousands of both types are found in South Africa and the world, and the decision on which type to implement in a particular project should be based on detail discussions between the implementing agent and the intended users.

UD sanitation systems have been developed and adapted over many years, and valuable lessons have been learned in the process. These guidelines are intended to illustrate what is generally regarded as “good practice”, incorporating the knowledge and experience acquired during evolvement of the technology. The guidelines should therefore not be regarded as the last word on the subject and the construction details shown here should be seen as suggestions, not mandatory requirements. The main criteria are that the basic principles governing UD sanitation, and good building practices, should be adhered to.

(b) Building materials and methods

Superstructure

Any suitable building materials may be used, as long as they meet the criteria of strength, durability and weather resistance, and have good thermal (i.e. poor heat-conducting) properties. Note that the latter requirement implies that galvanised corrugated iron should not be used for the walls. Most importantly, a toilet should be comfortable to use. User comfort will be enhanced by reducing heat gain in the superstructure.

In contrast to ventilated improved pit (VIP) toilets, which need to be partially darkened inside to assist fly control, UD toilets may be light and airy, as fly control is achieved by other means (covering faeces with ash, soil, etc). This enhances the attractiveness of the toilets. Provision should also be made for adequate ventilation of the superstructure.

Suitable roofing materials are galvanised corrugated iron, ferrocement, tiles, shingles, thatch or precast concrete. The main criteria are that the roof should be waterproof and adequately fastened to the walls of the superstructure. Ferrocement and precast concrete roofs have the advantage of not requiring timber beams or wire fixings, as they may simply be mortared in position. They are also the most durable and are not likely to require maintenance.

Figures 6.4 (a) to (e) show suggested dimensions for UD toilets that are built as separate rooms or structures. If retrofitting a new toilet into an existing dwelling or adding one to a new dwelling is being considered (Figure 6.7), the illustrations will also be useful in determining the feasibility and scope of the project. Dimensions have largely been determined by operation and maintenance requirements. Note that only basic, and not detailed, dimensions are shown, as different materials will require different thicknesses for the various elements, as well as different building techniques, etc.

Faeces vault

A faecal material accumulation factor of 70 litres per person per year is recommended for design purposes. This allows for the addition of covering material (ash, soil, etc) and soft toilet paper. If other types of anal cleansing material are used this will result in a substantial increase in the accumulation factor.

A minimum storage period of twelve months before use in the garden is recommended for faecal material. In the case of a single vault toilet, depending on the number of users and the size limitation of the vault, it may be necessary to remove the material from the vault periodically and store it in a sack or other suitable container for a further time so that a total period of twelve months elapses from the last addition to the pile until the material is used.

For a double vault system, each vault should allow for twelve months use in order for the resting period to be the same length of time before the material is removed from the vault. Because this resting period may be longer than what can be achieved in a single vault toilet, this system is superior to the single vault type from a safety point of view. The longer the material is able to be stored before handling takes place, the better.

It is essential to make provision for adequate stormwater drainage around the vault. Consequently, the floor should be a minimum of 75 mm (one brick height) above the natural ground. In addition, the ground should slope away from the access door of the

vault; however, if this is not possible, then a shallow ditch should be excavated around the vault to facilitate the diversion of stormwater away from the structure.

It is important for toilet owners to have easy access to the vault for emptying purposes (see Figure 6.5). Lids should be made of lightweight material (e.g. thin ferrocement sections or galvanized sheet iron (GSI)) and should not be grouted in place. They should, however, fit snugly in order to prevent flies and vermin from gaining entry, and to keep rainwater out (see Figure 6.4(b)). Figures 6.10 and 6.11 show some examples of poor practice that should be avoided. It is also preferable for the floor of the vault to be as close to ground level as possible. Where there is a slope to the natural ground this should be utilised to orient the toilet structure in such a way that the entrance to the toilet is on the higher side while the vault is on the lower side. In this way it is possible to minimise the number of steps at the entrance while ensuring that the vault is sunk into the ground to the minimum extent possible (Figures 6.6 and 6.8). Should it be necessary for the floor of the vault to be below ground level, a short ramp should be provided on the inside to facilitate the removal of faecal material by raking (Figures 6.4(c) and 6.5).

Urine pipes

Urine drainage pipes should preferably be not less than 38mm diameter and slopes should be at least 2% (1:50) in order to prevent struvite build-up caused by standing urine, which can eventually block the pipes. This minimum size reduces the likelihood of blockages occurring through accumulation of hair, etc. Standard 38mm diameter waste pipes with elbow inspection caps should be used, which enables blockages to be cleared easily. Metal pipes should be avoided, as fresh urine is corrosive.

Ventilation and fly control

UD toilets function on a different principle to VIP toilets, and their operating requirements are therefore not the same. Whereas VIP toilets require specific arrangements to be made for fly control as well as ventilation of the pit and superstructure, UD toilets are much less of a problem. Pit toilets produce odour due to mixing of faeces and urine, which causes the pit contents to be wet, or at least damp, more or less permanently. In a well-operated UD toilet, however, the faeces are covered with ash, dry soil or other moisture absorbing agent, urine is diverted and moisture kept out of the vault as far as possible. The faeces therefore dehydrate to some extent (this also depends on ambient temperature and humidity), flies are not attracted, and odours are virtually, and often completely, eliminated (efficiency of odour elimination depends to a large extent on proper use of the toilet). Therefore a different approach to building the toilet can be adopted.

As discussed above, the inside of the superstructure should be light and airy, not partially darkened as for a VIP toilet. In a well-operated UD toilet the faeces are covered with ash or soil; therefore they do not produce odours, so flies are not attracted. Proper windows may thus be provided, if desired. Should this be too expensive, or not preferred, then sufficient small openings should be left in the walls to provide for light and ventilation.

A ventpipe may be provided, if desired, in order to encourage ventilation of the vault. Although flies should not normally be a problem, a flyscreen should be fitted to the top of the ventpipe, and both the pipe and screen should be made of corrosion-resistant materials. Ventpipes should be 100 mm in diameter and extend to at least 500mm above the highest point of the roof. If possible, the ventpipe should be painted black and positioned to make maximum use of sunlight, although this is not a critical requirement. Ventilation occurs mostly due to movement of air across the top of the ventpipe, which

induces suction in the system. It is only on windless days that thermal convection caused by sunlight will be responsible for air movement in the pipe. Note that provision should be made to prevent rainwater entering the ventpipe, and thus the faeces vault, as shown in Figure 6.12.

The ventpipe should be rigidly fixed to the superstructure with galvanised wire ties, and the hole through the cover slab well sealed.

Practical experience in hot and temperate climates has shown that, as long as the toilet is operated correctly (see section 6.3 “Operation and maintenance aspects”) there will be no odours or flies. Under these conditions, a ventpipe is not strictly necessary and may be dispensed with. Its use is encouraged, however, as good operation of the toilet cannot be guaranteed.

Upgrading VIP and bucket toilets

From the drawings in Figure 6.4 it can be seen that pit and bucket toilets can be upgraded to UD toilets at minimal cost. All that is required is that the old pedestal be removed and replaced with a new UD type according to the user’s preference (plastic, concrete, etc) a urinal added, and urine drainage pipes fitted.

(c) Costs:

The current (July 2007) cost of building a double vault UD toilet similar to that shown in Figures 6.4(c) and (d) is about R4 500 to R5 000 (US$643 – 714). However, this is only applicable in areas that are easily accessible. In areas with poor access, or where the terrain is rough or steep, this cost can increase to R6 500 (US$929) (W. Pfaff, eThekwini Water Services, personal communication).

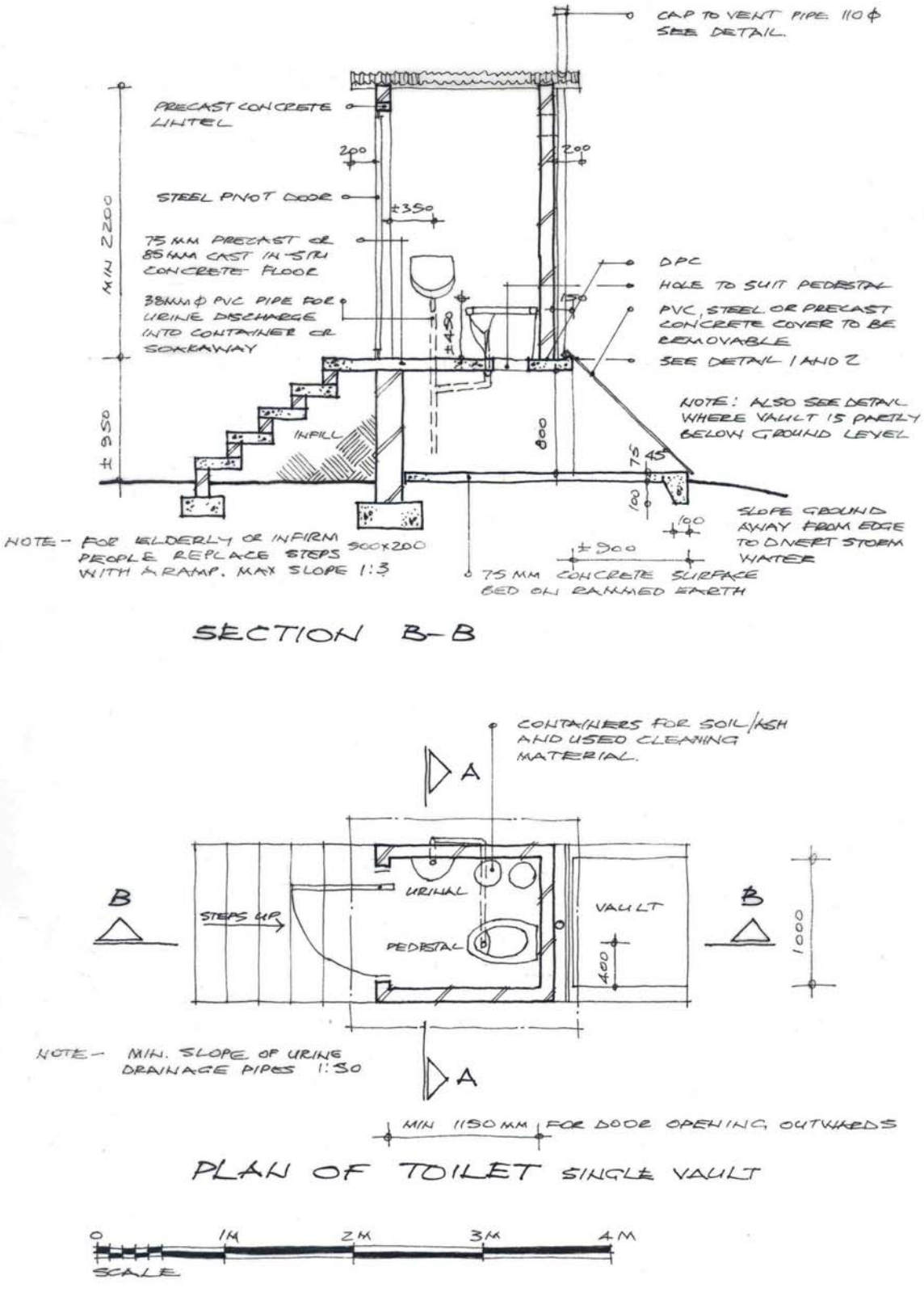


Figure 6.4(a): Details of a single vault UD toilet. The number of steps at the entrance can be reduced by constructing the floor of the vault below ground level (see Figure 6.4(c)).
(Drawing: MC Bolton)

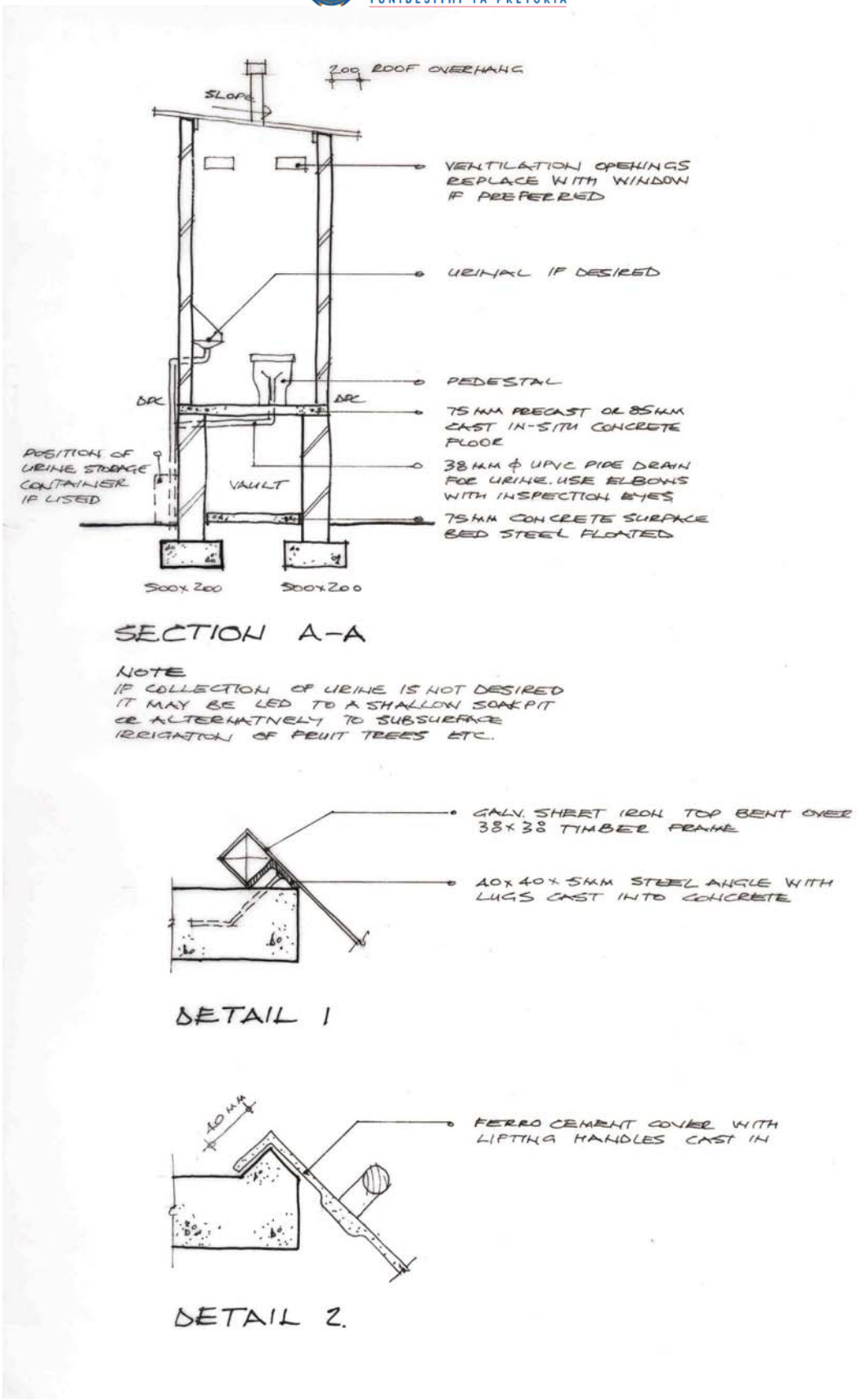


Figure 6.4(b): Details of a single vault UD toilet (continued)
(Drawing: MC Bolton)

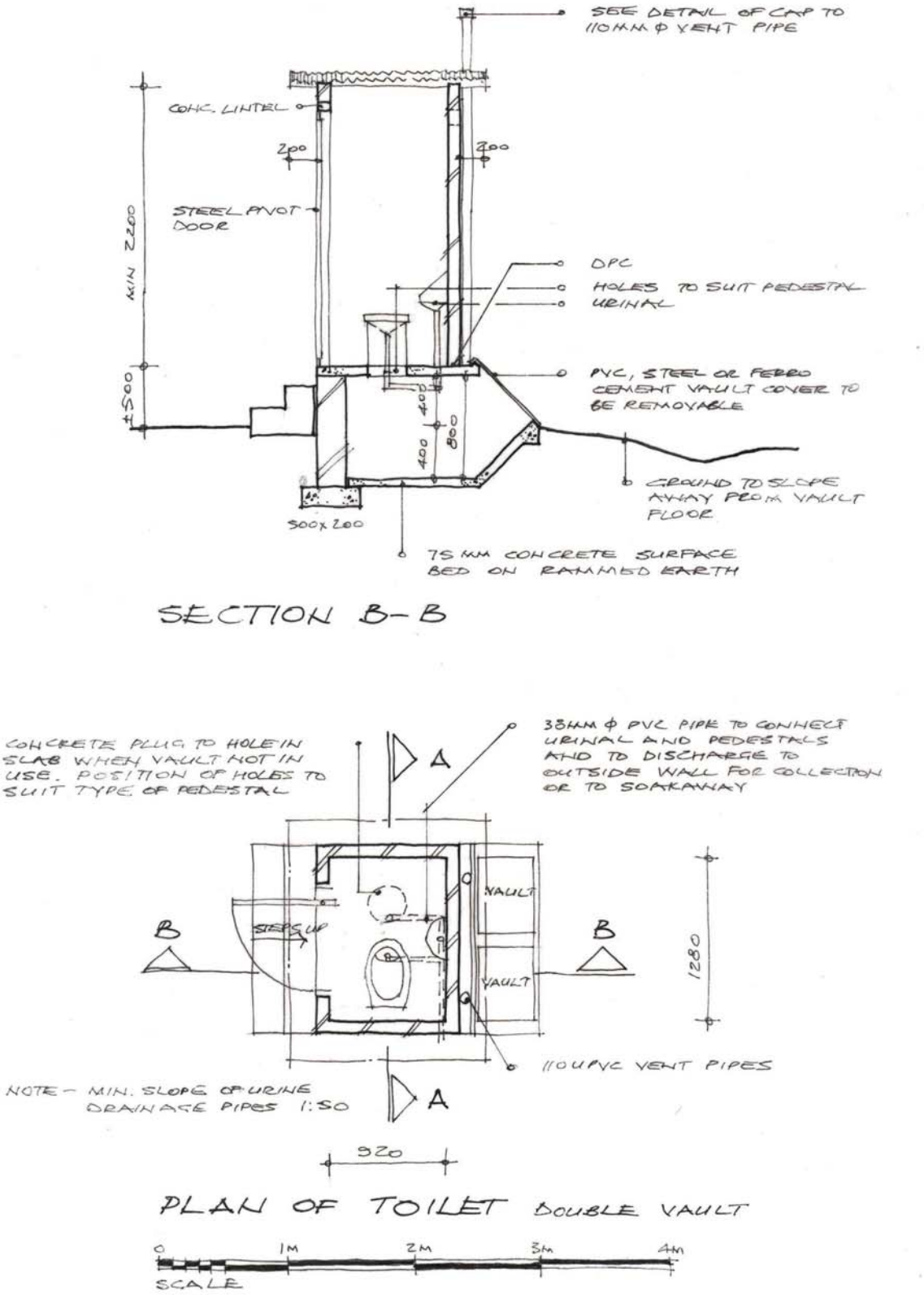


Figure 6.4(c): Details of a double vault UD toilet. Note reduction of steps by constructing the floor of the vault below ground level.
(Drawing: MC Bolton)

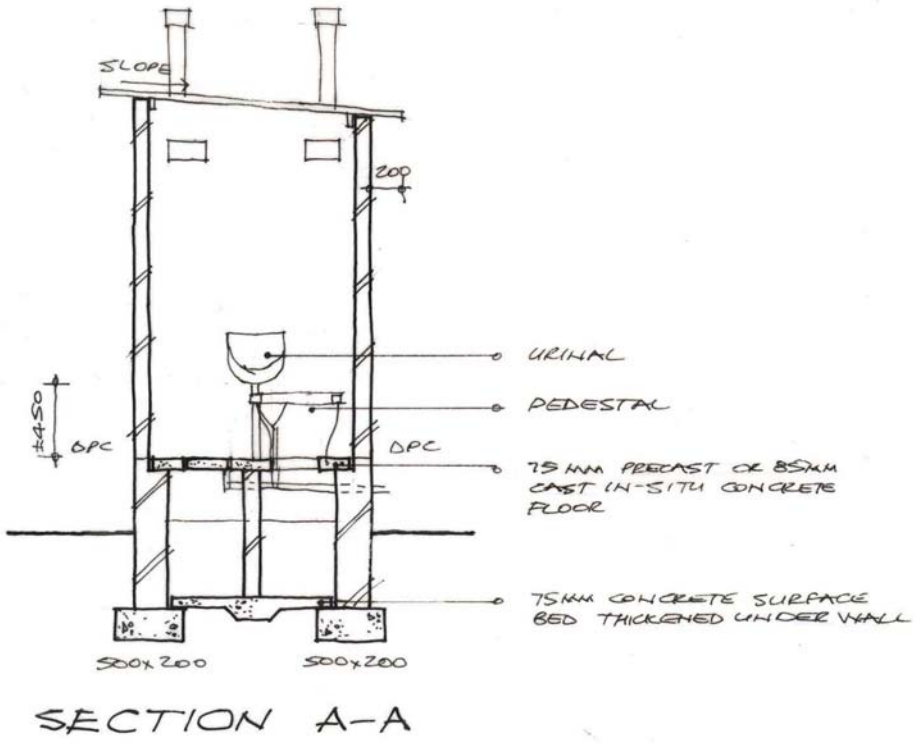


Figure 6.4(d): Details of a double vault UD toilet (continued)
(Drawing: MC Bolton)

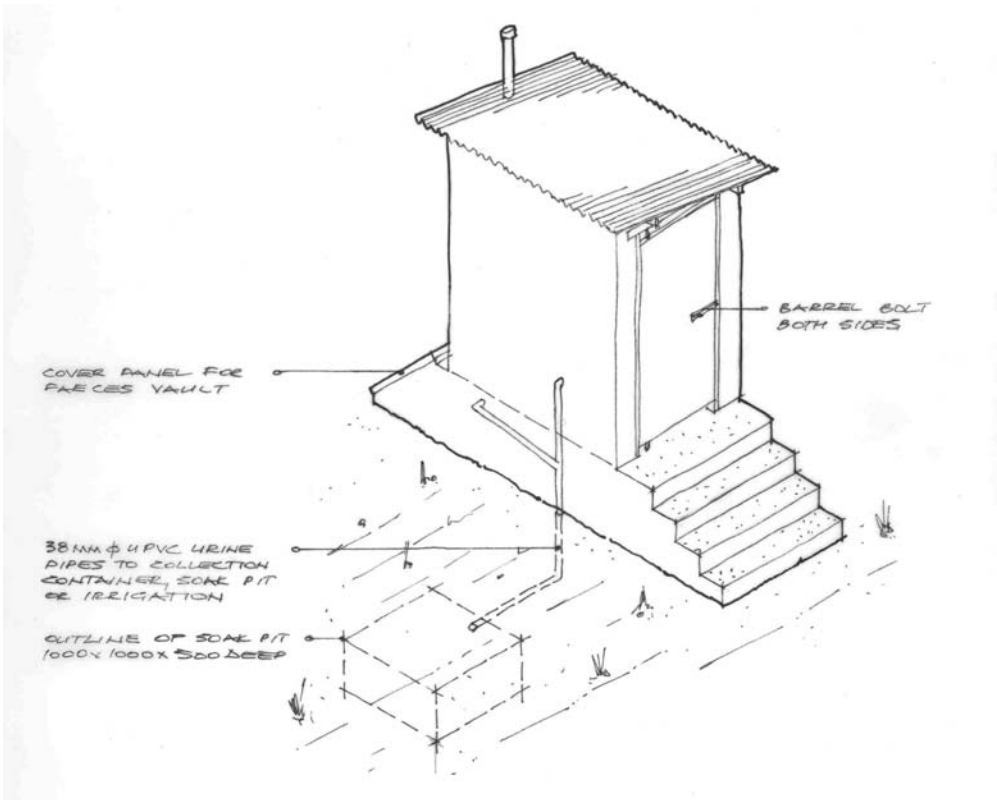


Figure 6.4(e): General layout of a UD toilet
(Drawing: MC Bolton)

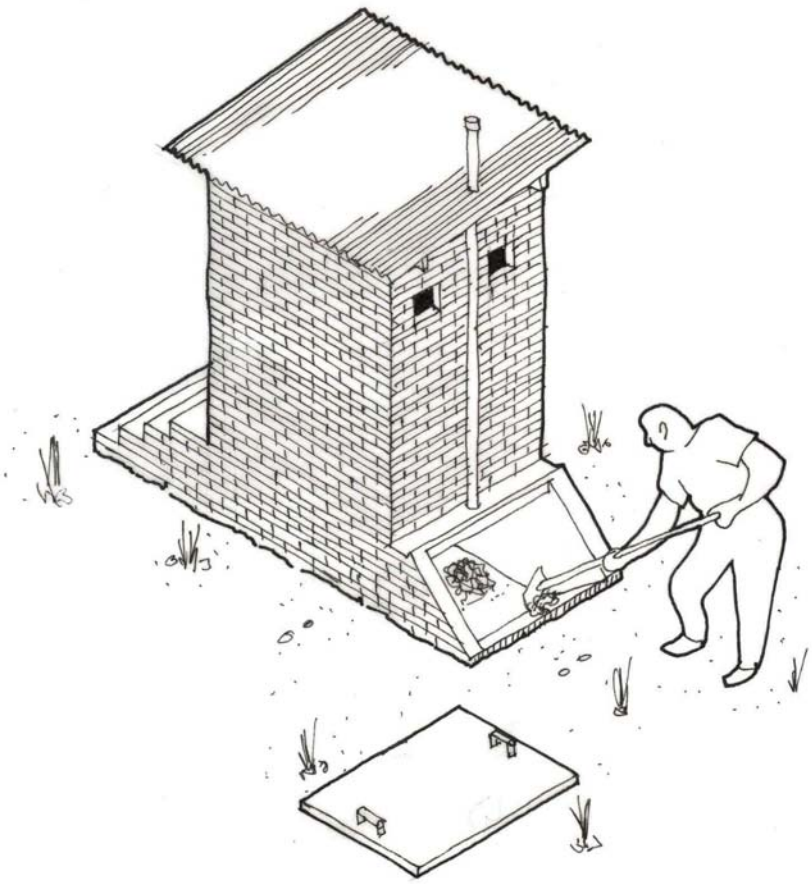


Figure 6.5: This vault is easy to empty
(Drawing: MC Bolton)

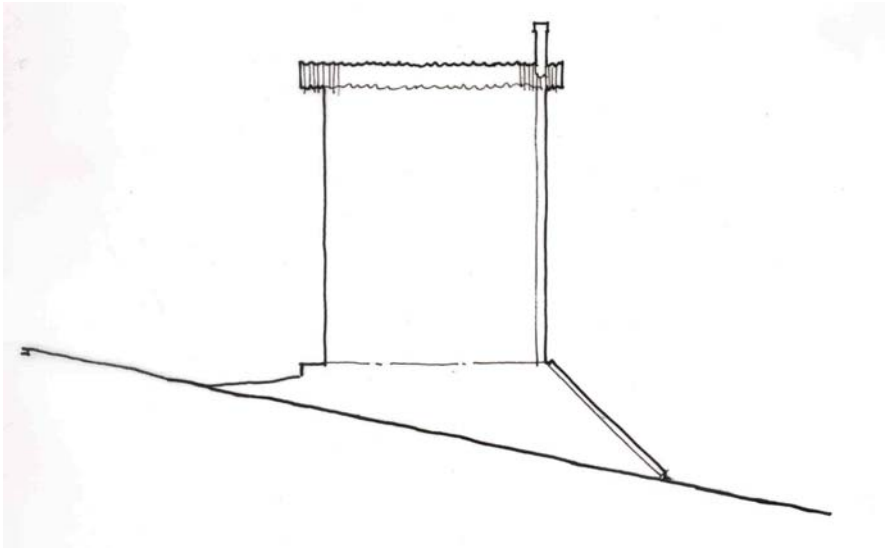
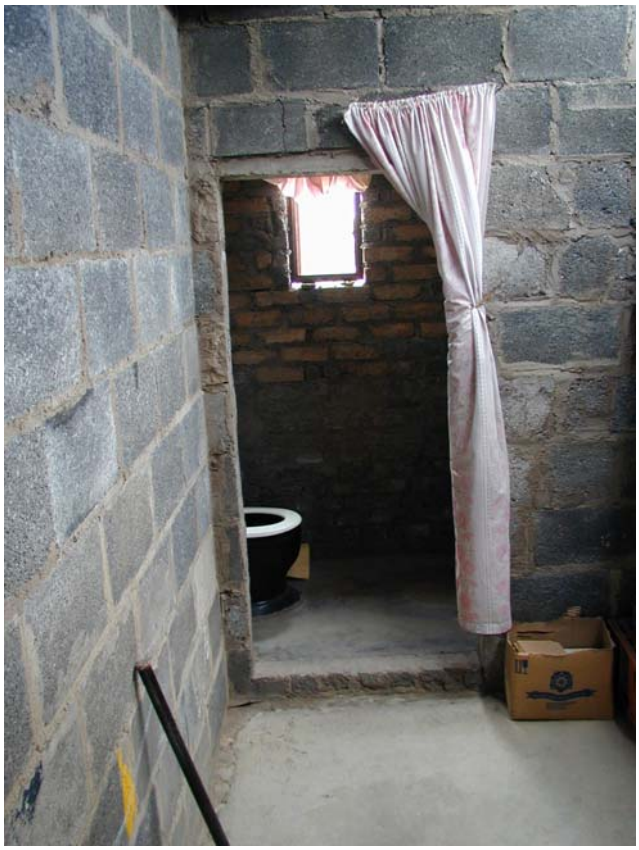


Figure 6.6: Using the natural ground slope to minimise steps at the entrance and depth of vault below ground level (1)
(Drawing: MC Bolton)

(a)



(b)

Figure 6.7: Double vault UD toilet being added onto a house.
(a) Exterior view; (b) interior view
(Photographs: R. Holden)

Figure 6.8: Using the natural ground slope to minimise steps at the entrance and depth of vault below ground level (2)
(Photographs: F. Stevens, eThekwini Water Services)

Figure 6.9: Well-fitting vault lids at a school toilet block
(Photograph: CSIR)

Figure 6.10: Examples of poor practice (1): It is extremely difficult to gain access to these vaults for emptying purposes
(Photographs: CSIR)

Figure 6.11: Examples of poor practice (2): These vaults are not sealed against ingress of flies, rodents, snakes, rainwater, etc
(Photographs: CSIR)

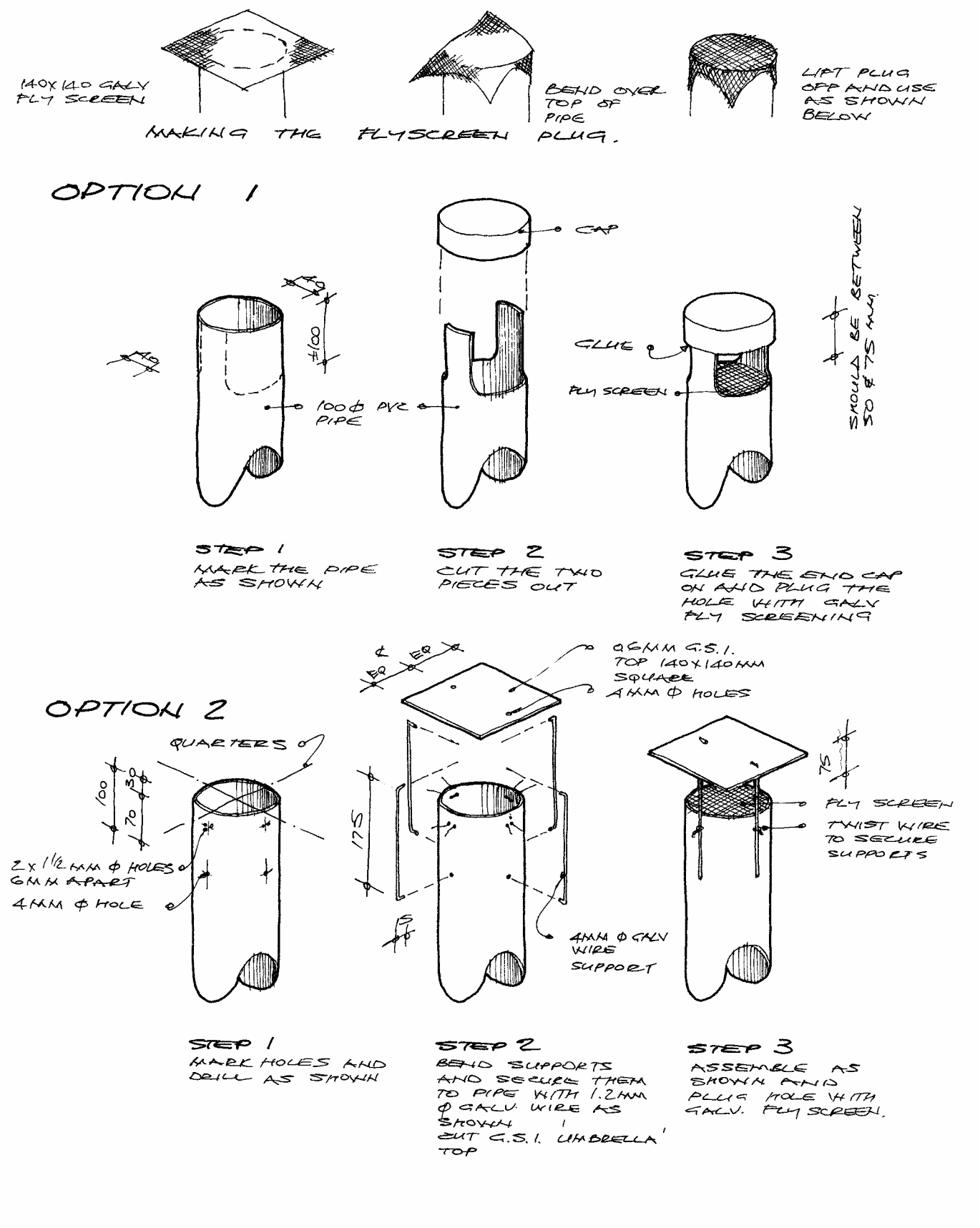


Figure 6.12: "Umbrella" for ventpipe
(Drawing: MC Bolton)

6.3 OPERATION AND MAINTENANCE ASPECTS

6.3.1 General

UD toilets require a higher level of commitment from users than do other forms of dry sanitation, such as VIP toilets. The reason is that they are more sensitive to, and consequently less tolerant of, abuse. In many of the poorer and under-serviced communities in South Africa, pit toilets are often used as rubbish depositories as well. The use of anal cleansing materials other than tissue paper, such as rags, plastic bags, newsprint, maize cobs, etc, is also common, and these objects then end up in the pits. Furthermore, wastewater may occasionally be poured into the pits. If one considers the nature of a UD toilet, it becomes obvious that abuse of this nature can only lead to failure of the system.

6.3.2 Dehydration, odour and fly control

The key operational factor for a successful UD toilet is minimal moisture. A supply of ash, dry soil, or other absorbent material, should always be available in a suitable container, and this should be sprinkled over the faeces after defecation. A cupful (approximately 200mℓ) should normally be sufficient, but users will quickly learn how much is required for their individual needs. This material will absorb the inherent moisture in the faeces, thus aiding the dehydration process. Flies and odours are also controlled in this manner. Furthermore, ash, particularly wood ash, has a relatively high pH (approximately 10), which is useful in reducing pathogenic organisms in the faeces.

6.3.3 Cleaning the pedestal

As with any toilet, cleanliness is essential for good hygiene. If the inside of the pedestal or squat plate becomes soiled, it may be cleaned with a damp toilet brush or cloth, as small amounts of water that enter the vault in this case will evaporate quickly. If disinfectant is used, care should be taken that only small amounts come into contact with the faecal material. The urine bowl, however, should be periodically rinsed with a little disinfectant diluted in water in order to eliminate odour. Only a small quantity of water (about 200 mℓ or a cupful) is required for this operation.

6.3.4 Disposal of anal cleansing material

Various methods are used for the disposal of anal cleansing material. It is usually recommended that this material not be put into the vault, as the lack of moisture prevents its breakdown. A special container should be kept next to the toilet for storing used cleansing material, which may then be periodically disposed of by burning or burial. Alternatively, where a well-operated solid waste removal service exists, the used materials can simply be enclosed in a suitable bag and disposed of in the rubbish container.

Where faecal material is used in the garden or co-composted with other organic material, the toilet paper can be deposited into the vault, as the paper decomposes when wetted afterwards. It should be noted that only soft tissue paper can be used in this case, and the quantity may need to be restricted, depending on the size of garden and extent of use.

In hot and dry climates, where faeces dehydrate rapidly, all cleaning paper may be deposited in the vaults and periodically burned – paper as well as dehydrated faeces. Where use of the faecal products is not desired, this is a relatively easy way to dispose of the contents of the vault.

6.3.5 Urine collection and disposal

Where it is intended to use urine for fertilising crops, it should be collected in a sealed container. If the container is not sealed, some nitrogen is lost in the form of ammonia and the urine thus loses part of its fertilising value. The soil should be loosened and the urine worked in quickly, in order to minimise nitrogen loss. This should be followed by ordinary watering.

For persons who do not wish to handle or use the urine, it may be led into a shallow soakpit adjacent to the toilet. The volumes produced by the average family are small and, except for very clayey soils, will not present a disposal problem.

6.3.6 Clearing blockages in the urine pipes

Occasional blockages of the urine pipes may occur due to precipitation of struvite (magnesium ammonium phosphate $MgNH_4PO_4.6H_2O$) forming on hairs or fibres. These may be cleared with conventional caustic soda drain cleaner.

6.3.7 Faeces management

Proper management of the excreted faeces is crucial for sustainable operation of a UD toilet. Various factors play a role in the dehydration process, and thus also in the reduction or elimination of pathogenic organisms. Because part of the management procedure consists of handling the faecal material, health and safety aspects are important.

The faecal material needs to be collected in a way that facilitates storage and easy removal from the vault. In a single vault toilet it can be collected and stored in either of two ways - in a suitable container or in a heap on the floor of the vault. For the former method, two separate containers are required. When the first container is full, it is moved to one side and the second one moved into place beneath the pedestal. By the time the second container is full (usually a few months, depending on the size of container and number of users) all the material in the first one should be sufficiently dehydrated to resemble a crumbly type of soil with a slight musty, not unpleasant, odour. If there is insufficient room in the vault it should be removed from the container and stored in a sack for a further period, as there may still be vast numbers of viable pathogens present. A minimum total storage period of twelve months, from the time when the container is full to eventual use in the garden, is recommended.

The second method of collection and storage, in a heap on the floor of the vault, involves a little extra attention. When the heap reaches a certain size, it should be raked to the side of the vault where it can dehydrate for a further period, until the space is needed to store more material. Further storage in a sack for a total storage period of twelve months is also recommended in this case.

With a double vault toilet the two sides are used alternately, thus allowing faecal material to be stored in a full vault for at least twelve months before it needs to be removed. This is better from the safety point of view.

Even if a community is not particularly inclined towards use of the desiccated faeces, experience in the field has shown that their disposal does not pose a problem, as they may simply be buried.

6.4 REGULATORY GUIDELINES

6.4.1 General

It is important to note that UD sanitation technology should not be regarded as being only applicable to poor and rural people, but rather to communities representing all income groups. However, these particular guidelines focus on the implementation of UD sanitation projects in mainly lower income areas, because special and specific interventions are necessary to ensure the success and sustainability of the technology in these cases (Austin and Duncker 2002).

Sanitation is not just about building toilets – for successful project implementation it is essential that the responsible local authority takes an active part in the process, from the initial conceptualisation right through to construction, handover and post-project monitoring. The local authority should also be aware of its responsibilities with regard to public and environmental health, and the various pieces of legislation governing these aspects. Further, the requirements concerning hygiene awareness in the communities receiving the toilets are an integral part of the sanitation process.

Implementing authorities (through their appointed agents if this is the case) need to ensure that good quality planning, design and construction processes are put in place. Design and construction of UD toilets should follow the guidelines given in the previous section. Note that the planning process includes the required community liaison activities. For a full exposition of the latter, refer to chapter 5 of the publication "*Urine-diversion ecological sanitation systems in South Africa*" (Austin and Duncker 2002).

6.4.2 Disposal/collection mechanisms for faecal material from UD toilets

Disposal of faecal material from UD toilets requires particular attention, as community and environmental health may be negatively affected by poor practices. Where there are no formal collection activities in a particular village or settlement, householders will normally need to empty the vaults themselves and either bury the contents or, should they wish, use it as a soil conditioner in their gardens. Where it is simply buried, householders should be encouraged to plant a tree on the spot – apart from beautifying the area this also serves to mark the place where the faecal material has been buried.

The practice of emptying the vaults should be monitored to ensure that, as far as possible, only faecal material that has been stored for at least 12 months is removed from the vault. This may not always be possible in the case of single vault toilets, however. In the latter case it should be ensured that no fresh faecal material is removed from the vaults and that any material that has been stored for less than 12 months is not used in a vegetable garden, but either stored in a sack or other suitable container until the 12 month period

has expired, or buried. Householders should also be encouraged to wear gloves during the emptying process, not to smoke while doing so and to observe good personal hygiene.

Where a community is not disposed towards using faecal material in their gardens, the local authority should support the establishment of a formal collection system. Such a system may be set up by a local entrepreneur using simple equipment such as hand tools and a horse-or donkey-drawn cart, or, where the disposal site is nearby, even an ordinary wheelbarrow. The fee for emptying a toilet vault is usually negotiated or may be a fixed fee. Disposal of the material should be at a site approved by the local authority, which should be protected. Alternatively, the municipality could support a co-composting venture, where the faecal material is composted together with waste from the local parks department, e.g. leaves, grass cuttings, etc.

6.4.3 Use of faecal material

Local authorities should monitor the use of faecal material in agriculture, particularly in food gardens. Education is of vital importance. The primary hazard is related to exposure of untreated or insufficiently treated faeces containing pathogens. The faeces may contaminate food or water. Contact may occur before treatment, during treatment (including handling or transport) or when the material is applied to the soil (WHO 2006b). Field trials have shown that the edible portions of certain crops can be contaminated by pathogens from inadequately treated faecal material (Mnkeni et al 2006). Treatment of the material (e.g. by storage) should aim to fully or substantially reduce the pathogenic content before application to the soil. For this reason it is important that the recommended minimum storage period of 12 months be adhered to and that the required bulking agents are added to the faeces, e.g. ash, lime or dry soil. The wearing of gloves, washing of hands, etc should also be encouraged. On-site treatment will always be beneficial from a health point of view, since this gives the initial pathogen die-off, which can be further corrected with off-site treatment (e.g. co-composting) if necessary (WHO 2006b).

Monitoring agents should refer to the WHO publication "*Guidelines for the safe use of wastewater, excreta and greywater, Volume 4: Excreta and greywater use in agriculture*" (WHO 2006b).

CHAPTER 7
RECOMMENDATIONS FOR FURTHER RESEARCH RELATED TO THIS THESIS

It is deemed important that the field trials described in chapter 5 are repeated in other climatic areas, e.g. a hot and dry area, or a cold area, as it is likely that different results regarding minimum storage periods will be obtained. This should be supplemented by trials involving co-composting of the faeces mix with other organic material, in order to compare the efficacy of this method with the dehydration process. Further, vault lids made of PVC should be tested for enhancing heat gain in the vaults. Finally, long-term measurements of heap pH should be made in order to ascertain whether high pH amendments (wood ash, lime, etc) do in fact maintain their initial pH level over time. The fact that this was not done in this particular research has been identified as a weakness in the project.

Additional field trials, similar to those described in chapter 4, should be undertaken with a view to making recommendations regarding maximum application rates of faecal material. Consideration should also be given to the maximum agronomic rates. These trials should consist of food crops where the edible portions are either in or near to the soil such as beetroot, onion, potatoes, tomatoes, etc. Trials including urine should also be considered, in order to determine the most advantageous application rates for the various crops.

Another important topic is recommended for further research on the subject of UD toilets. This has arisen due to the writer's ongoing work on the subject of ecological sanitation in general and has also been the subject of discussion in various forums, including communities, around the country. It concerns the feasibility of a collection/disposal service for faecal material.

At present, virtually all the UD toilets built in the country have been for communities on the lower end of the income scale and who previously had no formal sanitation facility at all or, at best, an unimproved pit toilet. Research carried out by CSIR in a number of communities has revealed people's resistance to handling their faecal material, while in others it has not been a problem. There is often a general viewpoint in a village that "the municipality must take the faeces away."

However, a willingness has also been expressed in some villages to pay for a faeces removal service. For instance, this has borne fruit in an area of Kimberley with UD toilets where householders pay a local resident to remove the faecal material on a regular basis. This is done by means of a wheelbarrow, and the material is stockpiled at a nearby approved facility from where it is destined for co-composting with other municipal waste.

This has not yet been attempted on a large scale in an area with hundreds, or even thousands, of UD toilets. The writer recently carried out a theoretical desktop study with the purpose of determining the feasibility of establishing such an entrepreneurial venture in a large settlement or village. Two scenarios were considered, namely:

- The use of an independent agent (entrepreneur) to collect faeces from UD toilets and transport them to a collection station or approved disposal area within 10km of the target community; and

- The use of an independent agent to collect faeces from UD toilets, transport them to a designated site (eco-station) within 10km of the target community for the manufacture of compost and to sell this compost to the local authority for use by its parks department.

The basic assumption in the models developed was that the collection service would be done by means of a small trailer and 47kW tractor or, in the case of animal-drawn carts, a horse or donkey. It was also assumed that the equipment and animals were to be purchased by means of a bank loan at prevailing interest rates, that mechanical equipment would be properly maintained and that animals would be well cared for in terms of food, veterinary and farrier services, etc. The above two scenarios were modelled for each type of collection service, i.e. tractor/trailer, horse/cart, and donkey/cart. Collection fees were assumed to be R80 per toilet per year.

The most critical factor determining the viability of the service was found to be the number of UD toilets available for servicing. The model simulations determined the following:

- For the first scenario, collection and disposal, the following number of toilets are required to enable a viable business to be conducted:
  - tractor/trailer collection 3 587
  - horse-drawn cart collection 1 379
  - donkey-drawn cart collection 1 188

- For the second scenario, collection and composting, the viability improves substantially, as follows:
  - tractor/trailer collection 997
  - horse-drawn cart collection 395
  - donkey-drawn cart collection 374

These are significant numbers of toilets that need to be available within an area of restricted size. Local authority cooperation will also be important with regard to the disposal/transfer site or eco-station, as well as for the co-composting operation. Based on the results of this theoretical study, it seems as if a faeces collection business based on the assumed parameters will not be viable and that some form of subsidy will be required.

It is suggested that an actual enterprise be set up in a suitable village or group of villages, in cooperation with the local authority, with the aim of testing the theory and looking for ways to make the operation more attractive where less toilets are available for servicing. It is entirely possible that substantial savings could be made in terms of equipment by using horses, donkeys and carts that are already available (i.e. that do not have to be purchased).

If successful faeces collection/disposal services could be established in areas with UD toilets it would greatly enhance the social acceptability, and therefore the viability, of this sanitation technology.

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Abbreviations:

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IWMI:	International Water Management Institute
SDC:	Swiss Agency for Development Cooperation
Sida:	Swedish International Development Cooperation Agency, Sweden.
UWEP:	Urban Waste Expertise Programme
WRC:	Water Research Commission, South Africa.
WHO:	World Health Organization, Geneva, Switzerland.
WSSCC:	Water Supply and Sanitation Collaborative Council Working Group on Promotion of Sanitation (World Health Organisation, Geneva).

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APPENDIX A

EXAMPLE OF TYPICAL OUTPUT FROM TEMPERATURE LOGGER

	A1_top	A1_mid	A1_bot	A1_amb	A2_top	A2_mid	A2_bot	A2_amb	B1_tmp	B1_amb	B2_tmp	B2_amb	C1_tmp	C1_amb	C2_tmp
1/21/2005 18:00	27,38	26,98	26,48	29,99	26,91	26,57	26,91	29,5	27,01	30,82	28,3	30,72	27,15	32,15	27,68
1/21/2005 21:00	28,83	27,44	26,87	32,21	28,52	27,46	27,37	32,65	27,71	33,89	28,95	34,41	27,78	34,32	27,95
1/22/2005	29,12	27,88	27,04	29,08	29,26	28,09	27,86	30,15	28,35	30,36	29,49	30,5	28,32	30,13	28,38
1/22/2005 3:00	28,6	27,75	26,96	27	28,81	28,01	27,95	27,48	28,4	28,08	29,51	27,9	28,34	27,9	28,59
1/22/2005 6:00	27,93	27,58	26,79	25,33	28,05	27,65	27,78	25,63	28,06	26,39	29,24	25,97	28,06	26,18	28,54
1/22/2005 9:00	27,04	27,29	26,55	23,84	27,16	27,13	27,47	24,04	27,53	24,77	28,81	24,2	27,62	24,64	28,34
1/22/2005 12:00	26,45	27	26,31	25,06	26,4	26,6	27,11	24,41	26,97	25,87	28,36	25,17	27,1	26,16	28,01
1/22/2005 15:00	27,31	27,13	26,41	30,07	26,78	26,62	27,01	28,46	26,91	30,93	28,34	30,35	26,98	32,07	27,79
1/22/2005 18:00	29,04	27,76	26,85	33,45	28,34	27,48	27,43	32,49	27,7	35,53	28,97	34,53	27,66	36,13	27,97
1/22/2005 21:00	29,93	28,19	27,26	32,25	29,61	28,33	28	33,05	28,67	35,17	29,71	33,78	28,55	34,65	28,43
1/23/2005	29,79	28,29	27,42	29,98	29,81	28,65	28,33	30,17	29,15	31,46	30,05	31,05	29,02	31,19	28,82
1/23/2005 3:00	29,92	28,9	27,38	28,14	29,3	28,51	28,36	28,12	29,13	29,29	30,01	28,83	28,99	29,03	28,95
1/23/2005 6:00	28,73	28,24	27,24	26,42	28,54	28,13	28,19	26,33	28,77	27,51	29,71	26,93	28,69	27,23	28,88
1/23/2005 9:00	27,9	27,9	27,05	25,28	27,73	27,64	27,9	25,13	28,24	26,17	29,29	25,49	28,23	25,91	28,65
1/23/2005 12:00	27,38	27,65	26,87	25,19	27,1	27,18	27,6	25,15	27,73	26,25	28,89	25,51	27,75	25,84	28,35
1/23/2005 15:00	26,99	27,39	26,72	25,31	26,72	26,88	27,38	25,21	27,41	26,39	28,64	25,71	27,41	26,45	28,07
1/23/2005 18:00	27,17	27,29	26,7	26,68	26,9	26,85	27,28	26,59	27,32	27,69	28,58	27,22	27,27	27,85	27,89
1/23/2005 21:00	27,38	27,32	26,74	26,86	27,2	27	27,34	27,1	27,45	28,06	28,68	27,55	27,36	27,71	27,85
1/24/2005	28,41	28,44	26,65	25,35	27,1	26,96	27,34	25,17	27,49	26,08	28,68	25,48	27,35	25,71	27,83
1/24/2005 3:00	26,71	27,08	26,45	24,08	26,41	26,53	27,11	23,85	27,2	24,82	28,39	24,13	27,08	24,5	27,67
1/24/2005 6:00	26,11	26,78	26,23	23,29	25,77	26,08	26,8	22,95	26,78	23,88	28,02	23,15	26,69	23,59	27,4
1/24/2005 9:00	25,6	26,5	26,03	22,79	25,22	25,65	26,48	22,48	26,36	23,39	27,65	22,58	26,25	23,13	27,09
1/24/2005 12:00	25,27	26,23	25,83	23,65	24,86	25,32	26,2	23,11	26	24,45	27,33	23,68	25,86	24,45	26,77
1/24/2005 15:00	26,37	26,33	25,97	30,12	25,61	25,54	26,18	28,16	26,15	31,15	27,44	29,73	25,92	32,24	26,62
1/24/2005 18:00	28,46	27,05	26,54	32,99	27,72	26,76	26,76	32,38	27,3	35,93	28,34	34,83	26,97	36,31	26,91
1/24/2005 21:00	29,42	27,65	27	32,26	29,2	27,86	27,5	33,45	28,52	35,97	29,3	35,64	28,2	35,68	27,54

APPENDIX B

MICROBIOLOGICAL RESULTS IN TABULAR FORMAT

VAULT A1 (FAECES + SOIL; CONCRETE LID; VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,90E+08	8,00E+07	1,00E+08	4,70E+07	
Total coliform bacteria count per g	1,70E+06	1,40E+04	2,80E+03	214	<3
Faecal coliform bacteria count per g	9,10E+05	1,20E+04	1,10E+03	88	<3
E coli bacteria count per g				53	<3
Faecal streptococci bacteria count per g	3,00E+05	2,20E+04	8,60E+03	4,00E+03	
Salmonella spp per g	Present	Present	Present	Present	
Coliphage count per g	1,30E+04	140	325	1,60E+03	37
Clostridium count per g	8,00E+03	833	1,40E+04	43	1,70E+03
pH	7,06				
Moisture content %	12,5	10,1	9,6	6,4	12
Cryptosporidium oocysts count per 10g dry weight	0,9	0**	0**		
Giardia cysts count per 10g dry weight	12	6**	0**		
Ascaris eggs per 10g dry weight	237*	344* / 13**	277* / 1**	64* / 0**	
Entamoeba spp eggs per 10g dry weight		20	11	8	
Taenia eggs per 10g dry weight		0	0	1	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT A2 (FAECES + SOIL; CONCRETE LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	3,00E+08	3,10E+08	2,10E+09	2,00E+07	
Total coliform bacteria count per g	3,30E+06	5,00E+03	5,60E+03	882	<3
Faecal coliform bacteria count per g	2,00E+05	1,50E+03	3,90E+03	235	<3
E coli bacteria count per g				206	<3
Faecal streptococci bacteria count per g	2,90E+05	1,10E+05	9,80E+03	7,35E+02	
Salmonella spp per g	Present	Absent	Present	Present	
Coliphage count per g	1,70E+03	1,20E+03	1,70E+03	9,10E+01	15
Clostridium count per g	6,00E+02	1,30E+04	2,90E+04	2,00E+03	1,80E+03
pH	7,18				
Moisture content %	16,4	14,5	15,5	15,2	15,0
Cryptosporidium oocysts count per 10g dry weight	2,4	0**	0**		
Giardia cysts count per 10g dry weight	32	0**	0**		
Ascaris eggs per 10g dry weight	237*	71* / 0**	68* / 0**	60* / 0**	
Entamoeba spp eggs per 10g dry weight		22	4	2	
Taenia eggs per 10g dry weight		0	0	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT B1 (FAECES + ASH; METAL LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,10E+08	6,40E+07	8,30E+07	6,70E+07	
Total coliform bacteria count per g	8,00E+04	5,30E+03	2,00E+03	<3	<3
Faecal coliform bacteria count per g	2,50E+04	3,70E+03	1,10E+03	<3	<3
E coli bacteria count per g				<3	<3
Faecal streptococci bacteria count per g	3,70E+04	1,80E+04	4,00E+03	9,30E+04	
Salmonella spp per g	Present	Absent	Present	Present	
Coliphage count per g	6,60E+03	450	161	3	<3
Clostridium count per g	2,60E+03	120	1,40E+04	<3	235
pH	6,90				
Moisture content %	12,8	6,7	12,9	5,7	9,5
Cryptosporidium oocysts count per 10g dry weight	2,2	0**	0**		
Giardia cysts count per 10g dry weight	ND	6**	0**		
Ascaris eggs per 10g dry weight	218*	234* / 14**	184* / 0**	58* / 0**	
Entamoeba spp eggs per 10g dry weight		81	24	11	
Taenia eggs per 10g dry weight		1	1	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT B2 (FAECES + WOOD SHAVINGS; METAL LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	6,10E+07	2,80E+07	6,30E+08	7,70E+07	
Total coliform bacteria count per g	6,60E+04	2,70E+05	3,00E+06	1,10E+06	<3
Faecal coliform bacteria count per g	3,10E+04	1,30E+04	2,00E+06	1,20E+05	<3
E coli bacteria count per g				5,90E+04	<3
Faecal streptococci bacteria count per g	6,00E+04	9,50E+03	2,70E+06	8,20E+04	
Salmonella spp per g	Present	Present	Present	Present	
Coliphage count per g	4,90E+03	430	3	90	<3
Clostridium count per g	1,10E+03	290	571	2,90E+04	1,70E+03
pH	6,37				
Moisture content %	12,9	12,9	8,0	6,0	18,0
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	305*	122* / 0**	132* / 0**	65* / 0**	
Entamoeba spp eggs per 10 g dry weight		30	19	3	
Taenia eggs per 10g dry weight		0	0	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT C1 (FAECES + ASH; PERSPEX LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,10E+08	9,60E+07	1,70E+08	9,70E+07	
Total coliform bacteria count per g	8,00E+04	1,50E+04	1,30E+04	163	<3
Faecal coliform bacteria count per g	2,50E+04	5,00E+03	538	64	<3
E coli bacteria count per g				32	<3
Faecal streptococci bacteria count per g	3,70E+04	2,40E+03	1,10E+03	4,50E+03	
Salmonella spp per g	Present	Present	Present	Present	
Coliphage count per g	6,60E+03	500	763	16	<3
Clostridium count per g	2,60E+03	110	4,60E+03	9,60E+03	3,10E+03
pH	6,90				
Moisture content %	12,8	5,6	7,1	21,8	23,0
Cryptosporidium oocysts count per 10g dry weight	2,2	0**	0**		
Giardia cysts count per 10g dry weight	ND	0**	0**		
Ascaris eggs per 10g dry weight	218*	215* / 21**	209* / 0**	40* / 0**	
Entamoeba spp eggs per 10 g dry weight		76	15	18	
Taenia eggs per 10g dry weight		0	0	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT C2 (FAECES + WOOD SHAVINGS; PERSPEX LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	6,10E+07	6,60E+08	7,20E+09	5,30E+08	
Total coliform bacteria count per g	6,60E+04	7,00E+04	2,50E+04	528	<3
Faecal coliform bacteria count per g	3,10E+04	4,10E+04	6,30E+03	<4	<3
E coli bacteria count per g				<4	<3
Faecal streptococci bacteria count per g	6,00E+04	1,30E+04	1,80E+03	240	
Salmonella spp per g	Present	Present	Absent	Present	
Coliphage count per g	4,90E+03	440	18	<4	<3
Clostridium count per g	1,10E+03	5,60E+03	1,20E+04	4,20E+03	2,70E+03
pH	6,37				
Moisture content %	12,9	14,3	28,9	38,6	40,7
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	305*	287* / 22**	171* / 1**	30* / 0**	
Entamoeba spp eggs per 10 g dry weight		27	27	7	
Taenia eggs per 10g dry weight		1	1	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT D1 (FAECES + ASH; CONCRETE LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,10E+08	1,60E+08	1,30E+08	7,80E+06	
Total coliform bacteria count per g	8,00E+04	2,60E+03	1,80E+04	<3	265
Faecal coliform bacteria count per g	2,50E+04	2,10E+03	1,80E+03	<3	185
E coli bacteria count per g				<3	159
Faecal streptococci bacteria count per g	3,70E+04	2,40E+04	2,60E+03	6,60E+04	
Salmonella spp per g	Present	Absent	Present	Present	
Coliphage count per g	6,60E+03	270	37	21	13
Clostridium count per g	2,60E+03	26	2,10E+03	3,60E+03	7,00E+03
pH	6,90				
Moisture content %	12,8	5,7	4,9	4,5	5,4
Cryptosporidium oocysts count per 10g dry weight	2,2	0**	0**		
Giardia cysts count per 10g dry weight	ND	0**	0**		
Ascaris eggs per 10g dry weight	218*	227* / 8**	181* / 0**	20* / 0**	
Entamoeba spp eggs per 10 g dry weight		93	36	18	
Taenia eggs per 10g dry weight		3	3	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT D2 (FAECES + WOOD SHAVINGS; CONCRETE LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	6,10E+07	1,30E+08	2,40E+08	3,80E+07	
Total coliform bacteria count per g	6,60E+04	2,60E+07	4,50E+06	1,10E+07	2,80E+05
Faecal coliform bacteria count per g	3,10E+04	3,10E+06	3,50E+06	2,90E+06	824
E coli bacteria count per g				1,80E+06	<3
Faecal streptococci bacteria count per g	6,00E+04	1,10E+05	5,60E+05	4,80E+06	
Salmonella spp per g	Present	Present	Present	Absent	
Coliphage count per g	4,90E+03	170	3	<3	<3
Clostridium count per g	1,10E+03	280	3,40E+03	6,60E+04	824
pH	6,37				
Moisture content %	12,9	10,0	10,5	9,1	9,3
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	305*	324* / 4**	351* / 0**	17* / 0**	
Entamoeba spp eggs per 10 g dry weight		39	12	9	
Taenia eggs per 10g dry weight		2	2	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT E1 (FAECES + NaOH; CONCRETE LID; VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	3,90E+07	1,10E+08	1,50E+07	<32	
Total coliform bacteria count per g	1,50E+04	1,10E+04	6,20E+03	<3	<3
Faecal coliform bacteria count per g	1,50E+04	8,80E+03	3,80E+03	<3	<3
E coli bacteria count per g				<3	<3
Faecal streptococci bacteria count per g	2,50E+04	1,90E+03	250	<3	
Salmonella spp per g	Present	Present	Absent	Absent	
Coliphage count per g	5,20E+03	270	3	<3	<3
Clostridium count per g	3,00E+02	1,30E+03	3	<3	<3
pH	10,09				
Moisture content %	8,6	6,4	106,0	22,9	16,8
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	272*	76* / 8**	29* / 0**	4* / 0**	
Entamoeba spp eggs per 10 g dry weight		18	9	1	
Taenia eggs per 10g dry weight		0	0	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT E2 (FAECES + NaOH; CONCRETE LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	3,90E+07	2,20E+08	5,40E+04	<33	
Total coliform bacteria count per g	1,50E+04	2,00E+04	2,10E+04	<3	<3
Faecal coliform bacteria count per g	1,50E+04	6,60E+03	637	<3	<3
E coli bacteria count per g				<3	<3
Faecal streptococci bacteria count per g	2,50E+04	2,80E+03	318	<3	
Salmonella spp per g	Present	Present	Absent	Absent	
Coliphage count per g	5,20E+03	410	3	<3	<3
Clostridium count per g	3,00E+02	1,70E+03	3	<3	<3
pH	10,09				
Moisture content %	8,6	9,5	21,4	23,6	23,4
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	272*	310* / 23**	308* / 2**	16* / 0**	
Entamoeba spp eggs per 10 g dry weight		69	31	2	
Taenia eggs per 10g dry weight		2	2	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT F1 (FAECES + GRASS; CONCRETE LID; VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,10E+08	1,40E+09	3,80E+08	5,70E+07	
Total coliform bacteria count per g	2,80E+05	3,00E+06	3,10E+04	<3	1,80E+05
Faecal coliform bacteria count per g	5,40E+04	8,20E+04	279	<3	368
E coli bacteria count per g				<3	<3
Faecal streptococci bacteria count per g	1,80E+05	1,80E+05	4,00E+04	9,60E+04	
Salmonella spp per g	Present	Present	Absent	Absent	
Coliphage count per g	2,00E+03	190	573	2	<3
Clostridium count per g	8,80E+03	6,30E+03	1,60E+04	4,50E+04	8,80E+03
pH	6,80				
Moisture content %	59,6	8,8	10,7	21,7	18,6
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	237*	295* / 0**	215* / 0**	23* / 0**	
Entamoeba spp eggs per 10 g dry weight		96	39	11	
Taenia eggs per 10g dry weight		1	1	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

VAULT F2 (FAECES + GRASS; CONCRETE LID; NO VENTPIPE)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,10E+08	4,70E+08	1,20E+08	1,20E+08	
Total coliform bacteria count per g	2,80E+05	2,40E+05	7,20E+04	<3	3,60E+03
Faecal coliform bacteria count per g	5,40E+04	1,30E+04	329	<3	<3
E coli bacteria count per g				<3	<3
Faecal streptococci bacteria count per g	1,80E+05	9,40E+04	3,90E+03	403	
Salmonella spp per g	Present	Present	Absent	Present	
Coliphage count per g	2,00E+03	1,80E+03	3	<3	<3
Clostridium count per g	8,80E+03	440	6,50E+04	8,40E+04	1,20E+04
pH	6,80				
Moisture content %	59,6	15,2	24,1	25,5	23,2
Cryptosporidium oocysts count per 10g dry weight	ND				
Giardia cysts count per 10g dry weight	ND				
Ascaris eggs per 10g dry weight	237*	337* / 27**	286* / 0**	72* / 0**	
Entamoeba spp eggs per 10 g dry weight		84	28	10	
Taenia eggs per 10g dry weight		3	2	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

MAIN HEAP (FAECES + SOIL)

Parameter	t=0	t=44d	t=97d	t=174d	t=278d
Heterotrophic plate count per g	2,90E+08	6,80E+07	5,10E+07	572	
Total coliform bacteria count per g	1,70E+06	270	2,30E+03	126	<3
Faecal coliform bacteria count per g	9,10E+05	270	1,20E+03	60	<3
E coli bacteria count per g				60	<3
Faecal streptococci bacteria count per g	3,00E+05	3,80E+04	9,10E+04	5	
Salmonella spp per g	Present	Present	Present	Present	
Coliphage count per g	1,30E+04	380	36	<3	<3
Clostridium count per g	8,00E+03	1,10E+04	1,70E+04	2,70E+04	899
pH	7,06				
Moisture content %	12,5	6,8	17,3	16,9	5,3
Cryptosporidium oocysts count per 10g dry weight	0,9	0**	0**		
Giardia cysts count per 10g dry weight	12	0**	0**		
Ascaris eggs per 10g dry weight	201*	174* / 0**	123* / 0**	62* / 0**	
Entamoeba spp eggs per 10g dry weight		68	13	6	
Taenia eggs per 10g dry weight		2	0	0	

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

MAIN HEAP (FAECES + SOIL); REHYDRATED FOR 7d AFTER 278d

Parameter	t=0	t=44d	t=97d	t=174d	t=278d	t=285d (soaked for 7d)
Heterotrophic plate count per g	2,90E+08	6,80E+07	5,10E+07	572		
Total coliform bacteria count per g	1,70E+06	270	2,30E+03	126	<3	<3
Faecal coliform bacteria count per g	9,10E+05	270	1,20E+03	60	<3	<3
E coli bacteria count per g				60	<3	<3
Faecal streptococci bacteria count per g	3,00E+05	3,80E+04	9,10E+04	5		
Salmonella spp per g	Present	Present	Present	Present		
Coliphage count per g	1,30E+04	380	36	<3	<3	<3
Clostridium count per g	8,00E+03	1,10E+04	1,70E+04	2,70E+04	899	75
pH	7,06					
Moisture content %	12,5	6,8	17,3	16,9	5,3	
Cryptosporidium oocysts count per 10g dry weight	0,9	0**	0**			
Giardia cysts count per 10g dry weight	12	0**	0**			
Ascaris eggs per 10g dry weight	201*	174* / 0**	123* / 0**	62* / 0**		
Entamoeba spp eggs per 10g dry weight		68	13	6		
Taenia eggs per 10g dry weight		2	0	0		

Note:
* indicates total no., i.e. viable plus non-viable
** indicates viable only
blank cells indicate no analysis done
ND = not detected

MAIN HEAP (FAECES + SOIL); SPIKED FOR 7d AFTER 278d; NO MOISTURE ADDED

Parameter	t=0	t=44d	t=97d	t=174d	t=278d	t=285d (spiked for 7d)
Heterotrophic plate count per g	2,90E+08	6,80E+07	5,10E+07	572		
Total coliform bacteria count per g	1,70E+06	270	2,30E+03	126	<3	
Faecal coliform bacteria count per g	9,10E+05	270	1,20E+03	60	<3	
E coli bacteria count per g				60	<3 / 1,0E+04***	1,60E+05
Faecal streptococci bacteria count per g	3,00E+05	3,80E+04	9,10E+04	5		
Salmonella spp per g	Present	Present	Present	Present	Present	Present
Coliphage count per g	1,30E+04	380	36	<3	<3 / 1,0E+04***	5
Clostridium count per g	8,00E+03	1,10E+04	1,70E+04	2,70E+04	899	
pH	7,06					
Moisture content %	12,5	6,8	17,3	16,9	5,3	
Cryptosporidium oocysts count per 10g dry weight	0,9	0**	0**			
Giardia cysts count per 10g dry weight	12	0**	0**			
Ascaris eggs per 10g dry weight	201*	174* / 0**	123* / 0**	62* / 0**		
Entamoeba spp eggs per 10g dry weight		68	13	6		
Taenia eggs per 10g dry weight		2	0	0		

Note:

* indicates total no., i.e. viable plus non-viable

** indicates viable only

*** indicates initial spiked value

blank cells indicate no analysis done

ND = not detected