Guidelines for the safe use of wastewater, excreta and greywater

Volume 4:
Excreta and greywater use in agriculture

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List of acronyms and abbreviations

AIDS	Acquired Immune Deficiency Syndrome
BOD	Biological Oxygen Demand
BKV	A polyomavirus
CBO	Community Based Organization
CDC	United States Centers for Disease Control and Prevention
C:N	Carbon to Nitrogen ratio
cfu	Colony Forming Unit
CMV	Cytomegalovirus
COD	Chemical Oxygen Demand
DALY	Disability Adjusted Life Year
EC	European Commission
EHEC	Enterohaemorrhagic *E coli*
EEA	Environmental Exposure Assessment
EIA	Environmental Impact Assessment
EU	European Union
FA	Fossa alterna
FAO	Food and Agriculture Organization of the United Nations
FS	Fecal Sludge
ha	Hectar
HACCP	Hazard Analysis Critical Control Points
HBT	Health-based Target
HCES	Household Centered Environmental Sanitation approach
HE	Helminth Eggs
HIA	Health Impact Assessment
HIV	Human Immunodeficiency Virus
HMU	Health related modeling unit
ID_{50}	Median Infectious Dose
IMSC	Inter-Ministerial Steering Committee
ISO	International Organization for Standardization
IWRM	Integrated Water Resource Management
JCV	A polyomavirus
log	Logarithmic
MDG	Millennium Development Goal
NBR	National Building Regulations
NGO	Non Governmental Organization
P_{inf}	Probability of infection
PDF	Probability Density Function
PK	Phosphorous /potassium
PPPY	Per Person Per Year
QMRA	Quantitative Microbial Risk Assessment
RO	Reverse Osmosis
SAR	Sodium Adsorption Ratio
SPS	Sanitary and Phytosanitary Measures
SS	Suspended Solids
STEG	Septic Tank Effluent Gravity system
T_{90}	Number of days for a decimal reduction (one log reduction)

TS	Total Solids
UK	United Kingdom
UNICEF	United Nations Children's Fund
USA	United States of America
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organization
VIP	Ventilated Improved Pit latrine
WTO	World Trade Organisation
WSP	Waste Stabilization Pond
WSSD	World summit on sustainable Development
WSTR	Wastewater Storage and Treatment Reservoir
ww	Wet Weight
YLD	Years Lived with a Disability
YLL	Years of Life Lost

PREFACE

The United Nations (UN) General Assembly adopted the Millennium Development Goals on 8 September 2000.[1] Similar International Development Targets developed at the World Summit on Sustainable Development were adopted in Johannesburg in 2002. The International Development Targets that are most directly related to the safe use of excreta and greywater are “Goal 1: Eliminate extreme poverty and hunger” and “Goal 7: Ensure environmental sustainability.” The use of excreta and greywater can help communities to grow more food and make use of precious water and nutrient resources. However, it should be done safely to maximize public health gains and environmental benefits.

To protect public health and facilitate the rational use of wastewater and excreta in agriculture and aquaculture, in 1973, the World Health Organization (WHO) developed guidelines for wastewater use in agriculture and aquaculture under the title *Reuse of effluents: Methods of wastewater treatment and health safeguards*.[2] After a thorough review of epidemiological studies and other information, the guidelines were updated in 1989 as *Health guidelines for the use of wastewater in agriculture and aquaculture.*[3] These guidelines have been very influential, and many countries have adopted or adapted them for their wastewater and excreta use practices.

Excreta and wastewater use in agriculture is increasingly being seen as a method for water and nutrient recycling and improving household food security and nutrition for poor households. Interest in excreta and greywater use in agriculture has been driven by water scarcity, availability of nutrients and concerns about health and environmental effects. It was necessary to update the guidelines to take into account scientific evidence concerning pathogens and other factors, including changes in population characteristics, changes in sanitation practices, better methods for evaluating risk, social/equity issues and sociocultural practices. There was especially a need to conduct a review of both risk assessment and epidemiological data.

In order to better package the guidelines for appropriate audiences, the third edition of the *Guidelines for the safe use of wastewater, excreta and greywater* is presented in five separate volumes: *Volume 1: Policy and regulatory issues*; *Volume 2: Wastewater use in agriculture*; *Volume 3: Wastewater and excreta use in aquaculture*; *Volume 4: Excreta and greywater use in agriculture*; and *Volume 5: Sampling and laboratory aspects.*

WHO water-related guidelines are based upon scientific consensus and best available evidence and are developed through broad participation. The *Guidelines for the safe use of wastewater, excreta and greywater* are designed to protect the health of farmers (and their families), local communities and product consumers. They are meant to be adapted to take into consideration national, sociocultural, economic and environmental factors. In places where wastewater, excreta and greywater are used in agriculture and aquaculture, especially at the subsistence level, the health benefits from increased household food security and better nutrition may outweigh some of the negative health impacts. It is therefore important to

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[1] United Nations General Assembly (2000). *United Nations Millennium Declaration*. Resolution A/RES/55/2. New York, United Nations (http://www.un.org/millennium/declaration/ares552e.pdf).
[2] WHO (1973). *Reuse of effluents: Methods of wastewater treatment and health safeguards*. *Report of a WHO Meeting of Experts.* Geneva, World Health Organization (Technical Report Series No. 517).
[3] WHO Scientific Group (1989). *Health guidelines for the use of wastewater in agriculture and aquaculture*. Geneva, World Health Organization (Technical Report Series No. 776).

balance the risks and benefits of these practices. Where the Guidelines relate to technical issues — for example, excreta and greywater treatment — technologies that are readily available and achievable (from both technical and economic standpoints) are explicitly noted, but others are not excluded. Overly strict standards may not be sustainable and, paradoxically, may lead to less health protection, because they may be viewed as unachievable under local circumstances and, thus, ignored. The Guidelines therefore strive to maximize overall public health benefits and the beneficial use of scarce resources.

Following an expert meeting in Stockholm, Sweden, WHO published *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease.*[4] This document presents a harmonized framework for the development of guidelines and standards for water-related microbial hazards. This framework involves the assessment of health risks prior to the setting of health targets, defining basic control approaches and evaluating the impact of these combined approaches on public health status. The framework is flexible and allows countries to take into consideration associated health risks that may result from microbial exposures through drinking-water or contact with recreational or occupational water. It is important that health risks from the use of excreta and greywater in agriculture be put into the context of the overall level of disease within a given population.

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* provides information on the assessment and management of risks associated with microbial hazards. It explains requirements to promote the safe use of excreta and greywater in agriculture, including minimum procedures and specific health-based targets, and how those requirements are intended to be used. This volume also describes the approaches used in deriving the guidelines, including health-based targets, and includes a substantive revision of approaches to ensuring microbial safety.

These Guidelines supersede those in previous editions (1973 and 1989). The Guidelines are recognized as representing the position of the UN system on issues of wastewater, excreta and greywater use and health by “UN-Water,” the body that coordinates among the 24 UN agencies and programmes concerned with water issues. This edition of the Guidelines further develops concepts, approaches and information in previous editions and includes additional information on:

- the context of overall waterborne disease burden in a population and how the use of excreta and greywater in agriculture may contribute to that burden;
- the Stockholm framework for development of water-related guidelines and the setting of health-based targets;
- risk analysis;
- management of risk, including quantification of different health protection measures;
- guideline implementation strategies.

The revised Guidelines will be useful to all those concerned with issues relating to the safe use of wastewater, excreta and greywater, public health and water and waste management,

[4] Fewtrell L, Bartram J, eds. (2001). *Water quality: Guidelines, standards and health — Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing on behalf of the World Health Organization, Geneva.

including environmental and public health scientists, educators, researchers, sanitary engineers, policy-makers and those responsible for developing standards and regulations.

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* Indicates preparation of substantial text inputs

Executive summary

This volume of the World Health Organization's (WHO) *Guidelines for the safe use of wastewater, excreta and greywater* describes the present state of knowledge regarding the impact of excreta and greywater use in agriculture upon the health of product consumers, workers and their families and local communities. Health hazards are identified for each group at risk, and appropriate health protection measures to mitigate the risks are discussed.

The primary aim of the Guidelines is to maximize public health protection and the beneficial use of important resources. The purpose of the Guidelines is to ensure that the use of excreta and greywater in agriculture is made as safe as possible so that the nutritional and household food security benefits can be shared widely in affected communities. The adverse health impacts of excreta and greywater use in agriculture should be carefully weighed against the benefits to health and the environment associated with these practices.

The Guidelines are intended to be used as the basis for the development of international and national approaches (including standards and regulations) to controlling the health risks from hazards associated with excreta and greywater use in agriculture, as well as providing a framework for national and local decision-making.

The information provided is applicable to the intentional use of excreta and greywater in agriculture and also should be relevant to the unintentional use.

The Guidelines provide an integrated preventive management framework for safety applied from the point of household excreta and greywater generation to the consumption of products grown with treated excreta applied as fertilizers or treated greywater for irrigation purposes. They describe reasonable minimum requirements of good practice to protect the health of the people using treated excreta or greywater or consuming products grown with these for fertilization or irrigation purposes and provide information that is then used to derive health-based targets. Neither the minimum good practices nor the health-based targets are mandatory limits. The preferred approaches adopted by national or local authorities towards implementation of the Guidelines, including health-based targets, may vary depending on social, cultural, environmental and economic characteristics, as well as knowledge of routes of exposure, the nature and severity of hazards and the effectiveness of health protection measures available.

The revised *Guidelines for the safe use of wastewater, excreta and greywater* will be useful to all those concerned with issues relating to the safe use of wastewater, excreta and greywater, public health, water resources development and wastewater management. The target audience may include public health, agricultural and environmental scientists, agriculture professionals, educators, researchers, sanitary engineers, policy-makers and those responsible for developing standards and regulations.

Introduction

Within a foreseeable future traditional waterborne sewerage will still dominate in sanitation.
Since only a fraction of existing wastewater treatment plants in the world is optimally reducing pathogenic microorganisms and since a majority of both rural and urban citizens people will not be connected to centralised wastewater treatment systems alternative sanitation approaches needs to be developed in parallel. In order to meet the demands of sanitation for all, prevention of environmental degradation and sustainable recycling of the existing plant nutrients in human excreta for food production, a household or community centered source separation is an alternative approach that is rapidly expanding. The principal forces driving the increasing use are:

- increasing water scarcity and stress;
- increasing population;
- recognition of the resource value of these substances;
- the Millennium Development Goals for a sustainable future.

Growing competition between agricultural and urban areas for high-quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase the pressure on this increasingly scarce resource. Most population growth is expected to occur in urban and periurban areas in developing countries (United Nations Population Division, 2002). Population growth increases both the demand for fresh water and the amount of wastes that are discharged into the environment, thus leading to more pollution of clean water sources. Household centered source separation and safe reuse will help to alleviate these pressures. The additional advantage of nutrient use from excreta as fertilizers is that this "product" is less contaminated with industrial chemicals than when wastewater is used and save water for other use. Its growing use and potential in mainly small-scale settings are exemplified. The guidelines for excreta and greywater mainly focus on small-scale applications but is applicable both to industrialized and third world countries.

The Stockholm framework

The Stockholm framework outlines a risk management strategy for controlling the transmission of waterborne and environmental related diseases from infectious agents and is based on:

- assessment of environmental exposures;
- assessment of health risk;
- definition of a tolerable health risk;
- development of health-based targets;
- implementation of health risk management procedures;
- impact on public health.

Environmental exposure assessment is central for both the assessment of risk and risk management. Environmental exposure assessment is a process that looks at the hazards in the environment and evaluates different exposure routes to human (or animal) populations. The primary hazards are the excreta-related pathogens, dealt with in these guidelines and the transmission to product consumers, farmers and local communities and others that may be at risk from these exposures. As a predictive approach the health risk are partly assessed based on quantitative microbial risk assessment which is further related to the health based targets and the risk management strategies. The management of risk is context-specific while the health-based targets should be comparable with those for other environmental exposures, thus the metric of disability adjusted life years (DALYs) is applied, which relates to the probability of infection for different etiological agens. The management of risk is facilitated by conducting an analysis of the entire production chain, from excreta or greywater generation to consumption of the product. Knowledge of the system is then used to develop control measures that can reduce health risks at different points.

Assessment of health risk

Three types of evaluations are used to assess risk: microbial analysis, epidemiological studies and quantitative microbial risk assessment.

Faeces contain a variety of different pathogens reflecting the prevalence in the human population, while only a few types of pathogens may be excreted in urine. The risks associated both with reuse of urine as a fertilizer or the use of greywater for irrigation purposes is related to the cross-contamination of faecal matter. Epidemiological data for the assessment of risk through treated faeces, feacal sludge, urine or greywater are scarce and unreliable, while ample evidence exists related to untreated faecal matter. Microbial analysis are also partly unreliable in the prediction of risk due to a more rapid die-off of several of the indicator organism, like *E coli*, in urine, underestimating the risk for pathogen transmission. The contrary may occur in greywater, where a growth of the indicator bacteria on easily degradable organics substances instead may overestimate the risks. Based on the above limitations quantitative microbial risk assessment is the main approach taken due to the range of organism with common features that govern their likelihood of transmission and their prevalence in the population. Factors accounted for are:

- Epidemiological features (including infectious dose, latency, hosts and intermediate host).
- Persistence in different environments outside the human body (and potential for growth)
- The major transmission routes
- Relative efficiency to be reduced by different treatment barriers and
- Management control measures

Health-based targets

Health-based targets define a level of health protection that is relevant to each hazard. A health-based target can be based on a standard metric of disease, such as a DALY (i.e. 10^{-6} DALY), or it can be based on an appropriate health outcome, such as the prevention of the transmission of diseases resulting from exposures to excreta from site of delivery at the household level to its use in agriculture. To achieve a health-based target, health protection measures are developed. Usually a health-based target can be achieved through a combination of health protection measures targeted at different steps in the system.

The health-based targets may be obtained through different treatment barriers or health protection measures. The barriers relate to the possibilities of verification monitoring, mainly in large-scale systems, as exemplified in Table 1 for excreta and greywater. Verification monitoring is not applicable for urine.

Table1. Guidelines values for verification monitoring in large-scale treatment systems of Greywater, Excreta and Fecal Sludges aimed for use in agriculture.

	Helm. Eggs (No/ g TS or Liter)	E. coli (No/100 ml)
Treated faeces and fecal sludge	<1/ g TS	<1000□□□/g TS
Greywater for use in: • Restricted irrigation	< 1/L □□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□ <1/L	$<10^5$ * • Relaxed to $<10^6$ when exposure is limited or regrowth is likely □□□□□□□□□□□□□□□

• Irrigation of crops eaten raw – Unrestricted irrigation		$<10^3$ • Relaxed to $<10^4$ for high growing leaf crops or drip irrigation

*These values additionally acceptable due to the high re-growth potential of *E coli* and other fecal coliforms in greywater.

The health-based targets may also relate to operational monitoring, like storage as an on-site treatment measure or further treatment for off-site treatment after collection. This is exemplified for faeces from small-scale systems in Table 2.

Table 2. Recommendations for storage treatment of dry excreta and fecal sludge before use at the household and municipal levels. No addition of new material.

Treatment	**Criteria**	**Comment**
Storage ; Ambient temperature 2-20 °C	1.5 - 2 years	Will eliminate bacterial pathogens; re-growth of *E coli* and *Salmonella* may be considered if rewetted; will reduce viruses, and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers
Storage Ambient temperature >20-35 °C	> 1 year	Inactivation of *Clonorchis* and *Opisthorchis* eggs will occur within days; substantial to total inactivation of viruses, bacteria and protozoa; Inactivation of schistosome eggs (<1 month); Inactivation of nematode (roundworm) eggs, e.g. hookworm (*Ancylostoma*/*Necator* and whipworm (*Trichuris*); Survival of a certain percentage (10-30) of *Ascaris* eggs (≥4 months) while a more or less complete inactivation of *Ascaris* eggs will occur within 1 year; (Strauss 1985)
Alkaline treatment	pH >9 during > 6 months	If temperature >35°C and moisture <25%, Lower pH and/or wetter material will prolong the time for absolute elimination.

For collected urine storage criteria apply, mainly derived from compiled risk assessment studies. The information obtained has been transferred into operational guidelines to limit the risk to a level of below 10^{-6} DALY also accounting for additional health protection measures. The operational guidelines are based on source-separation of urine (Table 3). In case of a heavy faecal cross-contamination, the guideline times may be prolonged. If urine is only used as a fertilizer of crops for own consumption, it can be used directly without storage, due to a much higher likelihood of inter-family transmission than through urine applied as a fertiliser.

Table 3. Recommended guideline storage times for urine mixture[a] based on estimated pathogen content[b] and recommended crop for larger systems[c].

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

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

[b] Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognised for causing any of the infections of concern.

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

[d] Not grasslands for production of fodder.

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

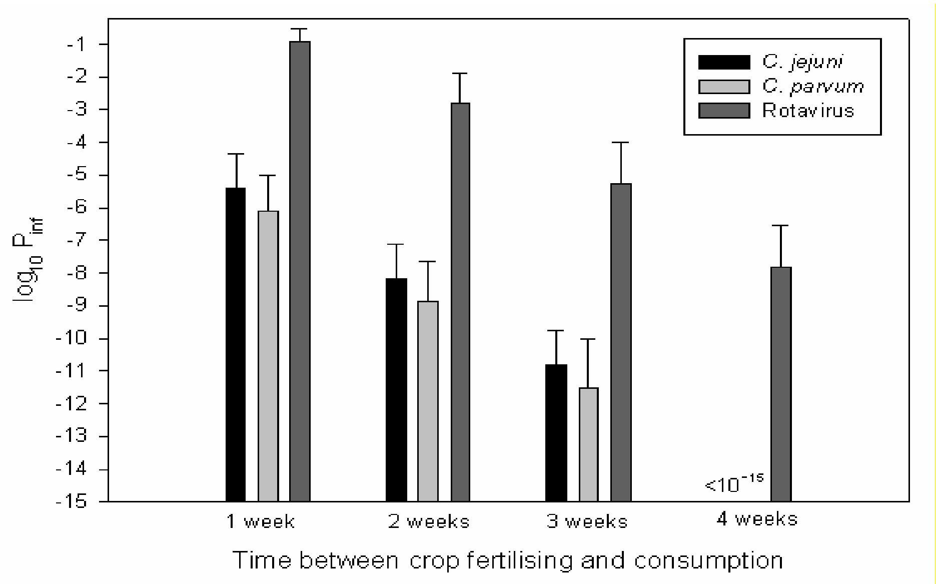


Fig 1. Mean probability of infection by pathogens following ingestion of crop fertilised with unstored urine with varying withholding periods.

For all types of treated excreta additional safety measures applies. These include for example a recommended withholding-time between times of application of the treated excreta as a fertilizer to the time of crop harvest of one month. Based on quantitative risk assessment this time period has shown to be well below a probability of infection of 10^{-4}, which is within the range of a 10^{-6} DALY level, as exemplified in Fig 1 for urine.

Health protection measures

A variety of health protection measures can be used to reduce health risks from the local communities to workers and their families and finally the consumers of the fertilised or irrigated products.

Hazards associated with the consumption of excreta fertilised products include excreta-related diseases. The risk from infectious diseases is significantly reduced if foods are eaten after thorough handling and cooking. The following health protection measures have an impact on product consumers:

- excreta and greywater treatment;
- crop restriction;
- waste application and withholding periods between fertilization and harvest to allow potentially remaining pathogen to die-off;
- hygienic practices and food preparation;
- health and hygiene promotion;
- produce washing, disinfection and cooking;

Workers and their families may be exposed to excreta-related diseases and vector-borne diseases (in certain locations) through excreta and greywater use activities. Excreta and greywater treatment is a control measure but may not directly impact vector-borne diseases. Other health protection measures for workers and their families include:

- use of personal protective equipment;
- access to safe drinking-water and sanitation facilities at farms;
- health and hygiene promotion;
- disease vector and intermediate host control;
- reduced vector contact.

Local communities are at risk from the same hazards as workers. If they do not have access to safe drinking-water, they may use contaminated irrigation water for drinking or for domestic purposes. Children may also play or swim in the contaminated water. Similarly, if the activities result in increased vector breeding, then vector-borne diseases can affect local communities, even if they do not have direct access to the fields. To reduce health hazards, the following health protection measures for local communities may be used:

- excreta and greywater treatment;
- limit contact during handling and control access to fields;
- access to safe drinking-water and sanitation facilities in local communities;
- health and hygiene promotion;
- disease vector and intermediate host control;
- reduced vector contact.

Monitoring and system assessment

Monitoring has three different purposes: validation, or proving that the system is capable of meeting its design requirements; operational monitoring, which provides information regarding the functioning of individual components of the health protection measures; and verification, which usually takes place at the end of the process to ensure that the system is achieving the specified targets.

The three functions of monitoring are each used for different purposes at different times. Validation is performed at the beginning when a new system is developed or when new processes are added and is used to test or prove that the system is capable of meeting the specified targets. Operational monitoring is used on a routine basis to indicate that processes are working as expected. Monitoring of this type relies on simple measurements that can be read quickly so that decisions can be made in time to remedy a problem. Verification is used to show that the end product (e.g. treated excreta or greywater; crops) meets treatment targets and ultimately the health-based targets. Information from verification monitoring is collected periodically and thus would arrive too late to allow managers to make decisions to prevent a hazard break-through. However, verification monitoring in larger systems can indicate trends over time (e.g. if the efficiency of a specific process was improving or decreasing).

The most effective means of consistently ensuring safety in the use of excreta and greywater is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the process from waste generation to treatment, use as excreta as fertilisers or greywater for irrigation purpose and product use or consumption. The following components of this approach are important for achieving the health-based targets: system assessment, identifying control measures and methods for monitoring them and developing a management plan.

Sociocultural aspects

Human behavioural patterns are a key-determining factor in the transmission of excreta-related diseases. The social feasibility of changing certain behavioural patterns in order to introduce excreta or greywater use schemes or to reduce disease transmission in existing schemes needs to be assessed on an individual project basis. Cultural beliefs vary so widely in different parts of the world that it is not possible to assume that any of the practices that have evolved in relation to use can be readily transferred elsewhere.

Closely associated with cultural beliefs is the public perception of treated excreta use. Even when projects are technically well planned and all of the relevant health protection measures have been included, the project can fail without adequately accounting for public perception.

Environmental aspects

Excreta are an important source of nutrients for many farmers. The intention with the direct use of excreta and greywater on arable land is to minimize the environmental impact both in the local and global context. Reuse of excreta on arable land secure valuable fertilisers for crop production and limit the negative impact on water bodies. The environmental impact of different sanitation systems can be measured in terms of the use of natural resources; discharges to water bodies; air emissions; resources; and the impacts on soils. In these type of assessments source separation and household centered use systems often comes out more favourably than conventional systems.

Application of excreta and greywater to agricultural land will reduce the direct impacts on water bodies. However, as for any type of fertiliser the nutrients may percolate to groundwater, if applied in excess or be flushed into surface water after excessive rainfall. This impact will always be less than the direct use of water bodies as the primary recipient. Surface water bodies are affected by agriculture drainage and runoff. Impacts depend on the type of water body (rivers, agriculture channels, lakes or dams) and their use, as well as the hydraulic retention time and the function played within the ecosystem but will be much less than if used as a primary recipient.
Phosphorous is an essential element for plant growth and external phosphorous from mined phosphate is usually supplied in agriculture in order to increase plant productivity. World supplies of accessible mined phosphate are diminishing. Approximately 25% of the mined phosphorous ends up in aquatic environments or buried in landfills or other sinks. The discharge into aquatic environments causes eutrophication of water bodies leading to more environmental damage. Urine alone contains more than 50% of the excreted phosphorous from humans. Thus the diversion and use of urine in agriculture can aid crop production and reduce the costs of and need for advanced wastewater treatment processes to remove phosphorous from the treated effluents.

Economic and financial considerations

Economic factors are especially important when the viability of a new is being appraised, but even an economically worthwhile project can fail without careful financial planning.

Economic analysis and financial considerations are crucial for encouraging the safe use of excreta. Economic analysis seeks to establish the economic feasibility of a project and enables comparisons between different options. The cost transfers to other sectors (e.g. the health and environmental impacts on downstream communities) also need to be included in a cost analysis. This can be facilitated by the use of multiple objective decision-making processes.

Financial planning looks at how the project is to be paid for. In establishing the financial feasibility of a project, it is important to determine the sources of revenues and clarify who will pay for what. The ability to profitably sell products fertilised with excreta or irrigated with greywater also needs analysis.

Policy aspects

Appropriate policies, legislation, institutional frameworks and regulations at the international, national and local levels facilitate the safe management of excreta and greywater practices. In many countries where this takes place, these frameworks are lacking.

Policy is the set of procedures, rules, decision-making criteria and allocation mechanisms that provide the basis for programmes and services. Policies set priorities and associated strategies allocate resources for their implementation. Policies are implemented through four types of instruments: laws and regulations; economic measures; information and education programmes; and assignments of rights and responsibilities for providing services.

In developing a national policy framework to facilitate safe use of excreta as fertilisers, it is important to define the objectives of the policy, assess the current policy environment and develop a national approach. National approaches for adequate sanitation based upon the WHO Guidelines will protect public health the most when they are integrated into comprehensive public health programmes that include other sanitary measures, such as health and hygiene promotion and improving access to safe drinking-water.

National approaches need to be adapted to the local sociocultural, environmental and economic circumstances, but they should be aimed at progressive improvement of public health. Interventions that address the greatest local health threats first should be given the highest priority. As resources and new data become available, additional health protection measures can be introduced.

Planning and implementation

Planning and implementation of excreta and greywater programmes require a comprehensive progressive approach that responds to the greatest health priorities first. Strategies for developing national programmes should include elements on communication to stakeholders, interaction with stakeholders and the collection and use of data.

Additionally, planning for projects at a local level requires an assessment of several important underlying factors. The sustainability of waste-fed aquaculture relies on the assessment and understanding of eight important criteria: health, economic feasibility, social impact and public perception, financial feasibility, environmental impact, market feasibility, institutional feasibility and technical feasibility.

1. INTRODUCTION

The *Guidelines for Safe Use of Excreta and Greywater* gives information on the health risks associated with pathogens that occur in human excreta and greywater and technical and operational barriers to minimize these risks. They include supporting evidence about the fertilizing value of treated excreta, relate their use to sustainability criteria, outline planning, prevention and implementation strategies and put their safe handling in a legal, institutional and economic framework. Any possible adverse impact will be weighted against the health and environmental benefits of recirculating nutrients to arable land. Positive health impacts such as the contribution to better nutrition and the impact on household security – especially for the poor, also need to be considered.

The poor suffer the most from diseases transmitted through faecal/oral pathways, including contaminated water and improper excreta disposal. Therefore, the positive health outcome of these guidelines is potentially greatest for the poorest members of society, reflecting a social equity dimension. A significant amount of excreta is used in subsistence agriculture. Although the main focus of the Guidelines is on small-scale systems, their scope is not limited to these.

Theses Guidelines for the Safe Use of Excreta and Greywater are structured as outlined in Figure 1.1.

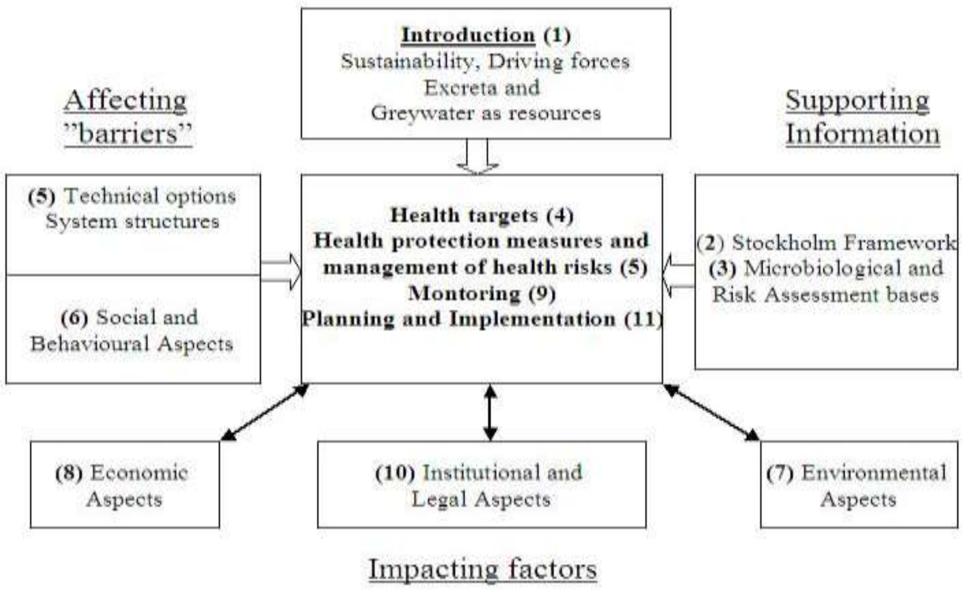


Figure 1.1. Structure of Guidelines for Safe Use of Excreta and Greywater.

Chapter 1 presents the objectives and introduces some conceptual issues; it also describes the target audience, the driving forces behind the excreta and greywater use, the resources value and the Millennium Development Goals. Chapter 2 provides an overview of the Stockholm Framework. Chapter 3 provides the epidemiological, microbiological, and risk assessment bases for the Guidelines. Chapters 4 and 5 present health based targets and health protection measures including technical components, crop restrictions, agricultural methods, human exposure control, hygiene education and health care aspects, while chapter 6 provide practical guidance on monitoring. Chapters 7 and 8 and 9 gives background information on socio-cultural, environmental and economic aspects. The policy, institutional and legal frameworks is covered in chapter 10 and on planning and implementation procedures in chapter 11.

1.1 Objectives and general considerations

The overall objective of these Guidelines is to protect the health of individuals and benefit the health status of communities by the **safe** use of excreta and greywater in a range of applications. They consider the positive health outcomes of this use (such as its contribution to better nutrition and food security through agricultural use), without presenting these as trade-offs.

The Guidelines are based on the development and use of health-based targets, thus establishing a goal of attaining a certain level of health protection in an exposed population. They describe recommended reasonable minimum safe practice requirements and system performance to protect the health of the people using excreta and greywater, local communities or the consumers of products grown with them. The Guidelines support the development and implementation of risk management strategies. The level of health can be achieved by using a combination of management approaches (e.g., handling and crop restriction, human exposure control) and quality targets to arrive at the specified health outcome. Thus 'Guidelines' consist of both good handling practices and quality specifications and may include:

- A level of management;
- A concentration of a constituent that does not represent a significant risk to the health of members of important user groups;
- A condition under which such exposures are unlikely to occur; or
- A combination of the last two.

The Guidelines relates to an integrated risk management framework (see Stockholm framework Chapter 2) applied from the point of generation to consumption of products grown with the excreta or greywater. The approach followed in these Guidelines is intended to lead to national standards and regulations that can be readily implemented and enforced and are protective of public health. It is essential that each country review its needs and capacities in developing a regulatory framework. In order to define national standards and procedures, it is necessary to consider the guidelines in the context of local environmental, social, economic and cultural conditions (WHO 2004). Successful implementation of the Guidelines will require a broad-based policy framework that includes positive and negative incentives to alter behaviour and monitor and improve situations. This will require significant efforts in intersectoral coordination and cooperation at national and local levels and the development of suitable skills and expertise.

In some situations it will not be possible to fully implement the Guidelines at one time. The Guidelines will allow progressive implementation. The greatest threats to health should be prioritized and addressed first. Over time it should be possible to adjust the risk management framework to strive for the continual improvement of public health.

Ultimately, the judgment of safety - or what is a tolerable level of risk in particular circumstances - is a matter in which society as a whole has a role to play. The final judgment as to whether the benefit from using any of the guidelines and guideline values as national or local standards justifies the cost is for each country to decide. The final judgment on safety standards and procedures - or what is a tolerable level of risk under specific circumstances at what costs - is a matter for broad public consultation as well as a transparent and accountable political decision-making process.

1.2 Target audience and definitions

These guidelines are targeted at decision makers and regulators in WHO Member States who are responsible for setting the framework for, planning and implementing activities in sanitation related issues. It is hoped that these guidelines also will be useful to all those with a stake or interest in the safe use of excreta and greywater, public health, water and waste management including environmental and public health scientists, educators, farmers, researchers, sanitary engineers, community planners, policy makers and regulators.

The health hazards linked to the use of excreta and greywater vary with local disease prevalence, the local transmission and exposure pathways and the capacity of health services to deal with them. The pathways are closely related to handling practices in the chain from the "producer to the use", including ingestion of contaminated food products. The responsibility to minimize health risks lies with the direct users of excreta and greywater, with the planners and managers of systems where excreta and greywater are applied and with the local and national regulatory authorities that set standards for norms and procedures. Non-governmental organizations and special interest groups also have an important role to play in assisting local communities to maximize the re-use of valuable resources while ensuring health risks are reduced to a minimum.

In the context of these Guidelines “excreta” refers to faeces and urine, but also to excreta-derived products such as faecal sludge and septage (i.e., sludge derived from pit toilets and septic tanks) (see box 1.1). Sludge derived from the treatment of municipal or industrial wastewater is not included in these guidelines. The main focus of these Guidelines is the prevention of infectious disease transmission and health issues associated with exposure to chemicals are only discussed in broad terms.

“Greywater” is per definition the wastewater from the kitchen, bath and laundry without the wastewater from toilets and therefore generally containing less concentration of excreta except in specific situations due to infant care or where anal cleansing water is combined with the greywater. Greywater is mainly used for irrigation, but health issues are also associated with the use of greywater for other purposes such as toilet flushing, service water or groundwater infiltration.

Box 1.1 Common Terms and Definitions
Excreta - Faeces and urine, (in general term also refer to faecal sludge, septage and nightsoil).
Greywater - water from the kitchen, bath and/or laundry, which generally do not contain significant concentrations of excreta.
Blackwater - source-separated wastewater from toilets containing faeces, urine and flushing water (and eventually anal cleansing water in “washing” communities**)**

Faecal Sludge - Sludge's of variable consistency collected from on-site sanitation systems, e.g., latrines, non-sewered public toilets, septic tanks, and aqua privies. Nightsoil, septage and other non-wastewater-derived sludges are included in this term.
Sludge - a mixture of solids and water that settles to the bottom of latrines, septic tanks, ponds, or is produced as a by-product of wastewater treatment (sludge produced from the treatment of municipal or industrial wastewater is not discussed in this document).
Nightsoil - untreated excreta transported without water, e.g. via containers or buckets.
Septage - sludge removed from septic tanks.
Sanitation - intervention (usually construction of facilities) that improve the management of excreta.
Off-site sanitation - system of sanitation where excreta are removed from the plot occupied by the dwelling and its immediate surroundings.
On-site sanitation - system of sanitation where the means of collection, storage and treatment are contained within the plot occupied by the dwelling and its immediate surroundings.
Source-separation: Diversion of urine, faeces, greywater or all, followed by separate collection (and treatment).

Sources: Montangero and Strauss, 2002; Ridderstolpe, 2004; WSSCC, 2005.

1.3 International guidelines and national standards

1.3.1 National standards

WHO Guidelines are intended to provide a consistent level of health protection in different settings and function as document to build further on and be adapted based on the national circumstances. Countries may wish to develop their own standards based upon their national environmental, socio-cultural and economic conditions. In some cases, countries may choose to develop different standards for products consumed locally than for exports. In circumstances, where relaxed national standards are set based on a locally adopted level of tolerable risk (see Chapter 2 for further discussion of tolerable risk) incidence of diarrhoeal or other diseases needs to be accounted for.

1.3.2 Food exports

As stated in the former paragraph, the guidelines can be adapted based on local conditions. The exception is in relation to the rules that govern international trade in food which were agreed during the Uruguay Round of Multilateral Trade Negotiations and apply to all members of the World Trade Organization (WTO). With regard to food safety, rules are set out in the Agreement on the application of Sanitary and Phytosanitary Measures (SPS agreement). According to this, WTO members have the right to take legitimate measures to protect the life and health of their populations from hazards in food, provided that the measures are not unjustifiably restrictive of trade (WHO 1999). The import of contaminated vegetables has led to disease outbreaks in recipient countries. Pathogens can be introduced into communities lacking immunity, resulting in large disease outbreaks (Frost et al. 1995; Kapperud et al., 1995). Guidelines for the international trade of excreta fertilised and wastewater irrigated food products therefore needs to be based on sound and scientific risk management principles.

WHO Guidelines for the safe use of excreta and greywater are based upon a risk analysis approach which is recognized as the fundamental methodology underlying the development of food safety standards that both provide adequate health protection and facilitate trade in food. Adherence to the recommended WHO Guidelines for exports of excreta fertilised or greywater irrigated food products will help to ensure the international trade of safe food products.

1.4 Factors that affect sustainability in sanitation

As defined in the Report of the World Commission on Environment and Development (WCED, 1987) sustainability is “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs”. Increasing access to adequate sanitation and making people adopt key hygiene behaviours is the first priority from a public health point of view.

Within the scope of "*The Guidelines for Safe Use or Excreta and Greywater*" sustainability could be described as “the ability to plan and manage excreta and greywater and use it in such a way that human health is not compromised, nutrients are recirculated for food production and negative impacts on water resources or the environment are avoided." Sustainability needs to be defined in relation to the interaction of users, organization and technology where different criteria are important:

- health,
- environment,
- economy,
- socio-cultural factors and
- technical function

These aspects should be addressed with appropriate policies and within a conductive legal and regulatory framework and are linked to different parts of the Guidelines.

1.4.1 Health and Hygiene

The health impact in reducing diseases in sanitation is associated with all factors and closely interlinked with hygiene requirements**,** behavioural changes as well as proper access and use of water and sanitation facilities. Focusing on just the provision of sanitation hardware will not result in sustainable change. Health aspects of excreta and greywater use are further elaborated on in Chapters 3 and 5.

1.4.2 Environment and Resource Use

Environmental sustainability is directly linked with minimizing the negative impact of surface- and groundwaters and make more efficient use of the nutrient resources for crop and energy production. The treatment and safe use of excreta and greywater will mostly benefit the environment in relation to:

- Recycling of water and nutrient resources;
- Reduction of pressure on freshwater resources;
- Reduction of downstream pollution in comparison to the discharge of wastes; and
- Reduction of potential environmental impacts from various chemicals (endocrine disruptors, pharmaceuticals, etc. partly adsorb to soil particles and/or biodegrade in the soil, reducing the environmental impact of waters).

Environmental aspects of excreta and greywater use are further discussed in Chapter 8.

1.4.3 Economy

Economic aspects of sanitation are import both at the national and household levels. At the national level, planners want to ensure optimal cost-effectiveness where investments in hygiene and sanitation gives substantial economic returns in health benefits and time gained (Hutton and Haller, 2004). The cost-effectiveness of reducing downstream health and other impacts from better wastewater treatment and/or reducing waste discharges into surface waters have not been estimated but are likely to be as important.

Several studies have indicated that it is more cost-effective to provide funding for creating sanitation and hygiene demand through promotion than to heavily subsidize sanitation hardware (Cairncross 1992; Samanta and van Wijk, 1998; Wright 1997; Kolsky and Diop 2004). Most costs of providing sanitation are incurred at the household level. Consumers want products that are durable that will not cost a lot to operate and maintain. It is unlikely that sanitation will become sustainable unless local resources are in focus, where people can make a living supplying services to those in need (Kolsky and Diop 2004). Economic aspects are further discussed in Chapters 9 and in relation to institutional and legal aspects in Chapter 10.

1.4.4 Socio-cultural aspects and Use

Socio-cultural factors are fundamental for sustainability. If a sanitation facility is disliked it will not be used. Use is linked to access and convenience factors, but is also governed by social, cultural and religious beliefs. For women and girls safety of access is a major concern. The feeling of ownership or responsibility is crucial and will for example affect the cleanliness of premises. The lack of felt responsibility (in addition to access) is a central factor in the failure of some public sanitary facilities. Socio-cultural issues concerning the use of excreta and greywater use are further discussed in Chapter 7.

1.4.5. Technology and Function

Technology function and selection are important aspects of sustainability. Technologies selected for the safe use of excreta and greywater should meet all of the other four sustainability criteria:

- Health - technologies should provide inherent individual and public health protection;
- Environment - technologies prevent contaminants to reach ground- or surface water supplies and provide other environmental protection;
- Economy - technologies should be cost-effective and available in a range of options that accommodate different levels of affordability and be possible to be upgraded or improved as more resources become available; and
- Socio-cultural - technologies should be compatible with local values and beliefs and designed with all potential users in mind.

Excreta and greywater treatment technologies, handling and use are further discussed in Chapter 5.

1.5 Driving Forces

Driving forces behind the increased use of excreta and greywater in agriculture and other contexts worldwide include:

- water scarcity - excreta and greywater use strategies which reduce water use for other purposes;
- population growth – excreta and greywater use will be required to cover the increasing needs due to predicted population growths
- resource value - excreta and greywater contain important nutrients, especially phosphorous which is predicted to be in short supply in 150 years;
- food production - use of excreta and greywater can increase food production; reduce malnutrition and food insecurity;
- downstream impacts - excreta and greywater use practiced close to where the wastes are generated helps to reduce downstream health and environmental impacts.
- Millennium Development Goals – the international policy on increasing the access to basic sanitation and water supply especially for the urban and rural poor will lead to increasing quantities of excreta and greywater to be handled

1.5.1 Water Scarcity and population growth

It is estimated that within the next 50 years more than 40% of the world's population will live in countries facing water stress or water scarcity. In 1995, 31 countries were classified as water-scarce or water-stressed, and it is estimated that 48 and 54 countries will fall into these categories by 2025 and 2050, respectively. These numbers do not include people living in arid regions of large countries where sufficient water is poorly distributed − e.g., China, India and the USA (China is predicted to reach water-scarcity by 2050 and India by 2025) (Hinrichsen *et al*., 1998).

Growing competition between agriculture and urban areas for high-quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase the pressure on this resource. Most population growth is expected to occur in urban and periurban areas in developing countries (United Nations Population Division, 2002). For example, most of the 19 cities for which the most rapid growth is predicted between 2000 and 2015 (with populations expected to more than double) are in chronically water-short regions of developing countries (United Nations Population Division, 2002).

The growth of urban populations, especially in developing countries will create several new challenges:

- greater populations will generate more wastes especially in and around cities;
- on-site waste disposal is more difficult in many densely populated areas; and
- urban agriculture (with greywater and excreta as inputs) will play a more important role in supplying food to cities

1.5.2 Excreta and greywater as resources

Excreta and greywater contain nutrients and water, which make them valuable resources. The use of excreta and greywater in agriculture, aquaculture, and other settings reduces the use of and need for artificial fertilizers and is important for nutrient recycling. Some studies indicate that the world's supply of readably available phosphorous is limited and will run out in 150 years (Rosemarin, 2004). Excreta are an accessible source of important plant nutrients, like phosphorous, nitrogen and potassium and its use can help to reduce the mining of finite phosphorous reserves and energy expended to create artificial fertilizers. Greywater is mostly being used for irrigation, as service water or sometimes for groundwater recharge at local scale. Its use is reducing the demand in fresh water supply and mitigates the stress on the water resources.

1.5.2.1 Excreta quantities and composition

Annually, around 130 million tonnes of fertilisers are sold globally, out of which 63 % in the developing world. Out of this, 78 million tonnes are nitrogen and 13,7 million phosphorous. The rest represents potassium, sulphur and micronutrients. The amount of nitrogen in excreta from 6 billion persons equals 27 million tonnes of nitrogen and 3 million tonnes of phosphorous. This means that one third of the worlds mineral nitrogen use could in theory be replaced by nitrogen in excreta. Regarding phosphorous, 22 % of the worlds use of mined phosphorous can be replaced by excreta.

The major plant nutrients nitrogen (N), phosphorous (P) and potassium (K) and sulphur (S) are found in human excreta and thus also in domestic wastewater but the contents will vary depending on the food intake. The greywater will mainly provide water for recirculation and only supply minor amounts of nutrients.

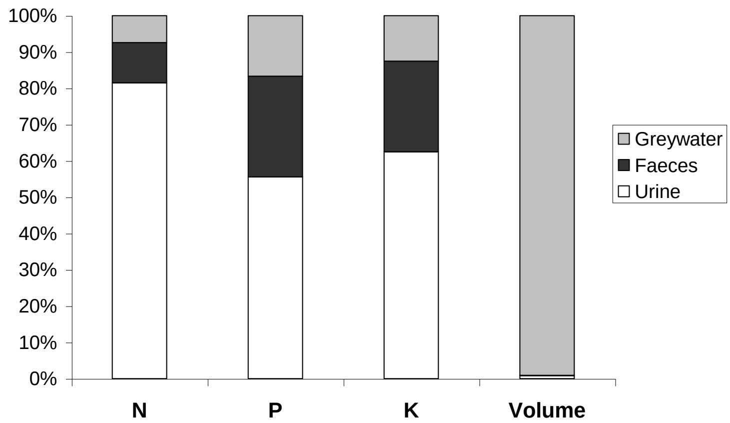


Fig 1.2 Content of major plant nutrients and volume in domestic wastewater, exemplified from Sweden. The daily mean excretion per person and day is: 13 g N, 1.5 g P and 4 g K in a volume of 150-200 litre including greywater (Vinnerås, 2002).

1.5.2.2 Mass balance and content of macronutrients in excreta

The nutrient content in urine and faeces directly depends on the amounts and quality of food consumed. Children need nutrients to grow but for adults food consumption is mainly for energy and only minor amounts of the nutrient are retained and accumulated in the body.

Almost all consumed plant nutrients will therefore leave the human body with excreta. Even during adolescence, accumulation of nutrients in the body is negligible, calculated to be less than 2% of the consumed nitrogen between the ages 3 and 13.

Since the main amounts of nutrients leave the human body with the excreta the excreted plant nutrients can be calculated from the food intake, where information is more readily available and the fertility of the arable land be maintained, as the recycled products contain similar amounts of plant nutrients as were taken up by the crops.
Based on the FAO statistics (www.fao.org) on the available food supply in different countries, calculations have been made of amounts and macronutrient content of excreta (Jönsson & Vinnerås, 2004).

Table 1.1. *Swedish default values for excreted mass and nutrients (Vinnerås, 2002)*

Parameter	Unit	Urine	Faeces	Toilet paper	Blackwater (urine+faeces)
Wet mass	kg/person,year	550	51	8.9	610
Dry mass	kg/ person,year	21	11	8.5	40.5
Nitrogen	g/ person,year	4000	550		4550
Phosphorus	g/ person,year	365	183		548

The estimated average amounts of excreta, the food intake according to the FAO statistics and the nutrient content in different foodstuffs, are used in a relationship (Equations 1-2) between the food intake according to FAO and the excretion of N and P.

N= 0.13* Total food protein ***Equation 1***

P= 0.011* (Total food protein + Vegetal food protein) ***Equation 2***

These equations can be used to estimate the average excretion of N and P in different countries as exemplified for a few countries (Table 1.2). Potassium values are more variable, but are still included as a guiding reference.

Table 1.2. *Estimated excretion of nutrients per capita in different countries (Jönsson & Vinnerås, 2004)*

Country		Nitrogen kg/cap, yr	Phosphorus kg/cap, yr	Potassium kg/cap, yr
China, total		4.0	0.6	1.8
	Urine	3.5	0.4	1.3
	Faeces	0.5	0.2	0.5
Haiti, total		2.1	0.3	1.2
	Urine	1.9	0.2	0.9
	Faeces	0.3	0.1	0.3
India, total		2.7	0.4	1.5
	Urine	2.3	0.3	1.1
	Faeces	0.3	0.1	0.4
South Africa, total		3.4	0.5	1.6
	Urine	3.0	0.3	1.2
	Faeces	0.4	0.2	0.4
Uganda, total		2.5	0.4	1.4
	Urine	2.2	0.3	1.0
	Faeces	0.3	0.1	0.4

The total per capita annual excretion reported by Gao *et al.* (2002) for China was 4.4 kg of N and 0.5 kg of P, which are in the same range as those calculated in Table 1.2, where the total excretion has been partitioned between urine and faeces.

Approximately 88% of the excreta N and 67% of the excreta P are found in the urine and the rest in the faeces. The relative amounts of nutrients in urine and faeces depend on the diet, where digested nutrients are mainly excreted with the urine, while the undigested fractions are excreted in the faeces. The above figures for N and P are higher compared to China where the urine contains approximately 70% of the excreta N and 25-60% of the P (Gao *et al.*, 2002).

The digestibility also influences the amount of faeces excreted. In Sweden it is estimated at 51 kg wet mass/person per year (11 kg dw) (Vinnerås, 2002), in China at 115 kg/person per year (22 kg dw) (Gao *et al*., 2002) and in Kenya at up to 190 kg/person per year (Pieper, 1987).

The nutrient concentration of the excreted urine depends on the nutrients and liquid intake, level of personal activity and climate conditions. The liquid intake is in the range of 0.8-1.5 litres per person per day (up to 550 litres/person, per year) and for children about half that amount in Europe (Lentner *et al*., 1981) but may be far higher due to climate or activity level. Similar amounts have been reported for China, 1.6 litres per person per day (580 litre/person per year) Gao *et al*. (2002). Excessive transpiration results in concentrated urine, while consumption of large amounts of liquid dilutes the urine.

1.5.2.3 Use of excreta as fertilizers

Urine as a fertiliser

Urine is rich in nitrogen and can be used for most non-nitrogen fixing crops after proper treatment to reduce potential microbial contamination. Crops with a high N-content that respond well to N fertilization are for example spinach, cauliflower, and maize. Direct use of urine as a plant fertiliser will entail the most efficient use of nutrients but addition of urine to improve composting of carbon-rich substrates is another possibility (may result in large ammonia losses). The nutrients in urine are in ionic form and their plant-availability and fertilising effect compares well with chemical (ammonium and urea based) fertilisers (Johansson *et al*. 2001; Kirchmann & Pettersson, 1995). When the nitrogen content of collected urine is unknown, a concentration of 3-7 grams of N per litre at excretion can be used as default value (Jönsson & Vinnerås, 2004). On a yearly basis the per person amount of nitrogen produced equals 30-70 kg/ha supporting one crop on 300-400 m^2 but up to 3-4 times this level may be an optimal application strategy.

The achieved yield varies depending on the soil conditions. As for chemical fertilisers, the effect is lower on soil poor in organic content. Under these conditions soil fertility may benefit from using both urine and faeces, or other organic fertilizers alternatively applied in consecutive years and for different crops. Urine can either be applied undiluted or diluted with water preferentially just before sowing or during the initial plant growth. Once the crop enters its reproductive stage nutrient uptake is low and nutrients are mainly relocated within the plant (Marschner, 1997). Plants with inefficient or small root systems, e.g. carrots, onions and lettuce, will benefit from repeated applications during the cultivation period (Thorup-Kristensen, 2001).

Box 1.2. Urine as fertiliser to barley, Sweden.
Urine was tested as a fertilizer on barley in Sweden during 1997-1999 (Johansson *et al*., 2001; Rodhe *et al*., 2004). Results showed that the N effect of urine corresponded to about 90% of that of equal amounts of ammonium nitrate mineral fertilizers, figure 1. The urine was spread before sowing with a conventional spreader for liquid manure, figure 2.

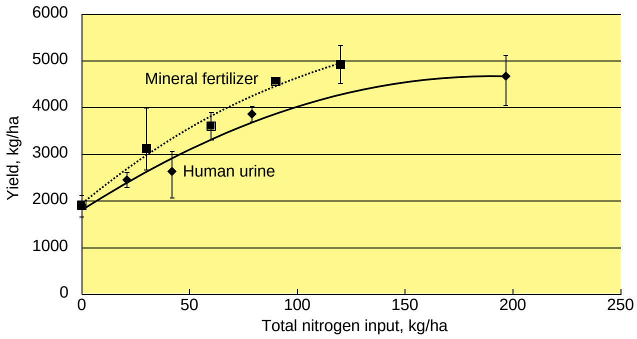


Figure 1.3. Results from field trials with urine as fertiliser to barley 1999.

Figure 1.4. Conventional slurry spreader used for application of urine

The best fertilizing effect is obtained when the urine is directly incorporated into the soil after application (Rodhe *et al*., 2004) whereas shallow incorporation is sufficient. Direct incorporation also minimizes ammonia losses to the air. Surface application generally gives a N-loss > 70% due to ammonia volatilisation and soil incorporation is therefore very important (Morken 1998)

Trials with different application strategies using urine as a fertiliser to leeks gave a three-fold yield increase (Båth, 2003). Application either in two doses or divided into smaller doses applied every 14 days, gave the same yield and nutrient uptake. In West Africa the strategy used foresees the frequent application of small amounts of urine in order to avoid leaching. Extensive trials have been performed on various vegetables in Zimbabwe (Morgan, 2004). Results confirm the experience that urine is a quick-acting fertiliser that can be used for most vegetables.

Table 1.3. Results of a field trial using human urine as a fertiliser for leeks. No statistically significant difference between treatments A, B and C (after Båth, 2003)

Treatment		N rate kg/ha*	Yield ton/ha**	N yield kg/ha *
A	Urine every 14 days	150	54	111
B	Urine twice	150	51	110
C	Urine every 14 days + extra potassium	150	55	115
D	Unfertilised	0	17	24

* kg/ha= gram/10 m^2
** ton/ha= kg/10 m^2

Faeces as a fertiliser

The total amount of nutrients excreted with faeces is lower than with urine but the concentration of especially P and K, is higher and may significantly increase the crop yield (Morgan, 2003). Its content of organic matter also increases the water-holding and ion-buffering capacities of the soils, which is of importance for improving soil structure and stimulates the microbial activity. Since faeces may contain high concentrations of pathogens appropriate treatment is crucial to ensure a safe handling. The fertilising effect of faeces varies more than for urine, since the proportion of N in mineral form and the content and properties of the organic matter varies dependent on the treatment applied.

Faecal compost applied together with urine may have advantages since the former conditions the soil and the later provide rapidly accessible nitrogen. Incineration of faeces results in ash with high contents of P and K as well as micronutrients but N and S are lost to the atmosphere. Ash in general (may also be added to the faeces), also increases the pH and the buffering capacity of the soil. The pH-increase is especially important on soils with very low pH (4-5) and to get the full benefit from fertilising with e.g. urine, as shown on experimental plots both in Uganda and Zimbabwe.

Faecal compost can be applied as a complete PK-fertilizer or as a soil improver. Approximately 40-70% of the organic matter and somewhat less of the N are lost through biological activity and volatilization. The remaining N will mainly become plant available during degradation. This slow process improves the water holding and buffering capacity of the soil. The P is also partly, but to a lesser extent bound in organic forms, while the K is mainly in ionic form and readily plant available. In anaerobic digest approximately the same proportion of organic matter is degraded as in composting, but the mineralised N will remain within the digestion residue and 40-70% of the N is in the form of ammonium, which is readily plant available. The digested residues make up a well-balanced, quick-acting and a complete fertiliser (Åkerhielm & Richert Stintzing). Additional substrates such as animal manure and household waste are often added to digestion processes, which affects the amount and composition of the residue.

If faeces are rapidly dried and low moisture levels prevail, the loss of organic matter and N will be small. Compared to composting, dry storage recycles more organic matter and N to the soil, but the organic matter is less stable. Dried faecal matter is a complete PK-fertilizer, contributing also considerable amounts of N.

Treated faeces, in a desiccated, incinerated, composted or mixed form is preferably applied and incorporated in the root zone of the soil prior to sowing or planting because the high content and availability of P is important for the development of small plants and of roots.

The faecal matter from one person is enough to fertilise 200-300 m^2 of wheat at a yield level of 3000 kg per hectare. Where the soil is devoid of P 5-10 times the removal rate can be applied. At this application rate, most of the P will remain and improve the soil with significant yield increases and without negative effects from P or organic matter. Application rates for farmyard manure in agriculture are in the range of 20-40 tons per hectare. If large amounts of lime or ash are used as additives, a minor risk of negative effects exists at high application rates, due to a high resulting pH (>7.5-8) in the soil. This risk will, however, only materialise at extremely high application rates or if the initial pH of the soil is already high.

In bucket experiments of low temperature composting of faeces in Zimbabwe, vegetables such as spinach, covo, lettuce, green pepper, tomato and onion were grown in 10-litre buckets with poor local topsoil (Morgan, 2003). Growth was compared between no additions and plants grown in a 50/50 mix of the topsoil mixed with an equal volume of humus derived from co-composted human faeces and urine. A dramatic increase in vegetable yield resulted from the addition of composted faeces and urine mix to poor soil (Table 1.5).

Table 1.5. Average yields (grams fresh weight) in plant trials comparing growing in topsoil only with growing in a mixture consisting of 50% topsoil and 50% Fossa alterna compost (Morgan, 2003)

Plant and soil type	Growth period	Fresh weight topsoil only (g)	Fresh weight 50/50 topsoil/FA*soil (g)	Relative yield improvement rate
Spinach, Epworth soil (n = 6)	30 days	72	546	7 .6
Covo, Epworth soil (n = 3)	30 days	20	161	8 .1
Covo 2, Epworth soil (n = 6)	30 days	81	357	4 .4
Lettuce, Epworth soil (n = 6)	30 days	122	912	7 .5
Onion, Ruwa soil (n = 9)	4 months	141	391	2 .8
Green pepper, Ruwa soil (n = 1)	4 months	19	89	4 .7
Tomato, Ruwa soil	3 months	73	735	10 .1

- *Fossa alterna* soil

Figure 1.5. Spinach grown in poor soil and soil mixed with faeces. Photo: Peter Morgan

Faeces collected from urine diverting toilets, where ash was added as desiccation material have been investigated as fertilisers in production of cabbage in South Africa and compared with sheep manure and mineral fertilisers. Results indicate that the phosphorous fertilising as well as liming effect of the faeces contributes to plant growth in a significant manner.

1.5.2.4 Greywater volume and composition

Greywater production and composition is dependent on sanitary standards, water consciousness, water availability and raw water composition (Lenz et al. 2001, Eriksson et al 2002). Greywater volume and composition also varies with lifestyle: family size, age of residents, eating habits and detergents used. The main sources of greywater are laundry, bathroom and kitchen. Below a digest of some studies reporting on greywater volume and composition is summarized.

Volume

The greywater volumes produced may be as low as 20-30 l/person and day in poor areas where water often is hand carried from taps (Ridderstolpe 2004, Winblad and Simpson-Hebert 2004). When the availability increases the production of greywater increases, but seldom exceeds 100 l/person and day in developing areas or countries. In industrialised regions the greywater production normally is in the range 100 - 200 l/person where the highest figures is reported from USA and Canada, sometimes exceed 200 l/person and day (Crites and Tchobanoglous 1998, Bertaglial *et al*., 2005). In new housing developments in Europe, where water consciousness is emphasized the per capita daily greywater production is less than 100 liters (Table 1.6).

***Table** 1.6 Examples of greywater production in liter per capita per day.*

Location	Liter/person/ day	Reference
China, ecological sanitation project	80	Ecosanres, 2005
China, Peking	89	Wilhelm, 2004
Belgium	85	Bertaglial e*t al*., 2005
Germany	35-65	Panesar and Lange, 2001
Germany	65	Wilhelm, 2004
Germany, Eco-village Flintenbreite	60	Ridderstolpe, 2004;
Germany, Norway and Sweden New-built house area - water conservation	<100	Ridderstolpe, 2004; Winblad and Simpson-Hebert, 2004
Norway, ecovillage	81	Krisitiansen and Skaarer 1978
Norway, student dormitories, water conservation	112	Jenssen 2001
Sweden, range ecovillages	66 - 110	Vinnerås et al 2002
Sweden, proposed norm	100	Vinnerås et al 2002
Sweden, existing norm	150	Vinnerås et al 2002
Europe, Northern part	110	Lens *et al*., 2001
Australia, western part	112	CEHBDH, 2002
Canada	240	CWL, 1999
USA	200	Bertaglial e*t al*., 2005 Crites and Tchobanoglous 1998
Developing regions	20-30	Ridderstolpe, 2004; Winblad and Simpson-Hebert, 2004
Range	70-275	Otterpohl 2002

Composition

In general the concentrations of plant nutrients (nitrogen, phosphorus and potassium) and pathogens of health concern are low in greywater (Ottoson and Stenström 2003, Jenssen and Vråle 2004) due to the fact that the majority of these are found in the excreta. Bacterial indicators tend to overestimate the fecal load in greywater because regrowth may occur (Manville et al. 2001) and compared to chemical biomarkers a 100 – 1000-fold overestimation of the fecal load was found (Ottoson and Stenström 2003). However, the microbial contamination of greywater is significant and must be taken into account when calculating risks and selecting treatment methods.

Greywater contributes 10 – 30% of the total amounts of phosphorus received to a combined wastewater system and the concentrations are governed by type of detergents (Rasmussen *et al* 1996, Vinnerås 2002, Jenssen and Vråle 2004). If phosphorus-containing detergents are used concentrations typically range from 3-7 mg/l. If phosphate free detergents are used, the concentrations are around 1 mg/l. Greywater contributes 10% or less of the total nitrogen content in wastewater and the nitrogen concentration in greywater is often 10mg/l or less, prior to treatment (Vinnerås 2002, Jenssen and Vråle 2004).

Greywater contains 50% or more of the readily degradable organic matter (measured as BOD or COD) in household sewage, but the concentrations are highly variable depending on household practices. In industrialized countries excess amounts of detergents including shampoos, shower oils, cleansing powders etc. are common and responsible for substantial BOD input in addition to grease and oil used in food preparation. In cultures where use of cooking oil is common the greywater organic content becomes very high and may call for special care when designing treatment systems. If collected separately the oil and grease can be processed to bio-diesel (Zhang et al. 2003), but can also increase biogas yield in anaerobic digestion. Examples of concentrations found in untreated or primary treated greywater is shown in Table 1.7.

Table 1.7 Example concentrations of some water quality parameters found in untreated or primary treated (septic tank effluent) greywater.

Country/Reference	Parameters							
	BOD_5 (mg/l)	COD (mg/l)	SS (mg/l)	Tot N (mg/l)	NH_4 (mg/l)	Kjeldahl N (mg/l)	Tot P (mg/l)	Faecal coliforms (log/100ml)
Sweden/Olsson *et al.*, 1968	205	395				9,1	18,1	6,15
Canada/Brandes, 1978	149	366	162	11,5	1,7	11,3	1,4[a]	6,15
Norway/Kristiansen and Skaarer, 1979	130	341	35	19	11,5		1,3(0,42[b])	5,08
USA[1]/Siegrist and Boyle, 1981	178	456	45			15,9	4,4	6,2
Sweden norm/Natur-vårdsverket, 1995	187		107	6,7			4(1,0[b])	
Norway[1]/Rasmussen *et al.*, 1996	116		39	42,2	36,1		3,97	
Australia/CEHBDH, 2002	160		115		5,3	12	8	5,24
Norway[1]/Jenssen 2001	88	277	-	8,8	3,8	4.9	1,0[b]	4 - 6
Sweden proposed norm /Vinnerås et al. 2003	260	520		13,6			5,2	
Germany/Li et al. 2004	73-142			8,7-13,1	2,5		6,8-9,2	4 - 6
Malaysia[1]/Jenssen et al. 2005	128	212	75	37	12,6	22,2	2,4	5,8

[1] Septic tank effluent, [a] excluding laundry, [b] phosphorus-free detergents

The concentrations in greywater depend on the per capita mass discharge and the water use exemplified by an assessment of the per capita discharges for Swedish conditions (Vinnerås et al. 2004) (Table 1.8).

Table 1.8. Collected amounts of greywater concerning volume (wet mass), dry mass, nitrogen, phosphorus and potassium (per person and day) in the Swedish eco-housing developments compared to the Swedish norm values (Vinnerås, et al. 2004).

Parameters	Ekoporten	Gebers	Vibyåsen	Swedish norm	Proposed norm
Volume (liters)	104	110	66	150	100,0
Dry mass (g)	59,2	15,1	29,2	20	59,8
BOD_7 (g)		21,1	27,7	28,0	26,0
COD (g)		47,9	39,0	72,0	52,1
Nitrogen (g)	1,7	1,4	0,6	1,0	1,4
Phosphorus (g)	0,4	0,6	0,5	0,3	0,5
Potassium (g)	4,0	1,0	0,5	0,5	1,0

Table 1.8 includes phosphorus containing detergents. According to Norwegian studies the per capita mass discharge of phosphorus is reduced to 0,2mg/l with phosphorus free detergents (Jenssen and Vråle 2004). The major part of the heavy metal load to household wastewater is

found in the greywater fraction (Vinnerås 2002) and concentrations of heavy metals can therefore be expected to be on the same level as in combined household wastewater.

1.5.3 Food Production

As stated above, excreta and greywater are important sources of nutrients and water for food production. Their use can help to improve food production - especially for subsistence farmers who otherwise might not be able to afford artificial fertilizers. The use of greywater for irrigating home gardens may also help to relieve malnutrition and food insecurity at the household level by providing a steady supply of water for crop irrigation, allowing the year-long production of vegetables.

The use of treated and source-separated faeces and urine has been suggested as suitable for urban agriculture. Wastewater is used to a large extent in these applications. Potentially treated excreta would pose less health risks in these types of applications. Esrey (2000) have summarized the impact in relation to nutrients in urban areas.

Eighty percent of the world's natural food resources are converted into waste, which is disposed of (Smit, 2000). According to the predictions for 2015, about 26 cities in the world are expected to have a population of over 10 million people, which implies the need to import an estimated 6,000 tonnes of food each day (FAO, 1998). More than 50% of the absolute poor live in urban areas and spend much of their income on food. Their dietary intakes are nutrient limited and urban residents in developing countries have a lower energy intake than residents of rural zones. Yet, poor urban dwellers will not be able to afford imported food.

Lowering the costs of inputs and producing food closer to where people live can reduce food production and costs. Urban agriculture and home gardening can produce more food per unit space, because food can be grown on roofs, walls and in and around buildings. Urban agriculture has enjoyed a revival in the past few decades (Smit, 1996). In greater Bangkok 60% of the land is under cultivation. The demand for food by consumers and water and nutrients by producers reconnects resources and wastes in a safe, non-polluting and economic fashion. Growing food closer to consumers also strengthens the livelihood of local communities.

Recovery and recycling of nutrients from human excreta and other organic matter provide a complete nutrition for plants. Access to affordable and more nutritious food increases and post-harvest food losses can be reduced if food is grown and consumed locally. This also represents a saving in water as well as nutrients.

When food is grown further away from population centres, it not only costs more but valuable micronutrients, are less likely to reach consumers, particularly people with little income. Urban farming and home gardening, though, can result in better diets, improving macro- and micro-nutrient intakes as well as improved nutritional status of vulnerable groups, such as women, children, the elderly and disabled (Maxwell et al, 1998).

1.5.4 Downstream impacts

Excreta and greywater can be treated and used close to their origin - either on-site or in decentralized treatment systems. This prevents their discharge into surface waters, thus reducing downstream microbial and chemical contamination. It also reduces the costs of developing infrastructure for elaborate conveyance systems (e.g., sewer networks).

Additionally, the concept of "polluter pays" is starting to take hold in many places, forcing upstream users to treat their wastes to higher standards before discharging them into water bodies. Previously, the additional costs of water treatment or loss of ecosystem services (e.g., destruction of fisheries or loss of aesthetic value) were passed on to downstream water users. Integrated Water Resources Management has led to the realization that waste discharges into surface waters have health, environmental, and economic implications for downstream users. As this awareness spreads, it will be more and more difficult to discharge inadequately treated wastes into surface waters. Therefore, treatment and use of excreta and greywater closer to the point at which they are generated becomes a more attractive option.

1.5.5 Millennium Development Goals

At the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, global leaders agreed to adopt a sanitation coverage target on sanitation namely “to halve, by the year 2015, the proportion of people who do not have access to basic sanitation”(United Nations, 2000). Expanding access to and proper use of improved sanitation facilities would have far ranging positive health consequences and would impact many of the other International Development Goals (see Table 1.9).

To achieve the sanitation target, taking into account projections of population growth, WHO estimates 1.9 billion people will need to gain access to improved sanitation by 2015 - one billion urban dwellers and 900 million rural dwellers. As of 2002, 77% of the un-served worldwide (i.e., two billion people) lived in rural areas (see Figure 1.9). Expanding access to basic sanitation in rural areas is an urgent priority (WHO/UNICEF 2004). A large percentage of population growth, however, is expected to occur in urban and peri-urban areas (often in slums or informal settlements) in developing countries.

Many of the 2.6 billion people without improved sanitation are among those hardest to reach: families living in remote rural areas and urban slums, families displaced by war and famine, and families mired in the poverty-disease trap (WHO/UNICEF 2004).

Table 1.9 Contributions of Water and Sanitation to the MDGs

MDGs Goals and Targets	Water and sanitation impacts on goals and targets
Goal 1. Eradicate extreme poverty and hunger	Safe water and access to and proper use of sanitation facilities means healthy people, able to secure improved livelihoods and break the cycle of poverty and ill-health
Goal 2. Achieve universal primary education	Freedom from diarrhoeal disease and other environmental health hazards will result in increased attendance and participation in school. School sanitation is an important determinant of girls´ attendance.
Goal 3. Promote gender equality and empower women.	The burden of water and sanitation falls disproportionately on women, effective interventions help to improve women´s lives and empower them through increased participation. Reducing this burden will enable more women to attend school, improve household health and earn more money.
Goal 4. Reduce child mortality	Water and sanitation interventions can significantly reduce the number of children under 5 who die as a result of water and waste related diseases.
Goal 6. Combat HIV/AIDS, malaria and other diseases	Less disease due to better water and sanitation allows people to delay the onset of AIDs and helps them to better fight off malaria and other diseases. Better water and waste management reduce vector breeding and subsequent transmission of malaria.

Goal 7. Ensure environmental sustainability. Halve by 2015 the proportion of people without sustainable access to safe drinking water and sustainable sanitation. By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers.	This goal directly recognizes the importance of water and sanitation for human development. Water and waste recycling are environmentally sustainable. Providing water and sanitation services are key interventions for improving the lives of slum dwellers.

Source: Adapted from Cairncross, O'Neill, McCoy and Sethi, (2003)

In urban and peri-urban centres much of the sanitation expansion may be in the form of sewerage (conventional sewerage in urban centres and simplified sewerage in peri-urban areas or slums). Sewerage systems are expensive to build and maintain and require relatively large volumes of water to function properly (simplified sewerage systems require less water than full sewerage systems). Although sewer systems protect the health of the user, health gains may be limited for the community as a whole because much of the wastewater is likely to be discharged into water-bodies without adequate treatment, thus exposing downstream users to human pathogens through untreated drinking water, food or contact with contaminated water. Therefore, if effective treatment were available at the household level, prior to discharge into the environment or use, the health of downstream users would be better protected.

Poverty has long been recognized as one of the primary impediments to sustainable development. In many countries, the poor and subsistence farmers don't have access to water resources and may not have money to buy fertilizers. The use of excreta and greywater in agriculture has the potential to affect poverty positively and negatively in several ways:

- Improved household food security and nutritional variety which reduce malnutrition;
- Increased income from sale of surplus crops (the use of excreta and greywater may allow cultivation of crops year-round in some locations);
- Money saved on fertilizer which can be put to other productive uses; or
- Increased poverty when poor management and dangerous practices lead to negative public health outcomes.

The use of excreta and greywater in agriculture is therefore a key development issue and is an integral component of the sanitation debate. Poor households spend a larger percentage (50−80%) of their income on food and water than better-off households (Lipton, 1983; World Food Programme, 1995). Based on household surveys in India, Buechler and Devi (2003) found that per capita expenditure on food averaged 30%, 44% and 66% in urban, peri-urban and rural areas respectively. Without access to resources such as excreta or greywater, many poor families would not be able to meet their nutritional needs or would spend more money on food and less on other health-promoting activities such as primary health care or education.

2 THE STOCKHOLM FRAMEWORK

An overall criterion for sustainability, from a human hygiene perspective is that the risk for infection, directly or indirectly, from environmental sources should never exceed a minimal background level. The acceptable background level may, however, differ for various regions of the world and over time, and local data on known infection rates should be amended.

The Stockholm framework is an integrated approach that combines risk assessment and risk management to control water-related diseases. The framework was developed for infectious diseases, but can equally be applied to diseases resulting from exposures to toxic chemicals. This Chapter contains a summary of the components of the framework and how it applies to assessing and managing risk associated with the use of excreta and greywater. The applied management and monitoring are further detailed in Chapters 5 and 6.

2.1The Stockholm Framework

Following an expert meeting in Stockholm Sweden, WHO published *Water Quality: Guidelines, Standards and Health; Assessment of Risk and Risk Management for Water-related Infectious Disease* (Fewtrell and Bartram, 2001). This provides a harmonized framework for the development of health-based guidelines and standards for water- and sanitation related microbial hazards. The Stockholm Framework involves the assessment of health risks prior to the setting of health-based targets and the development of guideline values, defining basic control approaches, and evaluating the impact of these combined approaches on public health (Figure 2.1, Table 2.1).

The framework encourages countries to adjust guidelines to local social, cultural, economic and environmental circumstances and compare the associated health risks with risks that may result from microbial exposures through excreta and wastewater use or other resulting routes such as through food, hygiene practices, drinking water or recreational/occupational water contact. This approach aims to facilitate the management of infectious diseases in an integrated, holistic fashion and not in isolation from other diseases or exposure pathways. Disease outcomes from one exposure pathway, or from one illness to another, is possible to compare by using a common metric, such as Disability Adjusted Life Years (DALYs) lost or normalized for a population over a time period (see Box 4.1).

Box 2.1 Disability Adjusted Life Years (DALYs)

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 (YLL) to the years lived with a disability (YLD). Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population. YLD are calculated from the number of cases multiplied by the average duration of the disease and a severity factor ranging from 1 (death) to 0 (perfect health) based on the disease (e.g., watery diarrhoea has a severity factor from 0.09 to 0.12 depending on the age group) (Prüss and Havelaar, 2001; Murray and Lopez, 1996). DALYs are an important tool for comparing health outcomes because they account for not only acute health effects but also for delayed and chronic effects – including morbidity and mortality (Bartram, Fewtrell and Stenström 2001).

When risk is described in DALYs, different health outcomes (e.g., cancer *vs* giardiasis) can be compared and risk management decisions can be prioritized.

WHO water - and sanitation related guidelines have been developed in accordance with the principles of the Stockholm Framework. The third edition of the WHO Guidelines for Drinking Water Quality (WHO, 2004) and the WHO Guidelines for Safe Recreational Water Environments (WHO, 2003a) have both incorporated a harmonized approach to risk assessment and management as outlined in the Stockholm Framework.

2.2Elements of the Stockholm Framework

This section describes the individual elements of the Stockholm Framework, as illustrated in Figure 2.1, and how they specifically relate to the use of excreta and greywater. Some of the framework elements are discussed in more detail in subsequent chapters of this document.

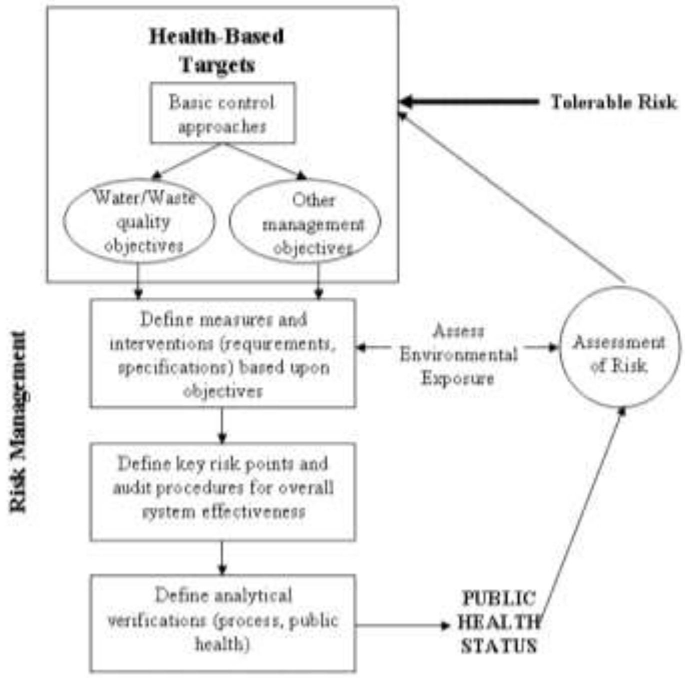


Figure 2.1 The Stockholm Framework for developing harmonised guidelines for the management of water-related infectious disease

Source: Adapted from Bartram, Fewtrell and Stenström 2001

Table 2.1. Elements and important considerations of the Stockholm Framework

Framework component	Process	Considerations
Assessment of health risk	Epidemiological studies	Best estimate of risk — not overly conservative Health outcomes presented in DALYs facilitates comparison of risks across different exposures and priority setting.
	Quantitative microbial risk assessment	Assessment of risk is an iterative process — risk should be periodically reassessed based on new data or changing conditions Risk assessment (QMRA) is a tool for estimating risk and should be

Framework component	Process	Considerations
	(QMRA)	supported by other data (e.g., outbreak investigations, epidemiological evidence, microbial risk assessment, and studies of environmental behaviour of microbes) Process dependent on quality of data Risk assessment needs to account for short-term under-performance
Tolerable risk/ health-based targets	Health-based target setting linked to risk assessment	Needs to be realistic and achievable within the constraints of each setting Set based on a risk–benefit approach, should consider cost-effectiveness of different available interventions Should take sensitive subpopulations into account Index pathogens should be selected for relevance to contamination, control challenges, and health significance (it may be necessary to select more than one index pathogen) Health-based targets (HBT) establish a desired health outcome
Risk manage-ment	Define water/waste quality objectives Define other management objectives Define measures and interventions Define key risk points and audit procedures Define analytical verifications	HBT should be basis for selecting risk management strategies, can combine exposure prevention through good practices and appropriate water quality objectives. Risk points should be defined and used to anticipate and minimize health risks; parameters for monitoring can be set up around risk points. A multiple-barrier approach should be used Monitoring — overall emphasis should be given to periodic inspection/auditing and to simple measurements that can be rapidly and frequently made to inform management Risk management strategies need to address rare or catastrophic events Analytical verifications may include testing wastewater and/or crops for *E. coli* or viable helminth eggs to confirm that the treatment processes are working to the desired level. Validation that control measures employed to control the hazards are working, e.g., that pathogens are being removed as predicted. Validation information should be used to make adjustments to the risk management process to improve safety.
Public health status	Public health surveillance	Need to evaluate effectiveness of risk management interventions on specific health outcomes (through both investigation of disease outbreaks and evaluation of background disease levels). Public health outcome monitoring provides the information needed to fine-tune risk management process through an iterative process. Procedures for estimating the burden of disease will facilitate monitoring health outcomes due to specific exposures Burden of disease estimates can be used to place water-related exposures in the wider public health context to enable prioritisation of risk management decisions

Source: adapted from Carr and Bartram (2004).

2.3 Assess Environmental Exposure

Environmental exposure assessment (EEA) is an important input to both the assessment of risk and to risk management. EEA is a process that looks at the hazards in the environment and evaluates different exposure routes to human (or animal) populations.

The primary hazard is related to exposure of untreated or insufficiently treated faecal excreta containing pathogens transmitted through the faecal-oral route. Excreted urine may also contain pathogens but to a lesser extent and in a lesser range of etiological agents (see Chapter 3). The excreta may contaminate be food or water. Several excreted helminths may also infect through the skin. Direct contact with contaminated material and subsequent accidental ingestion from contaminated fingers or utensils, is a major transmission pathway. Contact may occur before treatment, during treatment including handling, or when the material is used/applied to soil. Additionally, contamination of foods may occur directly from use but also through unhygienic practices in the kitchen. Even if the fertilised crop will be cooked before consumption, surfaces may be contaminated and pathogens transferred to other foods or fluids.

A systematic survey of a local system can identify potential risk factors and suggest counteractions to avoid pathogen exposure, either by means of reducing contact with the material or ways to decrease the number (concentration) of pathogens in the material that will be handled. General handling precautions are often defined as additional measures and not as proper barriers.

Treatment of excreta minimize exposure and relates both to containment on-sited under the toilet where additives or prolonged storage will reduce that the quantities of pathogens, or by further controlled treatment off-site to further reduce pathogen concentrations to acceptable limits.

Inactivation of potential remaining pathogens will also occur on agricultural land after application of the treated excreta as fertiliser and on crops that may have become contaminated by the application of fertiliser during crop. The additional reduction with time, constituting a "barrier function in agriculture", is of additional importance.

In the use of treated faecal excreta, urine or greywater certain key risk points and exposure pathways need to be considered (Chapter 5). For urine and greywater the risks are related to the degree of fecal cross-contamination and the efficiency of treatment.

2.4 Assessment of Health Risk

Risk is the likelihood and consequence that something with a negative impact will occur. The 'agent' that causes an adverse effect is a *hazard*. Risk incorporates the probability that an event will occur with the effect it will have on a population or the environment, accounting for the socio-political context where it takes place (Cutter, 1993).

The assessment of risks is central in preventive public health and combines with human exposure to pathogens. It can be carried out directly via epidemiological studies or indirectly through quantitative microbial risk assessment (QMRA).

Epidemiological studies aim to assess the health risks by comparing the level of disease in the exposed population (which uses excreta/greywater or consumes products grown with them) with that in an unexposed or control population (for example where no sanitation interventions have been carried out). The difference in disease levels may then be attributed to the practice of using the excreta/greywater, provided that the two populations compared are similar in all other respects including socio-economic status and ethnicity. Potential confounding factors and bias, which could affect results, need to be addressed. There have been very few epidemiological studies concerning the use of excreta in agriculture. Blumenthal and Peasey (2002) review some (See Chapter 3). No epidemiological studies are available on the use of urine or greywater.

The indirect assessment of risk in QMRA is usually dealt with in a step-wise approach. ***Risk analysis*** embrace the three components: risk assessment (here through QMRA), risk management and risk communication (Haas *et al.*, 1999). ***Risk assessment*** is the qualitative or quantitative characterization and estimation of potential adverse health effects associated with exposure of individuals or populations to hazards (here microbial agents). *Risk management* is the process of controlling risks, weighing alternatives and selecting appropriate action, accounting for risk assessment, values, engineering, economics, and legal and political issues. *Risk communication* is the communication of risks to managers, stakeholders, public officials, and the public. It includes public perception and the ability to exchange information.

QMRA can be used as a predictive tool to indirectly estimate the risk to human health by the infection or illness rates, based on given densities of particular pathogens, estimated or measured rates of ingestion and appropriate dose-response models for the exposed population. QMRA is usually done in four steps, (table 2.2). Examples of QMRAs used to estimate health risks for the use of excreta and greywater are provided in Chapter 3.

Table 2.2 QMRA Paradigm For Quantifiable Human Health Effects

Step	AIM
1. Hazard identification	To describe acute and chronic human health effects associated with any particular hazard, including pathogens or toxic chemicals
2. Exposure assessment	To determine the size and nature of the population exposed and the route, amount and duration of the exposure.
3. Dose-response assessment	To characterize the relationship between various doses administered and the incidence of the health effect
4. Risk characterization	To integrate the information from exposure, dose-response and hazard identification steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty

Source: Adapted from WHO (2003)

Hazard identification and problem formulation is the initial systematic planning step that identifies the goals and focus of the risk assessment, which also may include the regulatory and policy context of the assessment.

An initial characterisation of exposure and health effects is described with background information on, for example, the pathogens relevant in a special surrounding or environment. It also includes the spectra of human illness and disease associated with the identified microorganisms (Haas *et al*., 1999). A conceptual model is developed that describes the interactions of pathogens and defined population and exposure, specific questions, information needs and the assumptions made.

Exposure assessment describes the size and nature of the exposed population, as well as the duration or frequency of exposure and the pathways. Elements involved are:

- **Pathogen Characterisation:** Determining the properties of the pathogen that affects its ability to be transmitted to and cause disease in the host.
- **Pathogen Occurrence:** Characterising the occurrence and distribution including information on their ability to survive, persist and multiply.

The exposure profile provides a qualitative and/or quantitative description of the magnitude, frequency and patterns of exposure and a characterisation of the source and temporal nature of human exposure. The dose of a pathogen is calculated from the density of the organism through the contact route times the volume ingested. Densities are either based on occurrence data of actual pathogens or indirectly estimated through index organisms (Ashbolt, 2001) or through indirect estimations.

The analysis may also consider vulnerability and if and how social and/or behavioural traits influence susceptibility or severity. The clinical illness associated with the pathogen is summarized, including duration of clinical illness, mortality and sequelae.

The dose-response relationship between microbial agents and the infection rate in a population is seldom directly estimated but based on human volunteer studies presented in the literature. A mathematical relationship is obtained between the dose and the probability of infection (Haas *et al.* 1999, Teunis *et al.* 1996), where either exponential (1) or Beta-Poisson (2) relationships are applied.

Box 2.2 Example of mathematical determination of the dose-response analysis.
Calculations are made as follows:
(1): Random distribution and probability of infection for an organism equals r: $P_{inf} = 1 – e^{-rDose}$
(2): Probability r not constant and has a distribution in itself (β-distribution) either due to the organism or the exposed population where α and β, describe the relation: P_{inf} ~$1-(1+Dose/\beta)^{-\alpha}$
The Beta-Poisson model fits well with many dose-response datasets, and is conservative when extrapolating to low doses (Teunis et al., 1996). The exponential relationship is applicable when dealing with pathogens where no dose-response studies have been made, vulnerable populations are exposed or in worst-case scenarios. Then r = 1 can be applied as a generic single hit model where ingestion, inhalation or contact with one organism will lead to P_{inf} = 0.63.

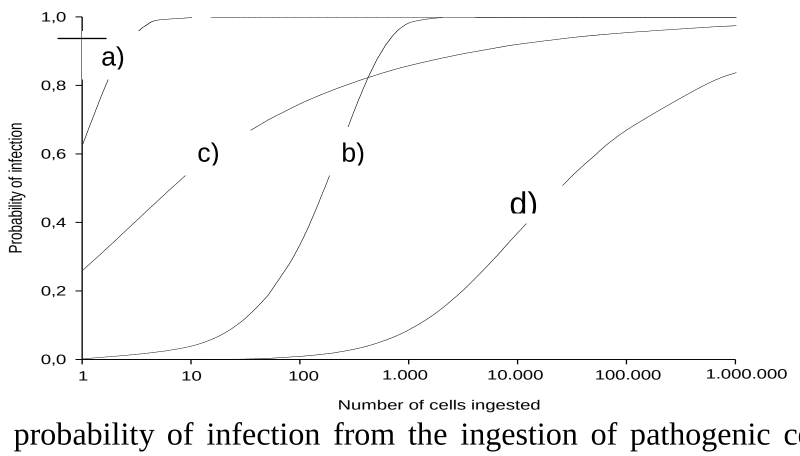


Figure 2.2. The probability of infection from the ingestion of pathogenic cells in different dose-response relationships: Exponential models for (a) a worst-case scenario, (b) *Cryptosporidium*, (c) Beta-Poisson models for rotavirus and (d) for *Salmonella***.**

The risk characterisation integrates the information from the hazard identification, exposure assessment and dose-response relationship to estimate the magnitude of the public health problem and to evaluate variability and uncertainty. Since information usually is incomplete and the density of pathogens fluctuates, probability density functions (PDFs) with Monte-Carlo simulations are better than point estimates or constant values in risk calculations. The microbial risk (probability of infection, P_{inf}) is either presented as the rate of infected people out of the number of exposed number of people or as total number of infections per annum or system lifetime (Fane *et al*., 2002). From a management point of view, the performance and reliability of a system might be more important than the absolute number of infections.

2.5 Tolerable risk and health-based targets

An important distinction is between the tolerable risk level of infection and the risk of disease. A number of factors determine whether infection with a specific pathogen will lead to a disease (virulence, the immune status of an individual etc). For example, hepatitis A infections in children are predominantly asymptomatic, but the same infection in adults often leads to clinical symptoms. Since rate of infection is harder to detect than disease symptoms the relationship to health targets is more easily based on disease.

2.5.1 Tolerable risk

Risk assessments relate to health targets. A tolerable risk level is determined by a competent national authority or decided politically. The definition of what is tolerable may be based on the current prevalence of faecal-oral disease in a given population and to what extent this level will significantly decrease or increase due to the use of excreta and greywater. Tolerable risk can be looked at in the context of total risk from all exposures, and risk management decisions can be used to address the greatest risks first. Tolerable risks can be set with the idea of continuous adaptation and improvement.

The disease burden associated with this level of risk and adjusted for the severity of the illness is approximately 1×10^{-6} DALY (1 µDALY) (WHO 2004) which is used as a benchmark value. This level of disease burden can be compared to a mild but more frequent illness such as self-limiting diarrhea caused by a microbial pathogen. The estimated disease burden associated with mild diarrhea (e.g., with a case fatality rate of $\sim 1 \times 10^{-5}$) at an annual disease risk of 1 in 1000 (10^{-3}) (~1 in 10 lifetime risk) is also about 1×10^{-6} DALY (1 µDALY) (WHO 2004).

2.5.2 Health-based targets (HBTs)

HBTs should be part of overall public health policy, taking into account status and trends and the contribution or reduction of the transmission of infectious disease both in individual settings and within overall health management, based on the use of treated excreta or greywater. The targets mark out milestones to guide and chart progress towards a predetermined health goal. To ensure effective health protection and improvement, targets need to be realistic and relevant to local conditions and may also directly relate to the management strategies. Periodic review and updating of priorities and targets are necessary and, in turn, norms and standards should periodically be updated nationally to take account of these factors and the changes in available information (WHO 2004).

An HBT uses the tolerable risk of disease as a baseline to set specific performance targets that will reduce the risk of disease to this level. Exposure through different transmission routes to different concentrations of pathogens is associated with a certain level of risk. Reducing this risk thus involves reducing the levels of exposures or concentration of pathogens.
HBTs can be specified in terms of combinations of different components or single parameters including:

- Health outcome: as determined by epidemiological studies, public health surveillance or QMRA;
- Excreta or greywater quality: e.g., viable intestinal nematode eggs and/or *E. coli* concentrations;
- Performance: e.g., a performance target for removal of pathogens through a combination of treatment requirements, handling practices and quality standards (Chapters 4 and 5). Performance may be approximated by other parameters: Storage time, temperature etc.
- Specified technology: specified treatment process, etc.

2.6 Risk Management

The basis for the health targets relates to certain basic control approaches. Risk management requires an assessment of the health risks at key points of the excreta or greywater use process (generation, point of use, final product consumption). Risk management strategies include controllable factors such as:

- Behaviours (hand-washing with soap; adding lime to faeces, etc.);
- Treatment technologies;
- Operational processes - application to fields; operations and maintenance of facilities;
- Protective action - cooking food properly prior to consumption; wearing protective clothing while coming into contact with wastes.

To best protect public health multiple strategies may be needed simultaneously to add additional barriers to the transmission of disease.

The impacts of risk management actions can only be measured if the baseline health status of the affected population is known. Similarly, tolerable risk and health targets can only be set with some knowledge of: the incidence and prevalence of disease in the community; the types of diseases that may be reduced by the safe use of excreta and greywater or impacted by this; and the vulnerability of different subsections of the population (e.g., people with reduced immune functions or susceptible to specific hazards). Initial information on background levels of faecal-oral disease in the population might be based on information collected from local health care facilities, public health surveillance, laboratory analysis, or specific research conducted in a project area. Outbreaks provide additional information. There may be seasonal fluctuations in disease occurrence, which should be considered. In evaluating the safe use of excreta and greywater in certain areas, knowledge of disease trends i.e., whether they are decreasing or increasing, are valuable. Increasing background disease levels (e.g., intestinal worm infections) or disease outbreaks (e.g., cholera) might indicate that risk management procedures were not being implemented adequately and would need to be strengthened or reconsidered.

Risk management strategies for excreta and greywater minimize exposures to pathogens by multiple barriers. They may include combinations of the following:

- On-site storage and treatment to reduce pathogens to a level that presents a tolerable risk;
- Off site additional treatment for further reduction
- Crop Restriction - growing crops that either are not eaten or are processed (cooked) prior to consumption;
- Application - that reduce exposures to workers and contamination of crops (including withholding periods, buffer zones); and
- Exposure control methods - limiting public access; workers wearing protective clothing; cooking food properly prior to consumption.

Information concerning the efficiency of processes in preventing exposures combined with data on the occurrence of pathogens enables definition of operating conditions that would reasonably be expected to achieve those targets. The greater overall relative emphasis should be given to periodic inspection/auditing and to simple measurements that can be rapidly and frequently made and directly inform management.

2.7 Public health status

In many countries excreta-related infections are common and excreta and wastewater contain correspondingly high concentrations of pathogens. The failure to properly treat and manage wastewater and excreta worldwide is directly responsible for adverse health and environmental effects. Human excreta have been implicated in the transmission of many infectious diseases including cholera, typhoid, hepatitis, polio, schistosomiasis, and a variety of helminth infections. Most of these excreta-related illnesses occur in children living in poor countries. Overall WHO estimates that diarrhoea alone is responsible for 3.2% of all deaths and 4.2% of DALYs lost worldwide (WHO, 2004b). In addition to diarrhoea, WHO estimates that each year, 16 million people contract typhoid and over one billion people suffer from intestinal helminth infections (WHO, 2000, 2003b, 2003c, 2004b). Diarrhoea or gastrointestinal disease is often used as a proxy for all excreta-related infectious diseases. Mead *et al*. (1999) estimated that the average person (including all age groups) in the USA suffers from 0.79 episode of acute gastroenteritis (characterized by diarrhoea, vomiting, or both) per year. The rates of acute gastroenteritis among adults worldwide are generally within the same order of magnitude. However, children − especially those living in high-risk situations, where poor hygiene, sanitation, and water quality prevail − generally have a higher rate of gastrointestinal illness. Kosek *et al.* (2003) found that children under the age of 5 in developing countries experienced a median of 3.2 episodes of diarrhoea per child per year.

The impacts of risk management actions can only be measured if the baseline health status of the affected population is known or can be approximated. Similarly tolerable risk and health targets can only be set with some knowledge of:

- the incidence and prevalence of disease in the community;
- the types of diseases that may result from the use of excreta (or wastewater); and
- the vulnerability of different subsections of the population (e.g., people with reduced immune function or those susceptible to specific hazards).

Table 2.3. Global mortality and DALYs lost due to some diseases of relevance to excreta and wastewater use.

Disease	**Mortality** deaths / yr	**Morbidity (DALYs lost / yr)**	**Comments**
Diarrhoea	1,798,000	61,966,000	99.8% of deaths occur in developing countries; 90% of deaths occur in children
Typhoid	600,000	N/A	Estimated 16,000,000 cases per year
Ascariasis	3,000	1,817,000	Estimated 1.45 billion infections, of which 350 million suffer adverse health effects
Hookworm disease	3,000	59,000	Estimated 1.3 billion infections, of which 150 million suffer adverse health effects
Lymphatic filariasis	0	5,777,000	Mosquito vectors of filariasis breed in contaminated water. Does not cause death but leads to severe disability
Hepatitis A	N/A	N/A	Estimated 1.4 million cases per year worldwide. Serological evidence of prior infection ranges from 15% -to nearly 100%.

N/A = Not Available
Sources: WHO (2000, 2003b, 2003c, 2004b).

Initial information on background levels of faecal-oral disease in the population might be based on information collected from local healthcare facilities, public health surveillance, laboratory analysis, epidemiological studies or specific research conducted in a project area. There may be seasonal fluctuations in disease occurrence, for example during the wet season or cold season (e.g., rotavirus infections peak in the cold season), which should be considered. In evaluating the use of excreta or wastewater in a certain area it would be important to evaluate disease trends i.e., whether they were decreasing or increasing. High background disease levels (e.g., intestinal worm infections) or disease outbreaks (e.g., cholera) might indicate that risk management procedures were not being implemented adequately and would need to be strengthened or reconsidered.

3 ASSESSMENT OF RISK

The use of excreta and greywater has the potential for both positive and negative health consequences. Positive health benefits may arise from the safe use of treated excreta and greywater especially when these activities increase household food security, nutritional variety and/or generate household income that can be used to support health-promoting activities such as education or access to better health care. These benefits, however, have rarely been quantified in a systematic way. The value of using excreta as a fertilizer has been exemplified in Chapter 1.

The negative health consequences relate to the transmission of infectious diseases through improper management of excreta and greywater and to a lesser extent exposure to chemicals. This chapter 3 gives an overview of health related organisms in faeces and urine. The microbial risks in relation to greywater relates to the load of faecal material, which is much lower than in wastewater. Easily degradable organic material may promote regrowth of indicator bacteria in greywater, which is briefly exemplified. The risks to consumers are dealt with from an epidemiological perspective. Chapter 3 further gives evidence based on existing information about the survival/die-off of pathogens and faecal load in urine and greywater systems which forms is an integrated concept in the assessment of risks. The evidences for risks, following the structure outlined in the Stockholm Framework, Chapter 2, are exemplified for faeces, urine and greywater.

3.1 Health Benefits

The health benefits from excreta are mainly linked with their value as a fertiliser to enhance crop productivity and thus availability of agricultural products, so far mainly applied in small-scale applications in rural areas and urban agriculture as exemplified in chapter 1. Greywater have its major benefit for irrigation and is a resource for the poor as well as generally in water scarce areas, there also benefiting crop production. Indirect health benefits also relates to its economic values (Chapter 9) and reduced environmental impact (Chapter 8). Although the benefits in relation to excreta as a fertilizer is well established the role of greywater is this respect is less well characterised.

In general, improving nutrition, especially for children, is very important for maintaining the overall health of individuals and communities. Malnutrition is estimated to have a significant role in the deaths of 50% of all children in developing countries (10.4 million children under the age of five die per year) (Rice et al., 2000; WHO, 2000). Malnutrition affects approximately 800 million people (20% of all people) in the developing world (WHO, 2000). Excreta and greywater, as a readily available resource of plant nutrients respectively for irrigation can help to alleviate malnutrition if managed well or it can also cause malnutrition (e.g., iron deficiency anaemia) through hookworm infection if proper risk management strategies are not employed (see chapter xx5).

According to the WHO report *Turning the tide of malnutrition: responding to the challenge of the 21st century* (WHO, 2000*)*, malnutrition is the single most important risk factor for disease; the second one is poor hygiene, sanitation and water. When poverty is added to the picture, it produces a downward spiral. At the individual level:

- Poor people may eat and absorb too little nutritious food and be more disease-prone.

- Inadequate or inappropriate food leads to stunted development (1 in 3 children under 5 in the developing world are stunted) and/or premature death.
- Nutrient-deficient diets provoke health problems (100 - 140 million children are vitamin A deficient; 4 - 5 billion people are affected by iron deficiency and 2 billion by anaemia); malnutrition increases susceptibility to disease.
- Disease decreases people's ability to cultivate or purchase nutritious foods.
- The downward spiral of poverty and illness is apparent.

Therefore, resources (including excreta and greywater) that improve the household's ability to produce or purchase sufficient quantities of nutritious food can impact the health at the individual and community levels.

3.2 Excreta related infections

In the primary step of the risk assessment "hazard identification" the pathogens relevant in a special surrounding or environment are identified and relates to the excreta related infections. These infections are common in the human population in many countries, with correspondingly high concentrations of excreted pathogens.

The range of organism has common features that govern their likelihood of transmission.

- Epidemiological features (including infectious dose, latency, hosts and intermediate host).
- Persistence in different environments outside the human body (and potential for growth)
- The major transmission routes
- Relative efficiency to be reduced by different treatment barriers and
- Management control measures

In the hazard identification of microbial risk assessment these features are accounted for. The relevant microbial agents are identified as well as the spectrum of human illness and diseases associated with each pathogen. This also includes aspects of acquired immunity and multiple exposures (for example exposure on different days or through different routes) *etc*. Since it is not feasible to assess the potential impact of all excreta related pathogens some are commonly chosen as "reference pathogens" (when their reduction due to different barrier are assessed, the term "index pathogens" are often used).

The governing factors relates to their potential occurrence in the environment. This in turn is a reflection of their occurrence in society. Factors of central importance (related to each organism) are thus:

- Disease incidence (corrected for underreporting)

- Percent infections leading to disease (morbidity, differs between organisms)

- Excretion density (differs between organisms)

- Excretion time and carriership (differs between organisms).

- Excretion route (faeces or urine)

The incidence rate of a disease is the yearly number of reported cases divided by the total population, often expressed per 100 000 people. This will vary due to the prevailing epidemiological situation within an area. The reported number of cases is however often substantially underestimated since the infected person, must be symptomatic, recognized in the medical care system with the right diagnosis and reported. Estimates of underreporting (*i.e.* how many more cases exist in the community than was reported) are exemplified in Table 3.1. Generally, pathogens causing less severe symptoms are less likely to be reported (Wheeler *et al.*, 1999).

The disease incidence and excreted amounts will, in general terms, give their concentration at the time of excretion. The subsequent risks will relate to (1) their persistence (or regrowth or environmental latency) which will vary due to the receiving environment and the organism in question, (2) dilution factors (for example the amount of human faeces, that will end up in greywater), (3) exposure route (and frequency of exposure), (4) dose, i.e. the amount of material, and thus number of pathogens, a person is exposed to (risk will vary due to the infectious dose of the organism in question and the vulnerability of the receiving population). In order to become infected when exposed to a pathogen, this must breach the host's defence mechanisms to reach the target cells where it multiplies. ID_{50} is the dose, or number of pathogens, at which 50% of a population will be infected. An infected person excretes pathogens, often in very high numbers and for many days (Table 3.1). Not all infections are symptomatic, however. Morbidity is a measure of the percentage of people that will acquire symptoms when infected.

Table 3.1. Example of different epidemiological data for selected pathogens (Westrell, 2004)

	Incidence (/100 000)	Under-report.	Morbidity (%)	Excretion (g^{-1} faeces)	Duration (days)	ID_{50}[a]
Salmonella	42-58	3.2	6-80	10^{4-8}	26-51	23 600
Campylobact.	78-97	7.6	25	10^{6-9}	1-77	900
EHEC	0.8-1.4	4.5-8.3	76-89	10^{2-3}	5-12	1 120
Hepatitis A	0.8-7.8	3	70	10^{4-6}	13-30	30
Rotavirus	21	35	50	10^{7-11}	1-39	6
Norovirus	1.2	1562	70	10^{5-9}	5-22	10
Adenovirus	300	-	54	X	1-14	1.7
Cryptospor.	0.3-1.6	4-19	39	10^{7-8}	2-30	165
Giardia	15-26	20	20-40	10^{5-8}	28-284	35
Ascaris	15-25	-	15	10^{4}	107-557	0.7

In Table 3.1 values are representing a developed region. The incidence data for noro- and adenovirus are based on Wheeler et al (1999) and for Ascaris on Arnbjerg-Nielsen et al (2004) in Denmark with corresponding values for underreporting (Wheeler et al (1999); Michel *et al.* (2000); Mead *et al.* (1999); Carrique-Mas (2001)) and morbidity (Haas *et al.* (1999). Havelaar *et al.* (2000b); Michel *et al.* (2000); Lemon (1997); Gerba *et al.* (1996b); Graham *et al.* (1994); (Van, 1992); (Feachem *et al.*, 1983); Tessier and Davies (1999)).

3.2.1 Health related organisms in faeces.

Enteric infections can be transmitted by pathogenic species of bacteria, viruses, parasitic protozoa and helminths. From a risk perspective, the exposure to untreated faeces always is considered unsafe, due to the potential presence of high levels of pathogens reflecting their prevalence in a given society.

Enteric bacterial pathogens are still of major concern, especially in developing countries, where outbreaks of cholera, typhoid and shigellosis even appears to become more frequent in urban and peri-urban areas. In areas with insufficient sanitation typhoid fever (*Salmonella typhi*) and cholera (*Vibrio cholera*) constitute major risks in relation to improper sanitation and contamination of water. *Shigella* is a common cause of diarrhoea in developing countries, especially in settings where hygiene and sanitation is poor. Among the bacteria, at least *Salmonella*, *Campylobacter* and enterohaemorrhagic *E. coli* (EHEC) are of general importance, both in industrialized and developing countries, when microbial risks from various fertilizer products are considered, including faeces, sewage sludge or animal manure. These bacteria are also important as zoonotic agents (transmission between humans and animals, as well as their faeces/manure).

Enteric viruses also are of general importance and are now further considered to cause the majority of gastrointestinal infections in industrialised regions (Svensson, 2000). Of the different types of viruses that may be excreted in faeces, the most common are members included in the enteroviruses, rotavirus, enteric adenoviruses and human caliciviruses (noroviruses) groups (Tauxe and Cohen, 1995). Hepatitis A has long been recognised as of major concern when applying wastes to land and is considered a risk for both water- and food-borne outbreaks, especially when the sanitary standard are low. The importance of Hepatitis E is emerging.

The parasitic protozoa, *Cryptosporidium parvum/hominis* and *Giardia lamblia/intestinalis* have been studied intensively during the last decade partly due to their high environmental persistence and low infectious doses. *Cryptosporidium* is association with several large waterborne outbreaks and *Giardia* is occurring with high prevalence as an enteric pathogen. *Entamoeba histolytica* is also recognised as an infection of concern in developing countries. The general importance of other protozoa such as *Cyclospora* and *Isospora* is currently debated.

In developing countries, geohelminth infections are of major concern. The eggs (ova), of especially *Ascaris* and *Taenia* are very persistent in the environment, and therefore regarded as an indicator and index of hygienic quality (WHO, 1989). Hookworm disease is widespread in most tropics and subtropics areas, and affects nearly one billion people worldwide. In some developing countries, these infections exaggerate malnutrition and indirectly cause the death of many children by increasing their susceptibility to other infections. The eggs from *Ascaris* and hookworms that are excreted in the faeces require a latency period and favourable conditions in soil or deposited faeces to hatch into larvae and become infectious (CDC, 2003).

Schistosoma haematobium are excreted both in faeces and urine while other types of *Schistosoma*, e.g. *S. japonicum* and *S. mansoni* are just excreted in faeces. *S. japonicum* is mainly prevalent in the Far East and *S. mansoni* in Africa and in parts of South- and Central America, mainly Brazil (WHO, 2003). More than 200 million people are currently infected with schistosomiasis. The use of treated excreta should not have an impact but fresh or untreated faecal material, constitute a risk close to fresh water sources where the intermediate host snail is present.

The pathogens of concern for environmental transmission through faeces mainly cause gastro-intestinal symptoms such as diarrhoea, vomiting and stomach cramps. Several may also cause symptoms involving other organs and severe sequels. Table 3.2 provides an exemplification of selected pathogens of concern and their symptoms.

Table 3.2. *Example of pathogens that may be excreted in faeces (can be transmitted through water and improper sanitation) and related diseases, including examples of symptoms they may cause (adapted from e.g. CDC, 2003; Ottosson, 2003)*

Group	Pathogen	Disease - Symptoms
Bacteria		
	Aeromonas spp	Enteritis
	Campylobacter jejuni/coli	Campylobacteriosis - diarrhoea, cramping, abdominal pain, fever, nausea; arthritis; Guillain-Barré syndrome
	Escherichia coli (EIEC, EPEC, ETEC, EHEC)	Enteritis
	Plesiomonas shigelloides	Enteritis
	Salmonella typhi/paratyphi	Typhoid/paratyphoid fever - headache, fever, malaise, anorexia, bradycardia, splenomegaly, cough
	Salmonella spp.	Salmonellosis - diarrhoea, fever, abdominal cramps
	Shigella spp.	Shigellosis - dysentery (bloody diarrhoea), vomiting, cramps, fever; Reiter's syndrome
	Vibrio cholerae	Cholera - watery diarrhoea, lethal if severe and untreated
	Yersinia spp.	Yersiniosis – fever, abdominal pain, diarrhoea, joint pains, rash
Virus		
	Enteric adenovirus 40 and 41	Enteritis
	Astrovirus	Enteritis
	Calicivirus (incl. Noroviruses)	Enteritis
	Coxsackievirus	Various; respiratory illness; enteritis; ; viral meningitis
	Echovirus	Aseptic meningitis; encephalitis; often asymptomatic
	Enterovirus types 68-71	Meningitis; encephalitis; paralysis
	Hepatitis A	Hepatitis - fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
	Hepatitis E	Hepatitis
	Poliovirus	Poliomyelitis – often asymptomatic, fever, nausea, vomiting, headache, paralysis
	Rotavirus	Enteritis
Parasitic protozoa		
	Cryptosporidium parvum/hominis	Cryptosporidiosis - watery diarrhoea, abdominal cramps and pain
	Cyclospora cayetanensis	Often asymptomatic; diarrhoea; abdominal

		pain
	Entamoeba histolytica	Amoebiasis - Often asymptomatic, dysentery, abdominal discomfort, fever, chills
	Giardia intestinalis	Giardiasis – diarrhoea, abdominal cramps, malaise, weight loss
Helminths		
	Ascaris lumbricoides	Generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia
	Taenia solium/saginata	
	Trichuris trichiura	Unapparent through vague digestive tract distress to emaciation with dry skin and diarrhoea
	Hookworm	Itch; rash; cough; anaemia; protein deficiency
	Shistosomiasis spp	

3.2.2 Health related organisms in urine

Environmental transmission of urinary excreted pathogens is of limited concern in temperate climates, but any faecal cross-contamination that may occur by misplacement of faeces in the source-separating toilet will end up diluted in the urine and subsequently pose a possible health risk. Also in tropical climates faecal contamination of collected urine is considered as the main risk but additionally some urine-excreted pathogens also need to be considered. The risk of pathogen transmission during handling, transportation and reuse of diverted urine is however mainly based on the amount of faecal material contaminating the urine fraction.

Traditional faecal indicators such as *E. coli* are not useful to monitor faecal contamination due to their short survival in urine. Faecal streptococci may be used as a "storage indicator" but are able to re-grow in the pipes of larger urine diversion systems. Studies conducted with chemical indicators of faecal contamination (faecal sterols) indicate that faecal amounts normally is low, but do occur in a significant proportion of urine diversion schemes. For example 22% - 37% of urine or sludge from urine storage tanks indicated slight faecal contamination (Schönning *et al*. 2002). Samples collected from systems where there were several user families (small communities or apartment blocks) were more frequently contaminated than samples from individual households.

In a healthy individual the urine is sterile in the bladder. In the urinary tract different types of bacteria are picked up and freshly excreted urine normally contains <10 000 bacteria per ml. In urinary tract infections, significantly higher amounts of bacteria are excreted. These are normally not transmitted to other individuals through the environment. Pathogens causing venereal diseases may occasionally be excreted in urine but there is no evidence that their potential survival outside the body would be of health significance.

Some pathogens are excreted in urine, like *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and *Schistosoma haematobium* and some viruses. There is a range of other pathogens that have been detected in urine but their presence may normally be considered insignificant for further risk of environmental transmission.

Leptospirosis is a bacterial infection causing influenza-like symptoms and is in general transmitted by urine from infected animals (Feachem *et al.* 1983; CDC 2003b). It is considered an occupational hazard e.g. for sewage workers and for farm workers in developing countries (CDC 2003b). In tropical and subtropical climates it is an important disease in domestic animals both for the risk for humans and due to economical losses. It is a severe disease with a 5-10 % mortality (Olsson, Engvall and Gustavsson 2001). The bacteria survive for several months in freshwater and moist environments at neutral pH and temperatures around 25°C. Leptospiras from urine-contaminated environments, enter a host through the mucous membranes and through small abrasions in the skin. Human urine is not considered to be an important route for transmission of leptospirosis due to low prevalence (Feachem *et al.* 1983; CDC 2003).

Persons infected with *S. typhi* and *S. paratyphi* excrete the organisms in urine during the phase of typhoid and paratyphoid fevers when bacteria are disseminated in the blood. Even though the infection is endemic in several developing countries with an estimated 16 million cases per year, urine-oral transmission is probably unusual compared to faecal-oral transmission (CDC 2003c). For diverted urine, the risk for further transmission of *Salmonella* is low, even with short storage times, due to the rapid inactivation of Gram-negative faecal bacteria (Höglund, 2001). Die-off rates of *Salmonella spp* are rapid and similar to the ones for *E coli* in collected urine.

Persons infected with *Schistosoma haematobium*, excrete the eggs in urine, sometimes for extended time periods. The eggs hatch in the environment and the larvae infect the specific intermediate aquatic snail hosts, living in fresh water. After a series of developmental stages aquatic larvae emerge from the snail and may infect humans through skin penetration. *S. haematobium* is mainly found in Africa and partly in the Middle East. An ill-defined focus of *S. haematobium* also occurs in India. If the eggs do not reach the snail host within days the infectious cycle is broken which is the case if the urine is stored for days and is used on arable land. Fresh urine should not be used close to surface waters in endemic areas.

Mycobacterium tuberculosis and *Mycobacterium bovis* may be excreted in urine (Bentz *et al.* 1975; Grange and Yates 1992). *M. tuberculosis* has exceptionally been isolated in excreta and greywater coming from hospitals (Dailloux *et al.* 1999). Humans are able to infect cattle with both the bovine and the human strain and individuals on farms have transmitted bovine tuberculosis to cattle by urinating in the cowsheds (Huitema 1969; Collins and Grange 1987). It is however unlikely that transmission of either human or bovine tuberculosis is significantly affected by exposure to urine (or faeces). Other mycobacterial species (atypical mycobacteria) may also be isolated from urine. They are widely distributed in the environment and commonly found in waters, including as contaminants in drinking water (Grange and Yates 1992; Dailloux *et al.* 1999).

Microsporidia, are a group of protozoa implicated in human disease, mainly in HIV-positive individuals (Marshall *et al.* 1997; Cotte *et al.* 1999). The infective spores are shed in faeces and urine, with possible environmental transmission (Haas, et al, 1999). Microsporidia have been found in sewage and in waters. Water- or foodborne outbreaks have been suspected but are not well documented (Cotte *et al.* 1999; Haas et al, 1999).

Cytomegalovirus (CMV) is excreted in urine, but CMV is a person-to-person transmitted disease and not considered to be spread by food and water (Jawetz *et al.* 1987). Two polyomavirus, JCV and BKV, are also excreted in urine (Bofill-Mas *et al.* 2000). Both have been found in sewage in various countries. Even if occurring in excreta transmission to humans by this route is unlikely. Infections will mainly occur through close contact within the family or outside the family at a young age (Kunitake *et al.* 1995; Bofill-Mas *et al.* 2000). In one Japanese investigation it was found that 46% of persons aged 20-29 years excreted urinary JCV (Kitamura *et al.* 1994).

One food-borne outbreak of hepatitis A caused by lettuce contaminated by urine has been reported (Ollinger-Snyder and Matthews 1996). Hepatitis B has also been found in human urine with potential further transmission in hyper-endemic areas (Knutsson and Kidd-Ljunggren, 2000). Adenovirus may also be excreted in urine, especially from children with hemorrhagic cystitis, transplant patients and HIV-positive individuals (Mufson and Belshe 1976; Shields *et al.* 1985; Echavarria *et al.* 1998). However, the public health significance from urinary transmission has not been recognised.

Table 3.3. *Pathogens that may be excreted in urine and the importance of urine as a transmission route*

Pathogen	Urine as a transmission route	Importance
Leptospira interrogans	Usually through animal urine	Probably low
Salmonella typhi and *Salmonella paratyphi*	Probably unusual, excreted in urine in systemic infection	Low compared to other transmission routes
Schistosoma haematobium (eggs excreted)	Not directly but indirectly, larvae infect humans in fresh water	Need to be considered in endemic areas where freshwater is available
Mycobacteria	Unusual, usually airborne	Low
Viruses: CMV, JCV, BKV, adeno, hepatitis and others	Not normally recognised other than single cases of hepatitis A and suggested for hepatitis B. More information needed	Probably low
Microsporidia	Suggested, but not recognised	Low
Venereal disease causing	No, do not survive for significant periods outside the body	Insignificant
Urinary tract infections	No, no direct environmental transmission	Low - Insignificant

It can be concluded that pathogens that may be transmitted through urine are rarely sufficiently common to constitute a significant public health problem and are not considered to constitute a health risk in the reuse of human urine in temperate climates. *Schistosoma haematobium* is an exception in tropical areas is, however with a low risk due to its lifecycle.

The main risks in the use of excreta are related to the faecal and not the urine fraction. Diminishing faecal cross-contamination to the urine fraction is therefore important. Even though some pathogens may be excreted in urine, the faecal cross-contamination that may occur by misplacement of faeces in urine-diverting toilet is related to the most significant health risk (Höglund *et al*., 2002).

Fig 3.1. Fecal cross contamination to the urine constitutes the major health risk in the subsequent handling of this fraction. It is necessary the toilets to be adapted to the user and the system.

3.2.3 Health related organisms in greywater.

The interest in reusing greywater has increased in recent years, especially in arid areas. In some densely populated areas such as Singapore and Tokyo, greywater reuse including different system approaches and treatment alternatives is a common practice (Asano and Levine, 1996; Jeppesen, 1996; Trujillo et al., 1998; Dixon et al., 1999; Shrestha et al., 2001). In source separating systems, opportunistic pathogenic bacteria may emanate from growth within the actual system or from washing, kitchen activities or personal hygiene.

In buildings, opportunistic pathogenic bacteria, like Legionella, mycobacteria and *Pseudomonas aeruginosa*, may grow. The risk is probably not greater than from exposure to hot tapwater.

The main hazard of greywater are, as for urine, due to faecal cross-contamination (Section 3.2.1). Faecal contamination is limited and related to activities such as washing faecally contaminated laundry (i.e. diapers), child-care, anal cleansing and showering. Faecal contamination has historically been measured by the use of the common indicator organisms such as coliforms and enterococci. These have also been applied for assessing faecal contamination of greywater with reported high numbers (Table 3.4).

Table 3.4. Reported numbers of indicator bacteria in greywater [log_{10}/100mL]. From Ottosson 2003.

Excreta and greywater origin	**Total Coliforms**	**Thermotolerant Coliforms**	**E. coli**	**Enterococci**	**Reference**
Bath, hand basin			4.4	1.0-5.4	(Albrechtsen, 1998)
Laundry	3.4-5.5	2.0-3.0		1.4-3.4	(Christova-Boal et al., 1996)
Shower, hand basin	2.7-7.4	2.2-3.5		1.9-3.4	(Christova-Boal et al., 1996)
Greywater	7.9	5.8		2.4	(Casanova et al., 2001)
Shower, bath	1.8-3.9	0-3.7		0-4.8	(Faechem et al., 1983)
Laundry, wash	1.9-5.9	1.0-4.2		1.5-3.9	(Faechem et al., 1983)
Laundry, rinse	2.3-5.2	0-5.4		0-6.1	(Faechem et al., 1983)
Greywater	7.2-8.8				(Gerba et al., 1995)
Hand basin, kitchen sink		5.0		4.6	(Gunther, 2000)
Greywater		5.2-7.0	3.2-5.1		(Lindgren & Grette, 1998)
Greywater, 79% shower	7.4	4.3-6.9			(Rose et al., 1991)
Kitchen sink		7.6	7.4	7.7	(Swedish EPA, 1995)
Greywater		5.8	5.4	4.6	(Swedish EPA, 1995)

However, greywater may contain an high loads of easily degradable organic compounds, which favors the growth of the faecal indicators, as reported by Manville et al., (2001) in excreta and greywater systems. Hence, bacterial indicator numbers may lead to an overestimation of faecal loads and thus risk. Occasionally enteric pathogenic bacteria, such as *Salmonella* and *Campylobacter*, can be introduced by food handling in the kitchen (Cogan et al., 1999) in addition to from the fecally derived matter directly from humans. The individual risk is higher from the direct handling of the contaminated food, but limited to a few exposed persons in the individual household, whereas a number of people can be exposed from the reused water. There is also a risk of regrowth of some pathogenic bacteria within the greywater system itself.

3.3 Pathogen survival in faeces, urine and greywater

3.3.1. Survival in faeces.

In 1983, Feachem *et al*. (1983) compiled extensive literature data on pathogen/indicator reductions in different materials, including nightsoil and faeces. The data were presented as "less than values", and do not consider the initial concentrations and die-off rate, but rather information on total inactivation. Additional compilations, Schönning *et al.*, (2006,) estimate the decimal reduction times for selected pathogens, but recent data of pathogen inactivation in human faeces are limited. If the initial concentrations are high and a 1^{st} order die-off kinetic applied, the time for a total die-off is longer than in Feachem (1983). However, this is not necessarily applicable during extended storage. The additional information was drawn from similar investigations of the die-off of selected pathogens in animal manure, animal slurry and sewage sludge (Arnbjerg-Nielsen et al, 2004) with its corresponding values after incorporation into soil (Table 3.6) and expressed as days for 90% inactivation (T_{90}-values).

Table 3.5 *Die-off of selected pathogens in faeces and soil, expressed as T_{90}-values.*

	T_{90} faeces (mean ± stdv)	T_{90} soil (mean ± stdv)
Salmonella	30 ± 8	35 ± 6
EHEC	20 ± 4	25 ± 6
Rotavirus	60 ± 16	30 ± 8
Hepatitis A	55 ± 18	75 ± 10
Giardia	27.5 ± 9	30 ± 4
Cryptosporidium	70 ± 20	495 ± 182
Ascaris	125 ± 30	625 ± 150

The number of pathogens in faecal material will be reduced with time during storage due to natural die-off, without further treatment. The type of organism and storage conditions governs the time dependent reduction or elimination. The ambient temperature, pH and moisture etc. will affect the inactivation as well as biological competition. Since the conditions during storage vary, so do the die-off rates.

In a South African study, *Salmonella* was found in stored faeces after one year (Austin, 2001). Wood ash sprinkled over the faeces, gave a pH of 8.6-9.4. The material had been partially wetted and Salmonella could have grown in the material. Weekly turnings of the faecal heap gave high reduction of pathogens and the faecal indicators and resulted in low moisture (Austin, 2001). Aeration increases the inactivation since a partial composting may have taken place (temperature not reported).

In a Danish study the subsequent risks related to the use of faeces that had been stored for 0-12 months without additional treatment, were calculated (Arnbjerg-Nielsen *et al.*, in press;). *Ascaris* posed the highest risk with a high likelihood of becoming infected upon exposure for vulnerable persons after accidental ingestion of the material. The protozoa (*Giardia* and *Cryptosporidium),* as well as rotavirus, also resulted in high risks after accidental ingestion during handling or using unstored faeces in the gardens. After storage for 6 months the risk was extrapolated to be 10% whereas after 12 months it was typically around 1:1 000. The risk for hepatitis A or bacterial infections was generally lower. The storage was assumed to occur at around 10°C.

In a study in Mexico (Franzén & Skott, 1999), with faecal material (moisture 10%, pH around 8, temperature of 20-24°C) a conservative viral indicator was added in controlled amounts and was reduced 1.5 $\log_{10}$ after six weeks of storage. Low moisture content had a beneficiary reduction effect in Vietnam, of added bacteriophages in latrines (Carlander & Westrell, 1999). These latrines also had a pH around 9 but higher temperatures (30 - 40 ^{o}C). A total inactivation of *Ascaris* was recorded within 6 months. This inactivation was not statistically related to any single factor in the latrines, but a combination of high temperature and high pH was suggested to account for the main reduction. If applying a safety margin, the guideline value stated for helminths by WHO (1989) were at least one year of storage at ambient temperature, without additional treatment. Strauss and Blumenthal (1990) suggested that one year was sufficient under tropical conditions (28-30°C), whereas at lower temperatures (17-20°C) 18 months would be needed. This has also been supported by additional studies in Vietnam (Phi et al, 2004).

In El Salvador an extensive study of the faecal material collected in urine diverting toilets has been conducted. Material to increase pH is added by the users to the faecal material but recording of some pH-values around 6 implies that, in some toilets, just treatment by storage is occurring (Moe & Izurieta, 2003). Survival analysis suggested that faecal coliforms would survive >1 000 days and *Ascaris* around 600 days in latrines with a pH of less than 9!

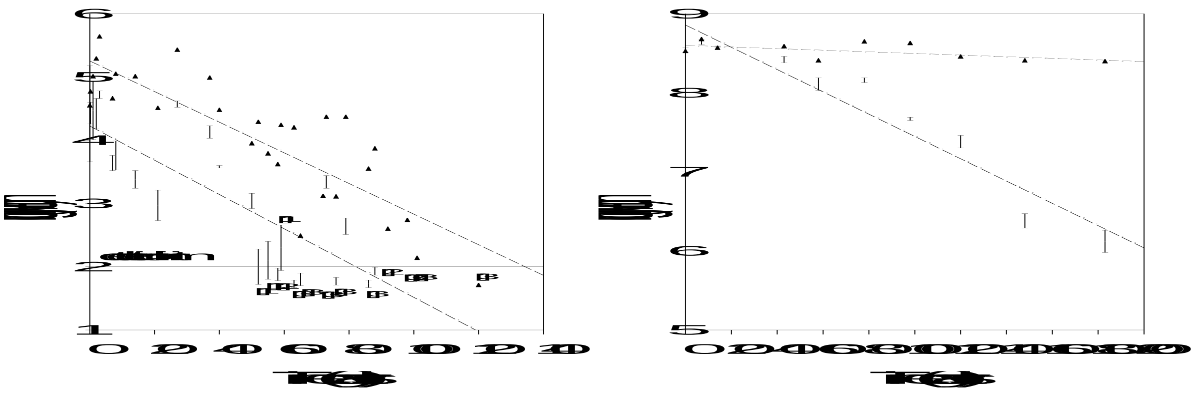
Storage is especially beneficial in dry-hot climates resulting in desiccation of the material and low moisture contents aiding to pathogen inactivation. If all the faecal material is dry right through, the pathogen decrease is facilitated. Esrey *et al.* (1998), suggested that there is rapid pathogen destruction at moisture levels below 25%, and that this level should be aimed for in ecological sanitation toilets that are based on dehydration (i.e. storage). Low moisture content is also beneficial in order to reduce smell and fly breeding (Esrey *et al.*, 1998; Carlander & Westrell, 1999). Regrowth of bacterial pathogens may however occur after application of moisture or if the material is mixed with a moist soil. Desiccation is not a composting process and when moisture is added the easily metabolised organic compounds will facilitate bacterial growth, including e g *E. coli* and *Salmonella* if small amounts of these are occurring or introduced into the material. Protozoan cysts are sensitive to desiccation also affecting their survival on plant surfaces (Snowdon *et al.*, 1989; Yates and Gerba 1998). Normal moisture levels do not inactivate *Ascaris* eggs. Values below 5% are needed (Feachem *et al.*, 1983) but values for the corresponding time is lacking.

3.3.2 Survival in urine

The fate of the enteric pathogens is of importance for the hygiene risks related to the handling and reuse of urine. Temperature, dilution, pH, ammonia and time are the main parameters affecting the persistence of organisms in collected urine. The technical design of the urine-diverting system, e.g. flushing and storage procedures may also influence.

The short survival of *E. coli* in urine makes it unsuitable as a general indicator for faecal contamination (Tab 3.7) of for example viruses and protozoa. It does, however, represent the die-off of Gram-negative bacteria. The T_{90}-values were generally from <1 – 5 days depending on the prevailing conditions; the longer time represent a pH value of 6. Longer persistence was also recorded if the urine was diluted tenfold. Gram-negative bacteria such as *Campylobacter*, *Salmonella*, *Aeromonas hydrophila* and *Pseudomonas aeruginosa*, were inactivated as rapid as *E coli*, indicating a low risk for transmission of bacterial gastrointestinal infections when handling diverted urine. The Gram-positive faecal streptococci had a longer survival (normally a T_{90} value of 4-7 days at 20 ^{o}C, but up to 30 days at 4 ^{o}C) and spore-forming clostridia were not reduced at all during a period of 80 days. In general, lower temperature and higher dilution result in longer survival of most bacteria. pH-values the furthest from neutral was most deleterious. The rapid reduction of bacteria at high pH-values is probably an effect both of the pH and of ammonia.

No significant inactivation of either rotavirus or a model phage occurred at 5ºC during six months of storage, while the mean T_{90}-values at 20ºC were estimated at 35 and 71 days for rotavirus and the phage, respectively (Figure 3.3). Rotavirus inactivation appeared to be largely temperature dependent, whereas there was an additional virucidal effect on the phage in urine at 20ºC (pH 9).



(a) (b)

Figure 3.2. Inactivation of (a) rotavirus and (b) Salmonella typhimurium phage 28B in diverted human urine (•) and control medium (▲) at 20°C.

Cryptosporidium parvum is known to be persistent in waste products as well as in water and to be resistant to disinfectants (Meinhardt *et al.* 1996) and a conservative index of protozoa in urine (Höglund and Stenström 1999). In urine mixture at pH 9 and 4°C, the oocysts were inactivated to below the detection limit within about 2 months. The T_{90}-value for *Cryptosporidium* was about 1 month at 4 ^{o}C and 5 days at 20 ^{o}C. The inactivation at pH 9 was significantly higher ($p < 0.01$) than at pH 5 and pH 7. The anti protozoan effect of urine at pH 9 seems to be mediated by other factors besides the actual pH. Ammonia (NH_3) has been demonstrated to act as an inactivating agent for *Cryptosporidium* (Jenkins *et al.* 1998). The concentration of free ammonia (NH_3) in urine (pH = 9; T = 4°C) was around 0.03 mol/l (Höglund and Stenström 1999).

In summary Gram-negative bacteria are rapidly inactivated while oocysts of *Cryptosporidium parvum* are reduced by approx. 90% per month in the urine mixture. Viruses are the most persistent group of microorganisms with no inactivation in urine at 5°C and T_{90}-values of 35-71 days at 20°C. Temperature may be considered the most important parameter (results summarized in Table 3.7). For bacteria further dilution of the urine prolonged the survival. The effect of pH and ammonia is combined. However, rotavirus was neither affected by pH nor ammonia. The information on helminths, including Ascaris, is limited and partly contradicts. According to Hamdy *et al.* (1970, in Feachem *et al.* 1983) urine is ovicidal and *Ascaris* eggs are killed within hours, while other indicates that the reduction of *Ascaris suum* in urine is minor with a 15-20 % reduction during a 21-day period. Early studies also reported inactivation of *Schistosoma haematobium* in urine (Porter 1938, in Feachem *et al.* 1983).

Table 3.6. *Summarised results from the survival experiments, given as T_{90}-values (time for 90% reduction). Further details inn text.*

	Gram-negative bacteria	Gram-positive bacteria	*C. parvum*	Rotavirus	*S. typhimurium* phage 28B
4°C	1	30	29	172[a]	1 466[a]
20°C	1	5	5	35	71

[a] survival experiments performed at 5°C

3.3.3 Faecal load and survival in greywater.

The pathogen related risks of greywater depend on the fecal load or misplacement. Since indicator bacteria may grow due to the presence of easily degradable organic matter in greywater, their numbers may overestimate the risks. A number of faecal indicator organisms and biomarkers have been compared for a quantification of the faecal load in greywater (Ottoson, 2003) (Table 3.8) calculated as follows:

$$\frac{\text{(Microorganism density [numbers mL}^{-1}\text{]* Flow [mL person}^{-1}\text{ day}^{-1}\text{])}}{\text{Excretion density [numbers g faeces}^{-1}\text{]}}$$

The indicator organisms gave a gross overestimation of the fecal input if the amounts of fecal sterols are used as a “true value”. Using *E. coli* to estimate the faecal load would lead to an overestimation of more than 1,000 times, enterococci 100 times, compared to the use of coprostanol. In the subsequent example of QMRA for greywater (p XX), coprostanol was used as a conservative biomarker.

Table 3.7. Faecal indicators in a greywater system [log 10 100 mL^{-1}] and the corresponding faecal load [g person^{-1} day^{-1}] with an average flow of 64.9 L person^{-1} day^{-1}

Organism/biomarker	***Mean***	***Min***	***Max***	***Excretion density [numbers or mg g^{-1} faeces]***	***Mean faecal load (min – max) [g person^{-1} day^{-1}]***
Coliform	***8.1***	***5.5***	***8.7***		
E. coli	***6.0***	***4.3***	***6.8***	***10E7[a]***	***65 (1.3 – 410)***
Enterococci	***4.4***	***3.0***	***5.1***	***10E6.5[a]***	***5.2 (0.2 – 26)***
Sulphite reducing anaerobes	***3.3***	***2.3***	***4.8***		
Somatic coliphages	***3.3***	***1.4***	***4.0***		
Coprostanol [μg L^{-1}]	***8.6***	***3.1***	***14.9***	***12.74[b]***	***0.04 (0.016 – 0.076)***
Cholesterol [μg L^{-1}]	***17.3***	***7.4***	***31.6***	***5.08[b]***	***0.22 (0.094 – 0.40)***

[a] (Geldreich, 1978)
[b] (Leeming et al., 1998)

The pathogen density in the untreated greywater can subsequently be calculated. Naturally a higher faecal load may prevail in other circumstances and the figures adjusted accordingly:

$$\frac{\text{(0.04 [g p}^{-1}\text{d}^{-1}\text{] * excretion density [numbers g faeces}^{-1}\text{] *excretion time [d] * yearly incidence)}}{\text{(6)(64900 [mL d}^{-1}\text{] * 365 [d])}}$$

with the faecal load, excretion density and excretion time expressed as PDFs.

Sediment is formed in several in-house piping installations and can provide growth niches for bacteria including indicator bacteria and pathogens, such as Salmonella and Campylobacter introduced from poor food handling. Campylobacter die rapidly from the effects of temperature, competition from commensal microbiota and nutrient availability (Ottoson and Stenström, 2002). Campylobacter isolates of clinical importance are not likely to grow in temperatures below 30°C (Hazeleger et al., 1998) and will not regrow under conditions most often prevailing in greywater treatment systems. Salmonella can grow at 20 °C and below, but is likely to be suppressed by the indigenous microorganisms, also shown by Sidhu et al. (2001). The growth rate of Salmonella at 20 °C, 0.022 ± 0.02 log day-1, was used in the worst-case scenario in further risk assessment calculations. In most situations pathogens are likely to decline outside their host. Decay rates in sediment and other matrices are additionally used in quantitative MRA is listed in Table 3.9. Enterococci can be used as a conservative index organism for Salmonella and Campylobacter; somatic coliphages and F-specific RNA bacteriophages for rotavirus and spores of sulphite reducing anaerobic bacteria for Giardia and Cryptosporidium (oo)cysts.

Table 3.8. Decay rate of selected microorganisms in different matrices and at different temperatures. Other values than for greywater were used as reference values.

Microorganism	*Decay rate [$\log_{10}$ dag^{-1}]*	*Matrix*	*Temp. [°C]*	*Method*	*Reference*
Bacteria **Salmonella typhimurium**	*- 0.048 ± 0.0092* *- 0.12 ± 0.0011* *- 0.36*	*Greywater sediment* *Greywater*	*4* *20* *ambient*	*Culture*	*(Ottoson & Stenström, 2002)* *(Nolde, 1999)*
Campylobacter jejuni	*- 1.30 ± 0.16* *- 0.11 ± < 0.01* *- 0.02 ± < 0.01*	*Riverwater with sediment*	*25* *15* *5*	*Culture*	*(Thomas et al., 1999)*
Enterococci (bacterial indicator)	*- 0.032 ± 0.016* *- 0.078 ± 0.038*	*Greywater sediment*	*4* *20*	*ISO 7899-2*	*(Ottoson & Stenström, 2002)*
Virus *Rotavirus*	*- 0.016 ± 0.010* *- 0.119 ± 0.00835*[a]	*Liquid waste* *Grass*	*12 – 17* *4 –16*	*Cell culture*	*(Pesaro et al., 1995)* *(Badawy et al., 1990)*
ΦX174 bacteriophage (viral indicator)	*- 0.018 ± 0.0048* *- 0.11 ± 0.031*	*Sediment*	*4* *20*	*ISO 10705-2*	*(II)*
MS2 bacteriophage (viral indicator)	*- 0.021 ± 0.0069* *- 0.029 ± 0.024*	*Sediment* *Groundwater*	*4 - 20* *4*	*ISO 10705-1* *Plaque assay*	*(II)* *(Yates et al., 1985)*
Parasites **Cryptosporidium parvum** *oocysts*	*- 0.006 ± 0.031* *- 0.010 ± 0.032* *- 0.011 ± 0.008* *- 0.010 ± 0.016*	*River water*	*15* *5* *15* *5*	*Excystation* *Dye exclusion*	*(Medema et al., 1997)*
Giardia intestinalis **cysts**	*- 0.042*	*Water*	*25*	*Dye exclusion*	*(Romig, 1990)*
Spores of sulphite reducing anaerobes (parasite indicator)	*- 0.00045 ± 0.0027* *- 0.027 ± 0.0043* *- 0.012 ± 0.0031*	*Sediment* *River water*	*4 – 20* *15* *5*	*ISO 6461/2* *Culture*	*(II)* *(Medema et al., 1997)*

[a] [h^{-1}]

3.4 Survival in soils and on crops

Inactivation of pathogens in the soil is important for the subsequent risk related to use of excreta, even though treatment of the material should aim to fully or substantially reduce the pathogens before application as a fertilizer. Inactivation is often more rapid on the soil and crop surfaces than in stored excreta and greywater and more rapid on crops than in soils. However, some pathogens can persist for extended periods of time in soil or on crop surfaces and be transmitted to humans or animals. The most environmentally resistant pathogens are the helminth eggs, which in extreme cases can survive for several years in the soil. In Vol 2 of the Guidelines the background evidences for pathogen survival in soils and crops have been reviewed, also applicable in relation to excreta and greywater. A summary of background information is included in this section.

Pathogen inactivation is much more rapid in hot and/or sunny weather than under cool, cloudy, or rainy conditions. The persistence in cold temperatures is additionally relevant for post-harvest storage. The greatest health risks are associated with insufficiently treated excreta in combination with crops eaten raw, for example, salad crops, root crops (e.g., radishes, onions) or crops grown close to the soil (lettuces, zucchinis). Certain crops may be more susceptible to contamination than others − for example, onions (Blumenthal *et al*., 2003), zucchini (Armon *et al*., 2002), and lettuce (Solomon *et al*., 2002). Crops with certain surface properties (hairy, sticky, with crevices, rough, etc.) protect pathogens from exposure to radiation and make them more difficult to wash off. Crops retaining water, e g from rain that splash up contaminated soil, is an important factor in exposure to pathogens. Lettuce retains a measured 10.8 ml of irrigation water while a cucumber only holds 0.36 ml (Shuval, Lampert and Fattal, 1997). Stine et al., (2005) showed that lettuce and cantaloupe surfaces retained pathogens from irrigation water spiked with *E. coli* and a bacteriophage (PRD1) but bell peppers which are smooth, did not.

Information on bacterial reduction are often based either on *E coli* as an indicator or include information about the frequency of detection of pathogens like *Salmonella sp*. on the crops. These values may however be used in extrapolation of the risks and generally validate that high amounts of these bacterial groups will be reduced to below a background level within 1-2 weeks or what is found on market products if irrigated with treated wastewater (Vaz da Costa Vargas *et al*., 1996; Bastos and Mara, 1995; Armon *et al*., 1994). A withholding time of at least 1 month between application of treated excreta and harvest is recommended in this guideline (which partly lower the risk as related to wastewater irrigation) and that the recommended level of $<10^3$ *E coli* per g TS or $< 10^5$ *E coli* in greywater would be appropriate (Chapter 4).

Petterson *et al.* (2001a) modelled the inactivation of enteric viruses on lettuce and carrots, using data collected on crops grown under glasshouse conditions with a model virus *Bacteroides fragilis* B40-8. Initial die-off was rapid but with a more persistent sub-population of viruses in the end of the experiments. Ward and Irving (1987) observed survival times of 1 to 13 days when the irrigation water contained between 5.1×10^2 and 2.6×10^5 type 1 poliovirus VU/L (decimal reduction needed to be useful in risk assessment). Petterson and Ashbolt (2002) have summarized viral die off data on different crops. These data are expressed as T_{99}-values (days for two logarithms reduction) not exceeding 4 days for leaf crops and 20 days for root crops. A withholding time of 1 month would as for bacteria, normally ensure a safety margin against viral contamination. On lettuce spiked with *Cryptosporidium* oocysts, no viable oocysts were detected after 3 days at 20°C while 10%

remained at 4°C (Warnes and Keevil; 2003). On crops the inactivation rate is often considered to be more rapid than in soils, with T_{90} values in the range of a few days (Asano *et al.*, 1992; Petterson *et al*). Studies carried out in glasshouses in the UK (Stott *et al*, 1994) with seeded effluent (*Ascaridia galli*) indicated that irrigation with wastewater containing 10 eggs per litre resulted in low levels of nematode contamination on lettuce (maximum of 1.5 eggs per plant), and improving wastewater quality further to ≤1 egg per litre resulted in very slight contamination of only a few plants (0.3 egg per plant). These values correspond with the excreta target values, with the exception that the later will give less contamination of the plant surfaces. The accidental occurrence of a few viable eggs can, however, never be excluded and, due to the latency period, may represent a potential risk to consumers both in relation to wastewater and excreta use. Data for pathogen survival in soil and on different crops are presented in Table 3.9 and 3.10.

Table 3.9. *Estimated survival times and decimal reduction values of pathogens during storage of faeces and in soil, presented in days if not stated otherwise (Feachem* et al.*, 1983*[a]*; Schönning* et al. 2006*, in press*[b] *Kowal 1985 in EPA 1999). No additional treatment is applied. norm. = normally*

Microorganism	Faeces and sludge[a] 20-30°C	Faeces T_{90}[b] ~20°C	Soil[a] 20-30°C	Soil T_{90}[b] ~20°C	Soil[c] absolute max[d]/ normal max
Bacteria					1 year/2 months
Fecal coliforms	<90 norm. <50	15-35 (*E. coli*)	<70 norm. <20	15-70 (*E. coli*)	
Salmonella	<60 norm. <30	10-50	<70 norm. <20	15-35	
Viruses	<100 norm. <20	rotavirus: 20-100 hepatitis A: 20-50	<100 norm. <20	rotavirus: 5-30 hepatitis A: 10-50	1 year/3 months
Protozoa (*Entamoeba*)	<30 norm. <15 [e]	*Giardia*: 5-50 *Cryptosporidium*: 20-120	<20 norm. <10 [e]	*Giardia*: 5-20 *Cryptosporidium*: 30-400	? /2 months
Helminths (egg)	Several months	50-200 (*Ascaris*)	Several months	15-100 (*Ascaris*)	7 years/2 years

[d] Absolute maximum for survival is possible under unusual circumstances such as at constantly low temperatures or at well-protected conditions.[a] [e] Data is missing for *Giardia* and *Cryptosporidium*, their cysts and oocysts might survive longer than presented here for protozoa.[a]

Table 3.10 Survival of various organisms in days on crops at 20-30°C (as reported in WHO Wastewater Guidelines).

Organisms	Crops
Viruses Enteroviruses*	<60 but usually <15
Bacteria Thermotolerant coliforms *Salmonella* spp *Shigella* spp. *V. cholerae*	 <30 but usually <15 <30 but usually <15 <10 but usually <5 <5 but usually <2
Protozoan cysts *E. histolytica* cysts *Cryptosporidium* oocysts	 <10 but usually <2 <3 but usually <2

Helminths	
Ascaris eggs	<60 but usually <30
Tapeworm eggs	<60 but usually <30

* poliovirus, echovirus, and coxsackievirus
NA = No data available
Sources: Feachem *et al*. (1983); Robertson, Campbell, Smith (1992); Warnes and Keevil 2003; Jenkins et al., 2002; and Strauss (1985).

3.5 Epidemiological and risk based evidence

Epidemiological evidences in relation to reuse of *treated* excreta, and greywater is mainly lacking. In areas where *untreated* human excreta is used as a fertilizer for crops, an elevated prevalence of Ascaris infection has occasionally been reported (in Iran (Arfaa and Ghadirian, 1977) and China (Xu et al, 1995)). Hookworm infection is also prevalent in wet climates when excreta are used (Vietnam (Needham et al, 1998) and Southern China (Xu et al, 1995)). Blum and Feachem (1985) include descriptive studies of the prevalence of helminth infections in areas where untreated excreta is used as fertilizer. The risks to consumers and farm workers exposed to untreated or treated excreta used as fertilizer for crops are shown in Table 3.11 mainly from elderly studies. Exposure to *treated* nightsoil was in one study significantly associated with a reduction in Ascaris and hookworm infection compared with the exposure to untreated nightsoil. Baseline prevalence rates in the study groups were similar.

A more recent study from Viet Nam focused on the traditional treatment of faeces before use as fertilizer (Humphries et al, 1997). Women helped prepare and distribute the faeces on the crops. Most used fresh faeces but some used wet, dry or composted faeces for fertilizer. Dry faeces mixed with ash were distributed with a shovel or by hand, whereas wet faeces were mixed with water and poured onto the plants using dippers or buckets. Treatment of faeces consisted of mixing dry faeces with ash and putting the mixture in a pit along with coconut and banana leaves and organic waste. Most families used the faeces before it had been stored for 4 months (Hanoi Medical School, 1994: unpublished observations). Women who reported using fresh faeces as fertilizer had significantly higher hookworm egg counts ($p<0.05$) than women who used treated faeces or who did not use human faeces as fertilizer. Since the result was not reported separately for those who used treated faeces, a conclusion about the effectiveness of treatment of faeces on hookworm infection cannot be drawn. There is some indication, from the presented data that treatment of faeces may reduce the number of women with higher intensity infections. The epidemiological study showed that the use of fresh faeces as fertilizer was associated with increased intensity of hookworm infection when compared to the use of treated faeces or no use of excreta as fertilizer. Comparisons are lacking between those who used treated faeces with those who did not use excreta. Excreta treatment or other management procedures to reduce risk should always be advocated before use. Treatment with ovicide could be considered (as occurs in parts of China), alongside consideration of technologies for dry excreta storage and composting or thermophilic digestion.

Comparisons can be made with epidemiological studies, when raw wastewater has been used. These have revealed an increased risk for parasitic infestations and other enteric diseases associated with raw wastewater use in agricultural irrigation (Katzenelson *et al.*, 1976; Fattal *et al.*, 1986; Cifuentes, 1998; Srikanth and Naik, 2004; Se further WHO Guidelines for the Safe Use of Wastewater in Agriculture, Vol 2). Several foodborne outbreaks of disease have been associated with the irrigation of crops with sewage-impacted water (Colley, 1996;

Hardy, 1999; Doller *et al.*, 2002) The treatment options of wastewater, *e.g.* in storage lagoons, seems to be efficient in reducing the transmission of pathogens and is also relevant for the judgements in relation to greywater use (Shuval, 1991; Blumenthal *et al.*, 2001).

Table 3.11 Studies of risks to consumers and workers exposed to untreated or treated excreta in agriculture – prevalence of parasitic infections in populations exposed vs non-exposed [a]

Author (year)	Health outcome	Excreta quality	Population group	Prevalence of infection or re-infection after treatment (%)	Relative risk	Study group and comparison
Anders[34] (1952)	Ascaris	Overflowing septic tank contents and excreta composted with animal manure	School children	(i) 14.3 vs 2.9 (ii) 6.7 vs 2.9	4.9[b] 2.3	School children (i) in urban area where vegetables fertilized with overflowing septic tank contents vs in sewered urban area (ii) in rural area where human faeces composted with animal manure or applied at 'appropriate' time to vegetables vs in sewered urban area
Kreuz[35] (1955) citing Harmsen[36] (1953)	Ascaris	Untreated	Farming population	52 vs 0	52.0[b]	Families using excreta as garden fertiliz er vs families using animal manure as garden fertilizer
Kozai[37](1962)	Ascaris (+ve conversion after chemotherapy	Ovicide treated	Farming population	(i) 27.4 vs 41.5 (i) 35.9 vs 41.5	0.66 (0.51-0.86)[c]** 0.86 (0.69-1.07)	(i) Ovicide-treated nightsoil vs untreated nightsoil (ii) Ovicide-treated nightsoil (commercial preparation) vs untreated nightsoil
Kutsumi[38] (1969)	(i) Ascaris (prevalence) (ii) Trichuris (prevalence)	Ovicide treated	Farming population	A 11.0 vs 17.5 B 21.0 vs 33.1 C 14.6 vs 11.6 (ii) 47.1 vs 65.0	0.63 (0.40-0.98)[c]* 0.63 (0.44-0.92)* 0.79 (0.53-1.18) 0.73 (0.64-0.82)	(i) A After nightsoil treatment with ovicide plus chemtherapy vs before treatment B After nightsoil treatment with ovicide vs before treatment C Chemotherapy alone (ii) After nightsoil treatment plus ovicide vs before treatment
Kozai[37](1962)	Hookworm (+ve conversion after chemotherapy	Ovicide treated	Farming population	(i) 17.7 vs 32.2 (ii) 17.4 vs 32.2	0.55 (0.36-0.81)[c]** 0.54 (0.36-0.81) **	(i) Ovicide-treated nightsoil vs untreated nightsoil (ii) Ovicide-treated nightsoil (commercial preparation) vs untreated nightsoil
Kutsumi[38] (1969)	Hookworm (+ve conversion after chemotherapy	Ovicide treated	Adults	7.1 vs 12.5	0.56 (0.27-1.16)	Families using ovicide-treated nightsoil vs untreated nightsoil
Humphries[39] (1997)	Hookworm	Treatment with ash and storage	Adult women		P<0.05	Egg counts in women using fresh faeces vs women using treated faeces or not using faeces as fertilizer

a Comparision is exposed vs unexposed for untreated excreta use; comparison is treated vs untreated excreta or after vs before treatment for treated excreta
b crude relative risk calculated from prevalence or incidence data reported
c relative risk and 95% confidence interval calculated from prevalence or incidence rates and population data reported
* Statistical significance

3.6 Quantitative microbial risk analysis

Use of excreta and greywater is currently mainly practised on the household and community levels and to a lesser extent as part of overall large-scale management schemes. In both applications it is necessary to ensure a realistic protection, which is a reflection of exposure and the disease prevalence within a given area. A key objective of urine collection and use is to minimise fecal cross-contamination. The same applies for greywater. Thus, the baseline in assessing both these types of systems is the degree of fecal contamination that occurs. The general recommendation of urine storage is mainly aimed at reducing the microbial health risks from consuming urine-fertilised crops. It will also reduce the risk for the persons handling and applying the urine. In greywater use systems, the main objective is to minimize contact with the untreated greywater in larger systems as well as in small-scale applications. Subsurface wetlands as well as resorption systems will minimize contact. Greywater treatment in pond systems will reduce the content of potential pathogens present. In relation to guideline values, it is essential to consider the phenomenon of overestimating the health risks due to re-growth of indicators. Elevated indicator values should therefore always be assessed in relation to potential fecal input.

In one large scale collection system for source-separated urine the fecal cross-contamination was estimated to be within a range of 1.6 – 18.5 mg of faeces per L of urine, with a mean of 9.1± 5.6 mg/L, thus resulting in about a 5 log lower concentration of potential pathogens than in faeces. The fecal contamination of greywater was at a similar level, estimated to correspond to a fecal load of 0.04 g $person^{-1}$ day^{-1}. These values were based on a relationship with measurements of coprostanol as norms. Comparing these levels with the amounts occurring in wastewater, they correspond to a conservative risk level that is at least 1000-fold lower than wastewater. Using this relationship a combination of treatment and other management options would need to achieve a 2.9 (maximum) or 1.6 (minimum) log reduction for protozoa and a 3.3 (maximum) or 2.3 (minimum) log reduction for viruses in urine and greywater to reach a 10^{-6} DALYs median annual risk per person based upon the total exposure volume. For faeces, however, the corresponding values would be about 5 logs higher.

The performance targets that apply to guarantee a technological safety and barrier effect against microbial hazards should ensure that the collection and handling of excreta and greywater is done so as to minimize exposure to untreated material, even if the relative risks are substantially lower in urine and greywater. Small communities have limited capacity and capability to run individual system assessment and management plans. Therefore, if necessary, competent authorities should support the implementation and function as reference points (see further institutional aspects). Performance targets assist in the selection and use of control measures that are capable of preventing pathogens from breaching the technical and handling barriers. In addition, they should minimise overall exposure to untreated excreta. Simple design and handling practices are central in this respect.

3.6.1 Example of risk calculation for a greywater scenario

In greywater systems, microbial hazards mainly emanate from faecal cross-contamination, e.g. from anal cleansing, misplaced excreta, hygiene practices, contaminated laundry and other sources. Pathogens may also be introduced through food cleansing and preparation.

Exposure to potential pathogens in greywater may occur through direct contact (see example excreta), through contaminated drinking water sources and ground water recharge where the exposure depends on drinking water treatment. Greywater used for irrigation may, depending on distribution practices, expose people via inhalation of aerosols as well as through consumption of irrigated contaminated crops in a similar way as for wastewater (Guidelines for the Safe Use of Wastewater in Agriculture).

Ottosson, (2003) made a risk calculation for a greywater system with pre-treatment in a settling tank and activated sludge step before the water entered a pond system. The index organisms chosen were *Salmonella*, *Campylobacter*, rotavirus and the parasitic protozoa *Giardia* and *Cryptosporidium*. The performance of the treatment steps was assessed and modelled for treatment barrier efficiency. The assessed barriers and transmission pathways are summarised in Table 3.12.

Table 3.12. Transmission pathways for exposures to used or discharged greywater and health-related modelling units (HMUs) involved, except treatment

Exposure	HMUs involved	Volume ingested	References
1) Drinking recharged groundwater (yearly risk from 365 exposures).	Dilution[a], unsaturated zone[a] and saturated zone*	$e^{(6.87 \pm 0.53)}$ mL day^{-1} [b]	[a](Asano et al., 1992), [b](Roseberry & Burmaster, 1992)
2) Accidental ingestion to treated greywater (one time exposure)		1 mL $exposure^{-1}$	
3) Ingestion from a field irrigated with treated greywater (yearly risk from 26 exposures)	Survival on grass*	1 mL $exposure^{-1}$	
4) Ingestion/inhalation of aerosols	Tank*	$e^{(-4.2 \pm 2.2)}$ mL [c, d]	[c] (Dowd et al., 2000), [d] (Kincaid et al., 1996)
5) Swimming in recreational water receiving treated greywater.	Dilution	$e^{(3.9 \pm 0.3)}$ mL	
6) Untreated greywater, *Salmonella* regrowth	Sink trap* (growth)[e]	0.1 g	[e] (II)

The fecal load in the greywater in the system was assessed based on a range of microbial indicators (*E coli*, enterococci, sulphite reducing clostridia, coliphages) and chemical markers (fecal sterols). The faecal input to the greywater was estimated to be 0.04 ± 0.02 g faeces per person per day from the quantification of the fecal sterol coprostanol, compared to 65 g and 5.2 g per person per day using *E. coli* or enterococci as indicators (see Table 3.13).

Table 3.13. Indicator occurrence, measured as excreted organisms per person per day, and the corresponding fecal load (g per person per day) in greywater (flow 64.9 L per person per day) (from Ottoson and Stenström, 2003)

Organism	Indicators in greywater	Excretion rate (per gram of faeces)	Faecal load (g per person per day)
E. coli	$10^{8.8}$ cfu	10^{7} cfu	65
Faecal enterococci	$10^{7.2}$ cfu	$10^{6.5}$ cfu	5.4
Coprostanol	0.56 mg	12.74 mg	0.04

E. coli and enterococci may grow on the easily degradable organics in greywater. Their use as indicators for fecal load would therefore result in overestimation to the order of 1000 and 100 times, respectively. In the QMRA, coprostanol was used as a conservative biomarker.

Decay rates were either based on available information for the organism in question, or based on enterococci as the index organism for *Salmonella* and *Campylobacter*, somatic and F-specific bacteriophages for rotavirus and spores of sulphite reducing anaerobic bacteria for *Giardia* and *Cryptosporidium* (oo)cysts.

Four exposure scenarios were validated for the applied risk estimates in the QMRA.

1. Accidental ingestion of 1 mL treated greywater, P_{out}.
2. Accidental ingestion of 1 mL treated greywater, P_{in}.
3. Yearly risk from direct exposure after irrigation with greywater, assuming 1 mL intake day^{-}, 26 days year^{-1}.
4. Yearly risk from drinking groundwater recharged from the pond as described in Asano *et al*. (1992) with modifications on the environmental die-off data and the water intake

The different approaches used were:

1. Measuring faecal contamination in greywater with coprostanol concentrations and using epidemiological data to assess risks as in Höglund *et al*. (2002).
2. Using a dose–response model derived from occurrence of fecal enterococci in marine waters (Kay *et al.*, 1994) assuming an exponential probability of infection.
3. Using fecal enterococci as index organisms for the presence of *Salmonella* in

greywater based on sediment experiments.

In all exposure scenarios, the largest risk emanated from rotavirus partly due to its excretion in higher numbers, at least during the acute phase, compared to the other pathogens included in the study. *Giardia* cysts and *Cryptosporidium* oocysts have low infectious doses but were not excreted in sufficient amounts to constitute a substantial health problem with the low fecal load registered. A shift upwards will naturally occur with higher fecal loads, anticipated in other types of settings. The average number of (oo)cysts in untreated greywater was simulated to approximately 0.002 (oo)cysts mL^{-1} compared to 1.7 rotavirus particles mL^{-1}. Ottosson and Stenström (2003) suggested that guidelines for greywater recirculation and use should not be based on thermotolerant coliforms as a hygienic parameter, because of the large input of non-fecal coliforms and/or growth of coliforms unless their concentrations are adjusted for false-positive levels. The overestimation of the fecal load, and thus risk, resulting from these indicator bacteria is to some degree compensated for by the higher susceptibility to treatment and environmental die-off. The risk model based on fecal enterococci densities correlated well to the risk from viruses, which is supposed to be the most prominent in a system without disinfection due to their high excretion rates, environmental persistence and low infectious doses.

3.4.2 Example of risk calculation for collection and use of diverted human urine

The scenario considered for the urine diversion included the following transmission pathways (from Höglund *et al.* (2002)):

1. Ingestion of urine. Workers may be accidentally exposed while cleaning blocked toilet drains, through ingestion in the case of splashing while emptying the collection tank or by contaminated hand to mouth contact.
2. Ingestion of stored urine. Farmers or other workers may accidentally ingest urine during handling of stored urine.
3. Inhalation of aerosols while fertilising crops with urine.
4. Consumption of crops fertilised with urine.

The densities of pathogens are dependent on the prevalence of enteric diseases and the quantity of faeces that cross-contaminates the urine. For the collected urine, two different scenarios that will have an effect on pathways 2, 3 and 4 above were considered:

- ***worst case scenario:*** an epidemic had taken place right before the tank was emptied, resulting in no substantial inactivation in the collection tank; and
- ***sporadic case scenario:*** the events of enteric diseases were evenly spread out during the time of collection (one year), thus continuous inactivation occurred within the collection tank.

The risk calculations for stored urine considered the survival of microorganisms in urine (Höglund *et al.*, 2002; Höglund & Stenström, 1999). The validations were performed at 4°C and 20°C. The effect of storing urine from 1 to 6 months was investigated in the QMRA.

The volume accidentally ingested was assumed to be 1 mL in pathways 1 and 2, as used for unintended ingestion of reclaimed wastewater (Asano *et al.*, 1992).

For the inhalation of aerosols the method of fertilising crops is important. In large-scale applications many farmers may use equipment (i.e. a splash plate) that spread the urine approximately one meter above the ground. In this case, the created drops are large (>1 mm) and will quickly settle. As a worst-case scenario, spray irrigation was assumed and the risk for people living in the vicinity was calculated using a Gaussian plume model (Matthias, 1996) where X is the number of pathogens per m^3 at a specific location, resulting in a person ingesting 0.83 m^3 of aerosol per hour (Dowd *et al.*, 2000) at a distance of 100 m from the point of spraying. No die-off of microorganisms was assumed to occur within the aerosol, which might be more conservative than reported (Ijaz *et al.*, 1994; Mohr, 1991).

To assess microbial risks from crop ingestion Shuval *et al*. (1997) measured 10.8 mL of wastewater to attach to 100 g of lettuce and Asano *et al*. (1992) assumed 10 mL to be ingested by consuming crops irrigated with wastewater. *Campylobacter jejuni*, *Cryptosporidium parvum* and rotavirus were chosen as index. Pathogen PDFs in urine were calculated from lognormal distributions of fecal cross-contamination, excretion days and excretion numbers (Table 3.14). The inactivation data were based on (Asano *et al.*, 1992; Petterson & Ashbolt, 2001) and use of a uniform triangular distribution for rotavirus inactivation on crops (k-values recalculated to T_{90}-values) during the period between fertilization and harvest. Since protozoa and bacteria reportedly have shorter survival times on crops than viruses, the same T_{90}-values were used as a conservative assumption for these microbial groups.

Table 3.14. PDFs used to calculate microbial health risks from various exposures of source-separated human urine (Höglund* et al.*, 2002)

	C. jejuni	*C. parvum*	Rotavirus
Mean pathogen density [no L^{-1}] (*worst-case* scenario)	4 564	152	243 793
T_{90} in urine 4°C [day^{-1}]	1	Triang(17,29,79)	no reduction
T_{90} in urine 20°C [day^{-1}]	1	5	Triang(15,35,42)
T_{90} on crop [day^{-1}]	Triang(1.4, 2.2, 3.0)	Triang(1.4, 2.2, 3.0)	Triang(1.4, 2.2, 3.0)
Dose-response model	β-Poisson N_{50}=896, α=0.145	Exponential k=238.6	β-Poisson N_{50}=5.6, α=0.265

Range of 1.6-18.5 mg.L^{-1} (mean 9.1± 5.6 mg.L^{-1}) of faeces cross-contaminated the separated urine. Triang - Triangular PDF; minimum, most likely and maximum given. T_{90} – time for 90% reduction in viable pathogen numbers.

1. Risk from exposure to urine that has not been stored: The estimated risks of infection by the three index pathogens following accidental ingestion of 1 mL of unstored urine is illustrated in Figure 3.3. In the case of an epidemic where no inactivation was assumed to occur in the collection tank, viruses may pose an unacceptably high risk and bacteria pose a greater risk than protozoa. Similarly, for sporadic cases evenly spread out during the year, the risk for viral infection is the same as during an epidemic at 4°C (probability of infection, P_{inf} = 0.81), since very low inactivation of rotavirus occurs at this temperature, and slightly lower at 20°C (P_{inf} = 0.55). In contrast, the risk for bacterial infection decreases significantly if sporadic rather than epidemic cases occur, since a large proportion of the added bacteria would die during collection at the two temperatures. For *Cryptosporidium* the risk is approximately 1 log_{10} lower if there are sporadic instead of epidemic cases in the population connected to the tank, and the collection occurs at 4°C ($P_{inf} = 3.1 \times 10^{-6}$). Collection at 20°C decreases the risk another log_{10} ($P_{inf} = 4.5 \times 10^{-7}$).

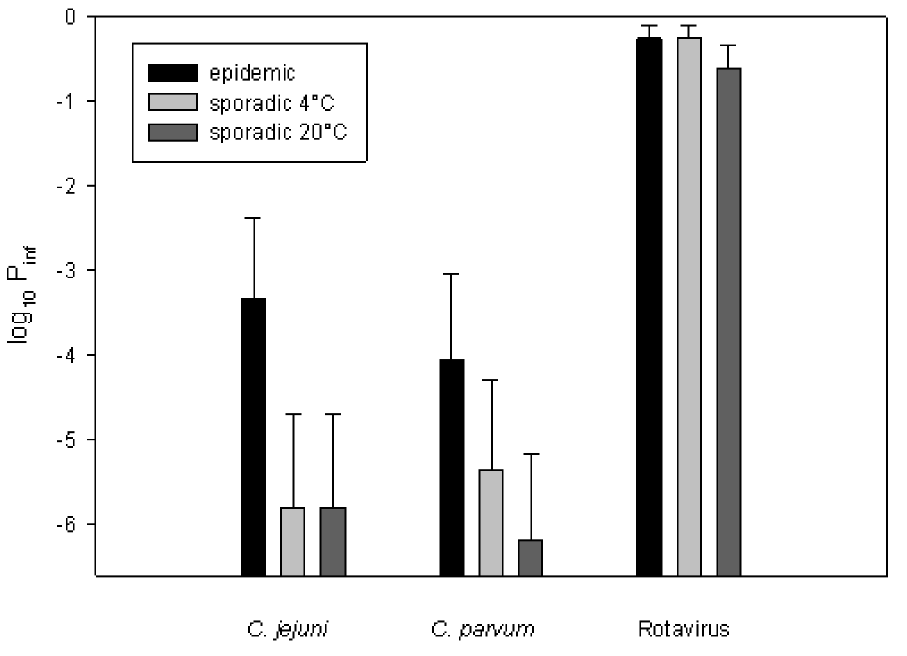


Figure 3.3. Probability for infection (5% - 95%) by *Cryptosporidium parvum* and rotavirus following ingestion of 1 ml stored urine (1 or 6 months, 4°C or 20°C) (Höglund *et al.*, 2002)

2. Risk from exposure to stored urine: Due to the inactivation of pathogens, risks associated with accidental contact decrease during storage. The exception was rotavirus during storage at 4°C, which yields the same risk independent of storage time. The risk for *Campylobacter* infections was negligible after 1 month of storage at either 4°C or 20°C. If the urine is stored at 20°C the mean risk from *Cryptosporidium* is only 4.7×10^{-11} after only one month, whereas if stored at 4°C for one or six months risks will be 1.1×10^{-5} and 2.8×10^{-9}, respectively. The risk for viral infection was much higher than the risk for protozoan infection, and inactivation was only measured in urine stored at 20°C. After 6 months at 20°C the mean risk was estimated to be less then 10^{-4} (Figure 3.4).

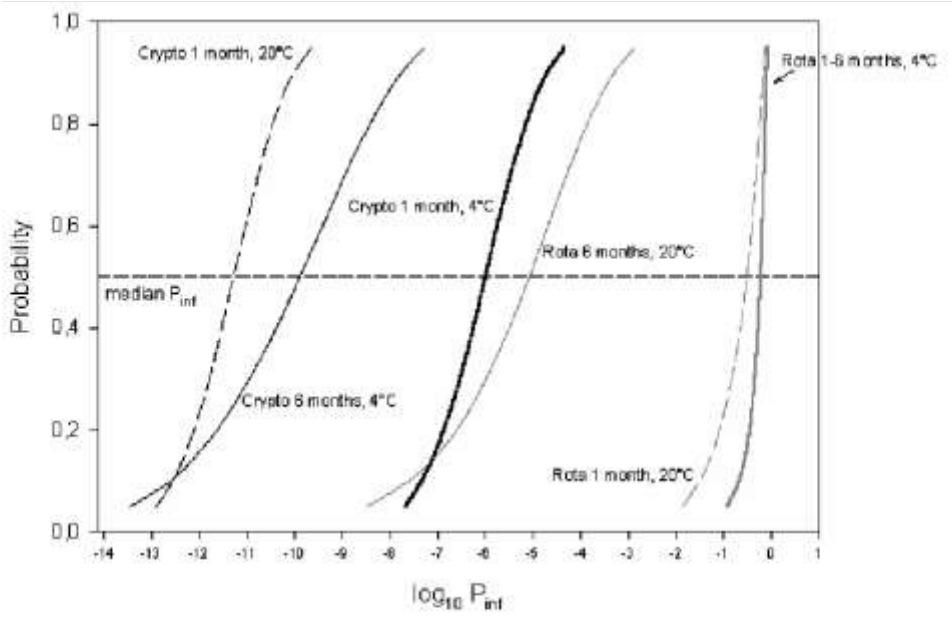


Figure 3.4. Mean probability of infection by pathogen after accidental ingestion of 1 mL of unstored urine for epidemic and sporadic scenarios and 4°C or 20°C during collection.

3. Risk from exposure to aerosols: The risk for infections through aerosols during the distribution of urine on arable land mainly depended on the urine storage time. For people within an area of 100 m from the application of urine, the risks for bacterial and protozoan infections were low at any of the storage conditions. However, the risk for rotavirus infection was 0.72 for unstored urine or urine stored at 4°C, if an epidemic was assumed. If the urine was stored for 6 months at 20°C before fertilisation the mean estimated risk was reduced to 3.3×10^{-5}.

4. Risk from exposure to fertilised crops: Possible risks following consumption of crops fertilised with fresh urine and urine stored for 1 or 6 months at 4°C and 20°C were examined. Crop withholding periods between 1 and 4 weeks were considered, to take into account the time between fertilisation and crop consumption. The implications of different withholding periods following consumption of 100 g of raw crop are illustrated in Fig 3.5.After one week between fertilisation and consumption the risk for bacterial and protozoan infections was very low ($<10^{-5}$), whereas a 3-week withholding period is needed for the risk of viral infection to reach the same level.

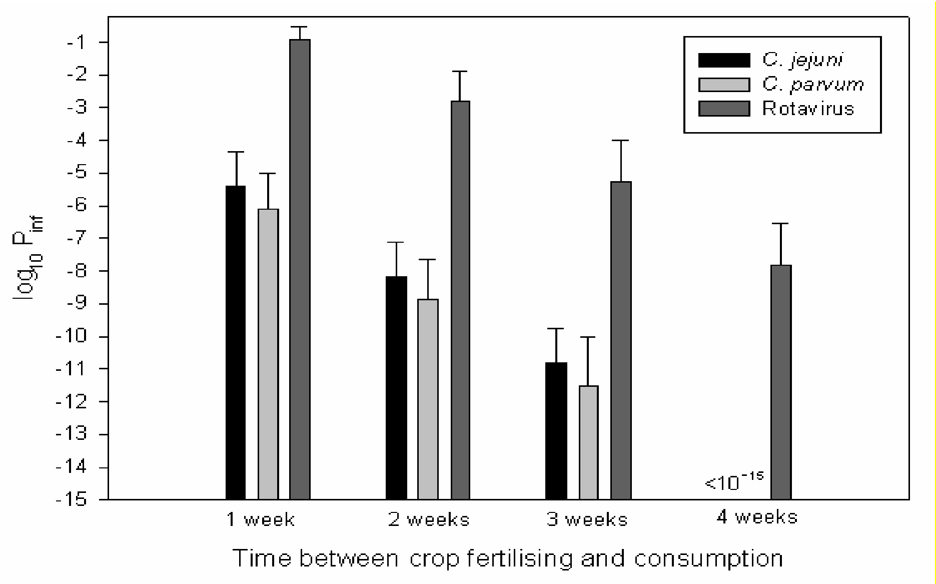


Figure 3.5. Mean probability of infection by pathogens following ingestion of crop fertilised with unstored urine with varying withholding periods. Error bars indicate one standard deviation (Höglund *et al.*, 2002)

3.4.3 Example of risk calculation for stored but otherwise untreated excreta

A theoretical assessment was performed to evaluate risks for the transmission of infectious disease related to the local use of faeces as a fertiliser. The faeces were collected from dry urine-diverting toilets in single-family households and used in their own gardens. The faeces were only treated by means of storage in the temperature range up to 20 ^{o}C prior to the application. The pH was 6.7 – 8.4 and the dry matter content 20-40%. The material was not fully stabilized. The following scenarios were evaluated:

1. Application directly without storage
2. Application after storage for 6 months
3. Application after storage for 12 months
4. Application and incorporation after storage for 6 months
5. Application and incorporation after storage for 12 months

Application meant that the faeces was evenly distributed as top-soil and incorporation that it was worked into the upper layer of the soil, resulting in a faeces to soil ratio of around 1:100.

Hazard identification. Fecal-orally transmitted organisms were included, such as *Salmonella*, EHEC, rotavirus, Hepatitis A virus, *Giardia*, *Cryptosporidium* and the helminth *Ascaris*.

Assessment of exposure. Each organism was modelled by probability density functions (PDFs), for incidence in the population, excretion and duration of infection as well as die-off in the storage container and die-off in the soil after application of the material in the garden. It was based on official reporting of incidence data for an European country adjusted for the underestimation (Wheeler *et al.*, 1999). Using the resulting incidence, the probability that the faeces in the storage container from a typical household contained at least one type of pathogen was calculated to be 11.6%. The die-off of pathogens is based on collected information from both human faeces and other materials, like animal manure and sewage sludge to establish PDFs for the inactivation. The human exposure was assumed to take place as accidental ingestion of small amounts of faeces or faeces and soil mixture during:

- Emptying of the container and distribution of the material
- Recreational activities in the garden
- Gardening

The faeces-soil intake was based on a literature study by Larsen (1998) where children are estimated to ingest around 200 mg of soil per day on an average with an absolute maximum of 5-10 g per day, occurring once every ten years by exposure each day. It was further assumed that adults ingest 15-50% of this amount, with a maximum of 100 mg per day. The container is emptied once a year, assuming that only adults are exposed.

The dose-response relationships. Information is virtually missing for the susceptible parts of the population, such as children, the elderly or immuno-compromised and is not accounted for in the models. The less susceptible parts of the population were not accounted for either. The uncertainty of the parameters in the dose-response relationships was included.

Microbial risk calculation. Calculations were made for two main scenarios i) applying the incidence in the population (unconditional) and ii) assuming that one member of the family actually had an infection during the period of collection (conditional).

The variations in the risk for infection depend on the organism in question. Some *Salmonellae* are able to re-grow in stored, but unstabilized materials, especially if they are partially moisturized. Viruses and parasites generally have longer survival in the environment as well as lower infectious doses, which resulted in high risks for rotavirus, the protozoa and *Ascaris*. The difference in risk between the conditional and unconditional scenario was 1-4 order of magnitudes and the difference between typical (50%) and worst case (95%) varied from none to 5 orders of magnitude depending on organism. For the unconditional scenario the risk is never higher than 4×10^{-2} (rotavirus). Only after 12 months of storage and taking incidence into consideration the risks are $<10^{-4}$ for all organisms, excluding *Ascaris* (P_{inf} 8×10^{-4}), when emptying the container and applying the material.

In approximately 9 out of 10 gardens, the use of stored faeces as a fertiliser would not result in any risk of infection. Rotavirus and *Giardia* would be the most frequently occurring pathogens based on the incidence in the population.The die-off during storage would be substantial for, *e.g. Salmonella*, while especially *Ascaris*, have a much higher persistence in faeces. The pathogen with the most severe symptoms, EHEC, was reduced to very low levels during storage in the toilet and did not constitute any significant risk in any of the scenarios. Use of material directly after emptying the toilet container resulted in median risks exceeding 10^{-4} for the unconditional scenario regarding rotavirus and the parasites. After one year of storage however the median risks were below this level for all pathogens, also in the conditional scenario (*i.e.* a family member excreting the pathogen) with the exception of *Ascaris*. The worst-case risks, however, exceeded the level regarding the viruses and parasites. The exposure to faeces in terms of ingested amounts was lower during recreational activities or gardening than when emptying the container due to the mixing with soil. Since the frequency of exposure was higher in the former exposure, the annual risks were, however, almost as high.

4. TARGETS FOR HEALTH PROTECTION.

4.1 Introduction

This chapter deals with the health based targets and related recommendations for health protection. The potential to relate protective measures responding to health risks to guideline values or good practice is associated with a realistic level of compliance. Guideline values are less possible to measure in small-scale settings, where procedural and best practice guidance may offer a better approach.

Harmonization with the “Guidelines for the safe use of wastewater in agriculture” has been pursued. Furthermore, issues specific to the safe use of excreta, urine and greywater are pointed out. Obviously, the risk for further transmission of pathogens through the environment by using un-sanitised faeces may lead to increased disease prevalence. Different subsequent treatment steps of human excreta and other barriers against human exposure are considered the most important precautions against such transmission (Chapter 5).

Health-based targets needs to be an integral part of the overall health policy, accounting for the trends and overall importance of different transmission pathways both on an individual and household level as well as in the overall management of public health. To ensure effective health protection the targets needs to be realistic, relevant to local conditions and commensurate to available resources. Health-based targets aim to improve public health outcomes and should assist in determining health safeguards, interventions and control measures, mainly in relation to treatment, exposure control and safe handling.

The concept of health-based targets applies universally, irrespective of the level of development. Although the targets tend to be set at the national level, they are applied at the local level. Risks are subject to variability in performance of technical installations and the frequency of exposure. It is, therefore, necessary that recommendations are practical and account for factors of variability. *Ad hoc* events as well as behaviour may affect the health outcomes, thus, a practical “multiple barrier approach” is needed.

The targets are also part of an overall management and evaluation strategy in relation to health protection goals and implementation of the scheme to use excreta and greywater. In these contexts any long-term effects also need to be considered. Where possible the health-based targets should relate to quantitative risk assessment, taking into account the local conditions and hazards. Epidemiological information on local handling and use of excreta and greywater is scarce and scattered. The available epidemiological information on wastewater and sludge use can partly be applied in this context.

Regulations and guidelines are currently more and more frequently based on the risk concept. By applying quantitative microbial risk assessments, partly based on predictions and assumptions, sanitation systems can be evaluated and compared to establish limits for acceptable risks. The treatment can also be adapted to reach a set of acceptable limits. Risk assessments can thus be made quite site-specific, depending on information regarding e.g. the local health status of the population and behavioural patterns. An approach towards acceptable local risk limits, applicable for sanitation system where the use of the excreta products is practised, are related to subsequent reduction or increase in the prevalence of infections. In developing countries with low sanitary standards, the goal will be to reduce the number of infections by implementing sanitation *per se* including introducing new, more efficient treatment or exposure reduction alternatives, combined with other interventions related to safe treatment and storage, hygiene/health education as well as provision of safe water supply.

The present guidelines for the use of treated excreta and greywater focus on treatment, but also include other technical, practical and behavioural aspects, intended to minimise the risk for disease transmission. Rules of thumb considered to obtain acceptable low risks are presented, without a bias towards numeric limits in small-scale systems.

4.2 Type of targets applied

Health-based targets may either be based on epidemiological evidence, risk assessment predictions, guideline values or performance. All have certain strengths and limitations. Health outcome targets based on epidemiological evidence are resource-dependent and need a developed institutional verification system. Risk assessment targets are based on validated predictions but may overestimate the factual risks, due to variability in behaviour and exposure. Guideline values often have limitations in expressing the risks for a broad range of organisms. Performance targets in many instances have limitations in expressing the risks, if solely based on indicator organisms and should preferably be based on a range of pathogens in relation to their persistence under adverse treatment or environmental conditions. The latter should ensure that the performance assessment also reflect other, more vulnerable microbial groups, and different conditions. All targets relate to variability and shorter periods of decreased efficiency in a number of processes. The targets should also reflect background rates of disease. Performance assessment does not normally need to be based on experimental evaluations carried out on site, but can also be approximated based on international evaluations that take on board the prevailing local conditions. It is, however, of value to link treatment performance with competent national or regional authorities or institutions. Different types of targets have been defined in WHO guidelines and are briefly summarized in Table 4.1 in relation to excreta and greywater use.

Table 4.1. Nature, application and assessment of health based targets.

Type of targets	Nature of targets	Application	Assessment
Health outcome; epidemiology based	Reduction in detected disease incidence or prevalence	Microbial with high measurable disease burden. Here, through direct impact of as food-associated disease.	Public health surveil-lance; analytical epidemiology. • Often difficult to assess actual impact • Multiple factors
Risk-based assessment	Tolerable level of risk due to direct or indirect exposure. Relationship to other alternative use, exposure or sanitation facilities in local context	Microbial hazards in situations where disease burden can not be directly measured.	Quantitative microbial risk assessment • Predictive tool • Needs to be related to local exposure

Quality targets	Guideline values	Measurements of pathogens or indicator organisms, *less applicable* in: • Small scale application • For urine due to rapid die-off of indicators • For greywater due to growth resulting in overestimation of risk	Measurements mainly valid in assessment of technical performance of treatment of faeces. Should mainly be applied within a similar framework as for the assessment of wastewater use. Ensure validity of measurement parameters. (System validation). Limitations in reflecting general pathogen risks
Performance targets	Generic performance targets for removal of groups of organisms Customized targets. Guideline values less applicable	Microbial contaminants	Compliance through system assessment Review by public health authorities. Checklists Recommended for small-scale applications. Limitations based on the local conditions
Specified technology	Authorities specify specific processes or system approaches to address constituents handling practises or behaviours in relation to health effects	Health effects in small scale settings	Compliance assessment Operation and handling

In relation to the use of treated excreta and greywater the health-based targets are related to exposure barriers and treatment performance in the overall risk assessment and management. Monitoring guideline values are mainly applicable in larger systems. The treatment alternatives give different levels of safety as barriers against pathogen transmission. Performance targets are further specified below, while the technical options and management aspects are dealt with in Chapter 5. Numerical guideline values can mainly be used for validations, but should be applied with caution and if applied always within a context of management strategies of risk.

4.3 Tolerable burden of disease and health-based targets

The most applicable metric for comparing and expressing the burden of disease is the disability adjusted life years (DALYs) (Murray and Acharya, 1997), (see further Chapter 2).

In the 3rd edition of Guidelines for Drinking-water Quality (WHO, 2004a) a tolerable burden of waterborne disease from drinking water consumption of ≤ 10^{-6} DALY loss per person per year was adopted. This level can be compared with a microbial self-limiting diarrhoea and the corresponding case fatality rate of approximately 1×10^{-5} at an annual disease risk of 1 in 1000 (10^{-3}), which also is about 1×10^{-6} DALY (1 µDALY) per person per year (WHO, 2004a). Since food crops fertilised with treated excreta or irrigated with treated greywater, especially those eaten uncooked, are also expected to be as safe as drinking-water, the same high health protection level of $\leq 10^{-6}$ DALY per person per year is applicable in this context as well.

For operational purposes the summary of treatment efficiency and other management options to reduce the level of pathogens and subsequent the degree of exposure should aim at this target. Campylobacter, Cryptosporidium and rotaviruses were chosen and used as index organisms (WHO Drinking water Guidelines (2004a), Havelaar and Melse (2003)). An example of a calculation of the values for tolerable infection risk is given in the Vol 2 of this series, "WHO Guidelines for the safe use of wastewater in agriculture", and is also applicable in this context. The cited values accounting for the infection ratios are:

Rotavirus (industrialized countries)	1.4×10^{-3}
Rotavirus (developing countries)	7.7×10^{-4}
Campylobacter	3.1×10^{-4}
Cryptosporidium	2.2×10^{-3}

Thus, the tolerable disease risks for these organisms are in the range 10^{-3}−10^{-4} per person per year. This is a conservative value, given that the current global incidence of diarrhoeal disease in the age group 5−80+ is in the range 0.1−1 per person per year (WHO Guidelines Vol 2 " safe use of wastewater in agriculture").

Reliable epidemiological data are scarce for the safe use of excreta and greywater. This range of tolerable disease risk can instead be deduced based on the quantitative microbial risk analysis, where the subsequent risks in relation to exposure for faeces, urine and greywater was exemplified in relation to this risk level in Chapter 3 both in relation to its final use and the handling. In this context the current guidelines harmonize with the health aspects of the use of treated wastewater in agriculture, where the epidemiological appropriate level of tolerable risk for both crop consumers (unrestricted irrigation) and field workers (restricted irrigation) has been identified (See WHO !"Guidelines for waste water use in agriculture").

In chapter 5 the combination of different primary and secondary treatment barriers that can achieve a risk reduction to the health target level is exemplified. Knowing (or estimating) the volume of treated excreta or greywater that a person is exposed to in the handling chain or that remains on the crop (ml or mg per 100 g crop), following fertilization, the withholding time and the die-off in the field determine the required degree of pathogen reduction to achieve the tolerable additional disease burden of $\leq 10^{-6}$ DALY per person per year. This step requires the numbers of pathogens present in the untreated excreta or greywater to be known or estimated. The use of *E coli* numbers, in this context for verification monitoring, is mainly applicable for the treated excreta, while it is not appropriate for the collected urine due to a rapid die-off in this. In greywater, sometimes a regrowth of *E coli* occur, which may over-estimate the risks if the verification monitoring is based on this parameter. The application of *E coli* guideline values, which is applicable for wastewater use, is suggested to be applied cautiously for greywater. If applied, they will give a level of additional safety in this application, since the faecal load is usually 100 – 1000 times less than in wastewater. For helminthic infections, the treatment verification monitoring level in terms of number of helminth eggs is exemplified in Table 4.3. The health-based protection to achieve the required pathogen reduction can either be achieved by the treatment alone or in combination with other health protection measures. A guideline value of $< 10^3$ per 100 ml is suggested for unrestricted irrigation with wastewater. The target value of $< 10^3$ *E. coli* per gram of treated faecal material applied as fertilisers would then ensure a comparative level of safety against bacterial pathogens and probably against viral pathogens as well. A clear relationship for parasitic protozoa does not exist.

The pathogen reduction that is needed in the on-site and off-site treatment of excreta is expressed as performance targets. This target for treated excreta is based on a withholding time in the on-site treatment for 12 - 18 months treatment (if only storage apply) and is combined with a stated period between application and harvest that will further minimise risks to the consumers. This period is applicable since the treated excreta is applied as a fertilizer and soil conditioner, and thus differ from the wastewater guidelines, where the water is mainly added for irrigation purposes. The verification in relation to target values for *E coli* and helminths are however applicable for faeces after the storage/treatment.

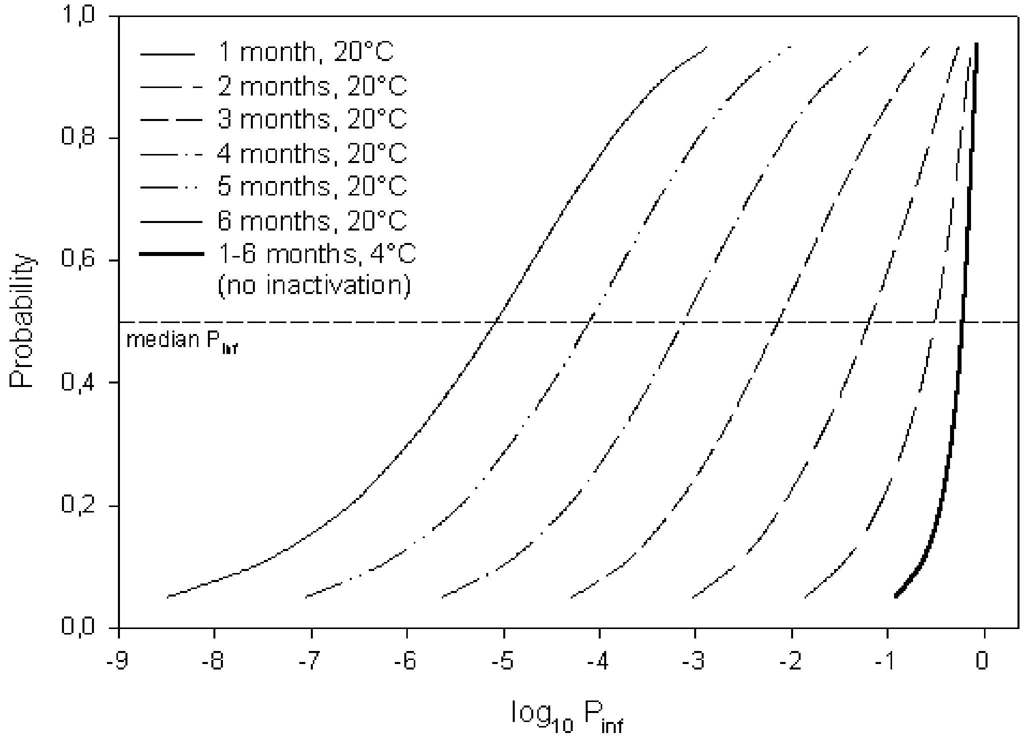
In the on-site treatment at least one year of storage at ambient temperature, without additional treatment, is also in accordance with the guidelines value for helminths stated in WHO (1989). Strauss and Blumenthal (1990) suggested that one-year was sufficient under tropical conditions (28-30°C), whereas at lower average temperatures (17-20°C) 18 months would be needed.

Storage is especially beneficial in dry and hot climates where rapid desiccation of the material takes place and low moisture contents aid pathogen inactivation. Esrey *et al.* (1998) stated that there is rapid pathogen destruction at moisture levels below 25%, and that this level should be aimed for in dry urine diversion toilets that are based on dehydration (i.e. storage). Low moisture content is also beneficial in order to reduce smell and fly breeding). Re-growth of bacterial indicators and some pathogens (EHEC and Salmonella) may however occur after application of moisture (water) or if the material is mixed with a moist soil as indicated by results reported by Austin (2001) while the reduction of viruses always relates to the storage period and conditions. Fig 4.1 exemplifies this with a risk calculation for rotavirus in relation to storage.

Protozoan cysts are sensitive to desiccation and this also affects their survival on plant surfaces (Snowdon *et al.*, 1989; Yates and Gerba 1998). Normal moisture levels do not inactivate *Ascaris* eggs. Values below 5% are needed (Feachem *et al.*, 1983) but information for the corresponding inactivation time is currently lacking.

To treat excreta, thermophilic digestion (50°C for 14 days) or composting in aerated piles for one month at 55-60°C (+ 2-4 months further maturation) is a recommended and generally accepted procedure (WHO, 1989) that will satisfy the reduction of pathogens to achieve the health target values. Recommendations for treatment of e.g. faecal sludge and organic household waste (food waste) also rely on such temperatures (EC, 2000). Under controlled conditions composting at 55-60°C for 1-2 days is sufficient to kill essentially all pathogens (Haug, 1993). The longer periods stated gives a handling margin. It is common that cold zones are formed within the digested or compost material, resulting in local areas with less inactivation.

Figure 4.1. Effect of storage time on rotavirus risk (from Höglund et al, 2001)



4.4 Microbial reduction targets

The approach adopted in these Guidelines focuses on risks from the handling chain of excreta and greywater to the consumption of food crops eaten. Data on the health effects were used to assess the infectious disease and harmonized with the approach in the Vol 2 "WHO Guidelines for the Safe Use of Wastewater in Agriculture". The analyses took account of consumption of crops eaten raw and of risks from direct contact with treated excreta (involving involuntary soil ingestion). Direct correlations in relation to the relative risks between wastewater and treated excreta applications have not been performed in practice. However the Guideline values presented are in the same range. This is exemplified for Ascaris in Box 4.1.

Based on the exposure scenario for wastewater irrigation it was shown that, in order to achieve $\leq 10^{-6}$ DALY per person per year for rotavirus, a total pathogen reduction of 6 log units for the consumption of leaf crops (lettuce) and 7 log units for the consumption of root crops (onions) is required. Applying these values to excreta, this implies about 8-9 logs reduction for faeces (assuming a 100 fold dilution). The risk related to source separated urine and greywater relates to the faecal cross-contamination that occurs. Based on measurements, this cross-contamination is usually much less than 10^{-4} of excreta; thus similar to a 100-fold dilution of wastewater with a need for a pathogen reduction of < 4−5 log units as the performance target for unrestricted irrigation to achieve the tolerable additional disease burden of $\leq 10^{-6}$ DALY per person per year. An example: In source-separated urine the fecal cross-contamination was estimated to be within a range of 1.6 – 18.5 mg of faeces per L of urine, with a mean of 9.1± 5.6 mg/L, thus resulting in about a 5 log lower concentration of potential pathogens than in faeces. The faecal contamination of greywater was at a similar level, estimated to correspond to a faecal load of 0.04 g $person^{-1}$ day^{-1}. Because the risks associated with exposure to rotavirus are estimated to be the highest, this level of pathogen reduction will provide sufficient protection against bacterial and protozoal infections.

Box 4.1 Comparative performance targets for viable helminths eggs in wastewater, faecal matter and faecal sludges

- Wastewater performance target for unrestricted irrigation ***≤ 1 egg /L***.
- **Rw** rate (water requirements expressed in m/year), compare with an egg application rate on the soil, **Re**, of: **Re < 10^7 Rw** (eggs/ha·y)

The use of treated excreta or faecal sludge should not enrich the soil with a higher egg concentration than the quantity permitted by the application of irrigation water. The sludge application rate depends on the egg concentration in the total solids **Eg** (expressed as eggs/g TS). The sludge quantity applied to the soil **Rs**, and meeting the WHO guideline, thus amounts to: **Rs < Re/Eg = 10^7 Rw/Eg** (g TS/ha·y) (TS-total solids)

Yearly helminths load from irrigation (using an average of e.g. 500 mm/year): ≤ ***500 helminths eggs/m²*** ∴ ≤ **500 HE/m² · year permissible**Application of treated faecal matter (same quantities as in good agricultural practice of manure): ***10 t manure/ha*year at 25 % TS (1 kg/m², year***

= 250 g TS/m²*year
[[helminths eggs] tolerable ≤ 500/250 = ***2 helminths eggs/g TS***
(with 1000 mm/year [4 helminths eggs/g TS).

•Guideline value set to **1 helminth egg/g TS** (to account for variability).

These log unit pathogen reduction levels may be achieved by the application of appropriate health protection measures, each of which has its own associated log unit reduction or range of reductions (Table 4.2). A combination of these measures is used such that, for all combinations, the sum of the individual log unit reductions for each health protection measure adopted is equal to the required overall reduction. Several of the steps are similar to what has been presented in Vol 2 of the Guidelines (like the post harvest procedures), while the pathogen reduction due to treatment will differ. Treated excreta are always applied as a fertilizer in combination with plantation or during the initial growth period. Thus a withholding period of normally more than one month applies, except for application with greywater that is normally done for irrigation purposes.

Table 4.2Pathogen reductions achievable by various health protection measures

Control measure[a]	**Pathogen reduction (log units)**	**Notes**
Excreta storage without fresh additions	6	The required pathogen reduction to be achieved by excreta treatment refers to the stated storage times and conditions in Table 4.4 - 4.6 without addition of fresh untreated excreta (Faeces and urine) as based on measurements and risk calculations. Pathogen reductions for different treatment options are presented in chapter 5) and examples of risk calculations in Chapter 3.
Greywater treatment	1->4	Values relate to the treatment options described in Chapter 5. Generally the highest reduction related to exposure is related to subsurface irrigation
Localized (drip) irrigation with urine (high-growing crops)	2- 4	Crops, where the harvested parts are not in contact with the soil
Materials directly worked into the soil	1	Should be done at the time when faeces or urine is applied as an fertilizer
Pathogen die-off (withholding time 1 month)	4->6	A die-off of 0.5−2 per day is cited for wastewater irrigation The reduction values cited here are more conservative to account for a slower die-off of a fraction of the remaining organisms. The log unit reduction achieved depends on climate (temperature, sunlight intensity, humidity), time, crop type, etc. a with-holding time apply
Produce washing with water	1	Washing salad crops, vegetables and fruit with clean water
Produce disinfection	2	Washing salad crops, vegetables and fruit with a weak disinfectant solution and rinsing with clean water
Produce peeling	2	Fruits, root crops
Produce cooking	6−7	Immersion in boiling or close-to-boiling water until the food is cooked ensures pathogen destruction.

Sources: Beuchat (1998); Petterson & Ashbolt (2003); NRMMC & EPHCA (2005).

In Vol 2 of these guidelines it was stated that in order to achieve the health-based target of $\leq 10^{-6}$ DALY per person per year for rotavirus, wastewater treatment is required to reduce the *E. coli* count by 4 log units or a similar pathogen reduction. The corresponding reduction of raw faecal material will thus be 6 log units while normally a 2 log unit reduction suffice for urine and greywater.

4.4.1 Microbial reduction targets for helminth eggs

Microbial reduction targets for protection against helminthic infections are based on the results of microbiological studies. A complication normally occurs in the measurements, since investigations related to risk should be based on the number of viable eggs. In the microbiological investigations the reduction refers to the percentage of these out of the total egg population and not the factual numbers. Volume 5 of this edition of these Guidelines discusses sampling and analytical procedures for determining small numbers of helminth eggs in treated wastewaters.

An effective health protection measure for removing helminth eggs from the surface of crops eaten uncooked (e.g. lettuce leaves) is washing the crop in a weak detergent solution (washing-up liquid is suitable) and rinsing thoroughly with safe drinking water. Helminth eggs are very "sticky," so they easily adhere to crop surfaces; the detergent solution releases them into the aqueous phase. This control measure reduces the number of eggs on the crop surface by 1−2 log units (B. Jiménez-Cisneros, personal communication, 2005).

Treatment processes to achieve, or partially achieve, the reductions exist. Different investigations shows that in collected and stored dry faecal materiala time period of between less than 6 to 12 months suffice dependent on the local conditions. Other treatment options which has given a substantial reduction is exemplified in Chapter 5. Table 5. X. If the number of helminth eggs is ≤1 per g TS, then no additional health protection measures are required in relation to this group of organisms, as the target value is automatically achieved (this is the typical situation in most industrialized countries).

4.5 Verification monitoring

To ensure that health-based targets are being met, it is important to develop performance targets that can be monitored. There are three types of monitoring:

- Validation is the initial testing of a system to prove that the system as a whole and individual components are capable of meeting the performance targets and thus health-based targets.
- Operational monitoring is the routine monitoring of parameters that can be measured rapidly (i.e. through tests that can be performed quickly, parameters measured online, or through visual inspection) to inform management decisions to prevent hazardous conditions from arising.
- Verification monitoring is done periodically to show that the system is working as intended. This type of monitoring usually requires more complicated or time-consuming tests that look at parameters such as bacterial indicators (*E. coli*) or helminth eggs.

Monitoring is further discussed in chapter 6. Verification monitoring requirements for treated faecal sludge, urine and greywater are discussed below.

4.5.1 Treatment of excreta and greywater

Pathogen numbers in raw or treated faecal sludge, excreta or greywater are not measured routinely (if at all) and the performance of the on-site treatment used to partially or wholly ensure $\leq 10^{-6}$ DALY per person per year cannot be determined on the basis of pathogen verification monitoring but instead on validation of the general treatment efficiency. Verification monitoring is mainly applicable in larger collection systems or when a secondary off-site treatment after collection from a number of individual units is made. Here the microbiological performance of the larger system or the off-site treatment is done by determining the treated material for its content of a pathogen indicator bacterium such as *E. coli*. The same apply for larger greywater collection and treatment systems, where the effluent may be monitored for verification purposes. For large-scale systems or when secondary off-site treatment is necessary the values in Table 4.3 apply.

Table 4.3 Guidelines values for verification monitoring in large-scale treatment systems of Greywater, Excreta and Fecal Sludges aimed for use in agriculture.

	Helm. Eggs (No/ g TS or Liter)	E. coli (No/100 ml)
Treated faeces and fecal sludge	<1/ g TS	<1000□□□/g TS
Greywater for use in: • Restricted irrigation • Irrigation of crops eaten raw – Unrestricted irrigation	< 1/L □□□□□□□□□□□□□□□□□□□ □□□□□□□□□□□□□□□□□□□ <1/L	$<10^5$ * • Relaxed to $<10^6$ when exposure is limited or regrowth is likely □□□□□□□□□□□□□□□□□ $<10^3$ • Relaxed to $<10^4$ for high growing leaf crops or drip irrigation

*These values additionally acceptable due to the high re-growth potential of *E coli* and other fecal coliforms in greywater.

When other exposure barriers are appropriate and can be enforced, the above guideline values can be relaxed based on national or local decisions, for example when a public body regularly controls the allocation and has the legal authority to require that crop restrictions be followed and when a strong project management exist. For fruits and vegetables special restrictions may apply. For sub-surface adsorption systems for greywater, no guideline values apply. However, the siting of such systems should not interfere with ground water quality. For pond systems for greywater treatment, the risks for mosquito breeding should be evaluated and pond systems should not be promoted under circumstances where vector breeding may have a substantial impact on health without appropriate mosquito control measures.

4.5.2 Other health protection measures

The operational health protection measures include the agricultural use practises and the preceding treatment and transport. Even if a treatment is validated and verification monitoring has been done process steps or handling practises may periodically malfunction, resulting in a fertiliser product that is not completely safe. Therefore, additional measures should be taken in order to further minimise the risk for disease transmission. These measures are applicable independent of the scale of the system (for small systems special considerations are stated in paragraph 4.5.3). Thus:

- Excreta and faecal sludge should be treated before it is used as fertiliser and the treatment methods validated.

- Equipment used for e.g. transportation of un-sanitised faeces should not be used for the treated (sanitised) product.

- Precautions related to the handling of potentially infectious material should be taken when applying faeces to soil,. These precautions include personal protection and hygiene, including hand washing.
    - Treated excreta and faecal sludge should be worked into the soil as soon as possible and not be left on the soil surface.
    - Improperly sanitised excreta or faecal sludge should not be used for vegetables, fruits or root crops that will be consumed raw, excluding fruit trees.
- A withholding period between fertilising and harvest apply for treated excreta and faecal sludge. This period should be at least a month.
- The treatments in Table 4.4 can be used as off-site secondary treatment (material removed from toilet and primary treated at household level).

Composting is mainly recommended as an off-site secondary treatment at large scale, since the process may be difficult to run. Temperatures >50°C should be obtained during at least one week in all material. Times may need to be modified based on local conditions. Large systems need a higher level of protection than what is required at the household level and additional storage adds to safety. Storage at ambient conditions is less safe, but acceptable, if the conditions above apply. Shorter storage times can be applied for all systems in very dry climates where a moisture level <20% is achieved. Sun drying or exposure to temperatures above 45^{o}C will substantially reduce the time. Re-wetting may result in growth of *Salmonella* and *E coli*.

Table 4.4. Additional treatments for excreta and fecal sludge off-site, at collection and treatment stations from large-scale systems (municipal level). Run in batch mode without addition of new material

Treatment	**Criteria**	**Comment**
Alkaline treatment	pH >9 during >6 months	Temperature >35°C and/or moisture <25%. Lower pH and/or wetter material will prolong the elimination time.
Composting	Temperature >50°C for >1 week	Minimum requirement. Longer time needed if temperature requirement can not be ensured
Incineration	Fully incinerated (<10% carbon in ash)	

4.5.3 Excreta - Small systems.

For smaller systems validation together with operational monitoring apply. In small-scale systems in developing countries it is impractical or even impossible to relate performance to actual guideline values. Validation of dry collection of excreta from latrines in Viet Nam showed that it is possible to achieve a total die-off of *Ascaris* ova and indicator viruses (>7 log_{10} reduction) within a 6 month period (mean temperature 31-37°C, pH in the fecal material 8.5-10.3 and the moisture content 24-55%). (Carlander and Westrell, 1999; Chien *et al.*, 2001). At lower temperatures (approx 20 ^{o}C) longer storage times apply for a total destruction of Ascaris (Phi et al, 2004) although similar high reductions were found under cold conditions in China (Wang et al, 1999; Lan et al, 2001). Addition of a pH-elevating chemical like lime or ash has been shown to enhance the inactivation of pathogens in small systems. Other methods to reduce the pathogen content rely on elevation in temperature, and desiccation or prolonged storage at ambient conditions.

The practical options depend on the scale of the system, i.e. at household or municipal level. On the latter, more technical options are available. Implementation of treatment on an individual level has added difficulties involving people's habits and practices sometimes established long ago. The scale also influences the combinations of suitable primary and secondary treatments and barriers. Handling systems need to be adapted to the different treatments. Within the operational monitoring the on-site storage conditions stated in Table 4.5 apply.

Table 4.5. Recommendations for storage treatment of dry excreta and fecal sludge before use at the household and municipal levels. No addition of new material.

Treatment	**Criteria**	**Comment**
Storage ; Ambient temperature 2-20 ^{o}C	1.5 - 2 years	Will eliminate bacterial pathogens; re-growth of *E coli* and *Salmonella* may be considered if rewetted; will reduce viruses, and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers
Storage Ambient temperature >20-35 ^{o}C	> 1 year	Inactivation of *Clonorchis* and *Opisthorchis* eggs will occur within days; substantial to total inactivation of viruses, bacteria and protozoa; Inactivation of schistosome eggs (<1 month); Inactivation of nematode (roundworm) eggs, e.g. hookworm (*Ancylostoma*/*Necator* and whipworm (*Trichuris*); Survival of a certain percentage (10-30) of *Ascaris* eggs (≥4 months) while a more or less complete inactivation of *Ascaris* eggs will occur within 1 year; (Strauss 1985)
Alkaline treatment	pH >9 during > 6 months	If temperature >35°C and moisture <25%, Lower pH and/or wetter material will prolong the time for absolute

		elimination.

For operational verification the following points should further be considered for on-site storage and collection.

- Primary treatment (in the toilet) includes storage and alkaline treatment by addition of ash or lime.
- pH elevation to above 9 is preferred which can be obtained by addition of lime or ash (200-500 ml; enough to cover the fresh faeces) of alkaline material after each defecation. (Total elimination may not occur, but a substantial reduction will be achieved).
- Secondary off-site treatments as for larger systems (municipal level) including alkaline treatments, composting or incineration (Table 4.4) can be applied off-site and give a further reduction when municipal collection is organized.
- In small-scale systems (household level), the faeces can be used after primary on-site treatment if the criteria in Table 4.2 are fulfilled.

As for larger collection and application systems the following apply:

- Personal protection equipment should be used when handling and applying faeces.
- Faeces should additionally be mixed into the soil in such a way that they are well covered.
- A withholding period of one month should be applied, i.e. one month should pass between fertilisation and harvest.

4.5.4 Operational monitoring for urine in large and small-scale systems

The major risks in relation to collected urine relates to the faecal cross-contamination in the source-separating toilets. Specific recommendations for large-scale systems may need to be adapted based on local conditions accounting for behavioural factors and the technical systems selected. If a system is clearly mismanaged, i.e. faeces can be seen in the urine bowl or other routes of cross-contamination are observed, prolonged storage apply. The recommended storage times related to pathogen reduction at different temperatures are based on validation monitoring and risk assessment calculations (Höglund *et al.*, 2002). The operational verification is divided between larger systems with a central collection (Tab 4.6). These values are applicable for all systems where the collected urine is mixed between several individual units and subsequently used as a fertilizer for crops.

For individual one family system and when the urine is used solely for fertilization on individual plots, no storage is needed.

Table 4.6. Recommended guideline storage times for urine mixture[a] based on estimated pathogen content[b] and recommended crop for larger systems[c]. (Adapted from Jönsson et al.*, 2000 and Höglund, 2001)*

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

[a] Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l.
[b] Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognised for causing any of the infections of concern.
[c] A larger system in this case is a system where the urine mixture is used to fertilise crops that will be consumed by individuals other than members of the household from which the urine was collected.
[d] Not grasslands for production of fodder.
[e] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

During storage the urine should be contained in a sealed tank or container. This prevents humans and animals to come in contact with the urine and hinders evaporation of ammonia decreasing the risk of odour and loss of nitrogen. The urine should preferably not be diluted. Concentrated urine provides a harsher environment for microorganisms, increases the die-off rate of pathogens and prevents breeding of mosquitoes; thus, the less water that dilutes the urine the better.

- For vegetables, fruits and root crops consumed raw, a one-month withholding period should always be applied.
- In areas where *Schistosoma haematobium* is endemic, urine should not be used nearby freshwater sources.
- Urine should be applied close to ground and preferably mixed with or watered into the soil.

The general recommendations for urine are

(1) direct use after collection or a short storage time is acceptable on the single household level
(2) storage should be made for larger systems (where the time and conditions, stated in Tab 4.6, should be followed),
(3) an interval of at least one month should be observed between fertilisation and harvest,
(4) additional stricter recommendations may apply on a local level, in the case of frequent fecal cross-contamination. The recommendations for storage times is directly linked to agricultural use and choice of crop (Table 4.6).

Additional practices to minimise the risks include the following:

- When applying the urine precautions related to the handling of potentially infectious material should be taken. These precautions could, *inter alia*, include wearing gloves and thorough hand washing.
- The urine should be applied using close-to-the-ground fertilising techniques avoiding aerosol formation.
- The urine should be incorporated into the soil. This could in practise be done mechanically or by subsequent applying irrigation with water.

5. HEALTH PROTECTION MEASURES

On-site sanitation installations are likely to grow in numbers and their use and performance is essential to achieve the targets for tolerable disease burden. The growing quantities of excreta and greywater will have to be dealt with. The excreta from these systems, i.e. from private and public toilets and from septic tanks, as well as the greywater from the households' are, in most cases, still disposed off untreated. Sanitation upgrading must aim at not only providing the sanitary facilities at home or in public, but also cater for the sustainable management of excreta and greywater, including collection, transport, treatment and use as fertiliser, soil conditioner, irrigation or for other purposes such as service water or groundwater recharge.

To achieve this by a combination of health protection measures needs to be taken that produce an overall pathogen reduction that differs due to the different system components. A pathogen reduction based on the occurrence in fresh excreta will be in the order of two log units higher than in wastewater, thus in the range of 8-9 logs units, while for source-separated urine and greywater it is substantially lower, based on the measured faecal cross-contamination in these system components, about 3-5 log units. In comparison to the safe use of wastewater (Vol 2, WHO Guidelines for the safe use of wastewater, excreta and greywater), most of the health protection measures are similar but some fundamental differences exist, for example the potential higher concentration of pathogens in excreta, but lower in urine and greywater and that a substantially higher die-off may be achieved in the field, since fertilization mainly occur during planting and does not continue for irrigation purposes up to harvest, like for wastewater. Otherwise the control measures are similar and include:

- crop restriction;
- excreta and greywater handling and application technique;
- pathogen die-off between fertilization and consumption;
- food preparation measures (washing, disinfecting, peeling, cooking);
- human exposure control and hygiene education;
- excreta and greywater treatment.

In planning for or assessing sanitation systems and health protection measures it is of prime importance to wherever possible and feasible, include all components, e.g. the sanitary facilities (toilets and latrines at private and public levels) and the treatment facilities, pit emptying, collection, transport, in the considerations.

Health hazards associated with excreta and greywater use are mainly linked to the occupational hazard of those who handle it, and the risk linked with potentially contaminated products. Technology alone does not break the cycle of disease transmission and accompanying ill health, if hygiene awareness in a community is low. Poor domestic and personal hygiene diminish the positive impact of improved excreta and greywater management on community health. The treatment needs to fulfill a reliable reduction of different groups of pathogens where the waste should meet the quality guidelines and performance criteria. If this is done, disease transmission to those collecting and using the material as fertilizers as well as those consuming fertilized products will be reduced to acceptable levels.

Measures that prevent pathogens from reaching the produce being farmed or, by selection of appropriate crops (bioenergy crops or crops aimed for further processing for example), may prevent pathogens from affecting the consumer and taking advantage of the positive nutritional effect of reliable fertilisers.

The feasibility and efficacy of any combination of the health protection measures will depend on local factors like:

- availability of resources (like fertilisers);
- existing social and agricultural practices;
- demand for fertilised food and non-food crops;
- existing patterns of excreta-related disease;
- health education and possibilities to ensure the efficacy of selected health protection and control measures

Especially for greywater use secondary risks may arise from the creation of habitats that facilitate the survival and breeding of vectors and a subsequent increase in the transmission of vector-borne diseases. Conducting an analysis of the storage, treatment and irrigation options will identify the key risk points, which is an important step in identifying which health protection measures are likely to be appropriate.

5.1 Specific considerations and exposure control in the use of urine, faeces and greywater.

Treatment of excreta could be either on-site directly in the toilet in relation to defecation, (e.g. by prolonged storage without mixing with untreated material, dryness of the material or the addition of a pH elevating compound) or secondary off-site where the material is collected from the toilet and treated in a controlled way with the purpose to reduce pathogens to acceptable limits. System designed for primary on-site treatment will always be beneficial from a health point of view, since this gives an initial pathogen die-off, that can be further corrected with off-site treatment if the monitoring (Chapter 6) shows that this is not sufficient in the local setting.

If secondary off-site excreta treatment is needed to reduce the risks to an acceptable level but not applicable from a logistic point of view, some of the other health protection measures should be stressed, for example suitable crop restriction can make it unnecessary to take any further measures to protect the public. On the other hand, if existing practices make it impossible to implement and enforce crop restrictions effectively, recourse must be made to other methods. Small-scale use schemes for excreta and greywater are often subsistence-level operations that are difficult to control in relation to treatment efficiency. Measures often need to be developed for minimization of risk to the individual, including health education and improved domestic water supplies.   It is often desirable to combine several health protection measures. For example, crop restriction may be sufficient to protect consumers but will need to be supplemented by additional measures to protect collectors or workers. Sometimes, partial treatment to a less demanding standard may be sufficient if combined with other measures.

Use of excreta and greywater is currently mainly practised on the household and community levels and to a lesser extent as part of overall large-scale management schemes. In both applications it is, however, necessary to ensure a realistic protection. The targets should account for the exposure and the disease prevalence within a given area. A key objective of urine collection and use is to minimise fecal cross-contamination. The same applies for greywater. Thus, the baseline in assessing both these types of systems is the degree of fecal contamination that occurs. The general recommendation of urine storage is mainly aimed at reducing the microbial health risks from consuming urine-fertilised crops. It will also reduce the risk for the persons handling and applying the urine. In greywater use systems, the main objective is to minimize contact with the untreated greywater in larger systems as well as in small-scale applications. Subsurface wetlands as well as resorption systems will minimize contact. Greywater treatment in pond systems will reduce the content of potential pathogens present. In relation to guideline values, it is essential to consider the phenomenon of overestimating the health risks due to re-growth of indicators. Elevated indicator values should therefore always be assessed in relation to potential fecal input.

As an example: in source-separated urine the fecal cross-contamination was estimated to be within a range of 1.6 – 18.5 mg of faeces per L of urine, with a mean of 9.1± 5.6 mg/L, thus resulting in about a 5 log lower concentration of potential pathogens than in faeces. The fecal contamination of greywater was at a similar level, estimated to correspond to a fecal load of 0.04 g person^{-1} day^{-1}. Comparing these levels with the amounts occurring in wastewater, they correspond to a conservative risk level that is at least 1000-fold lower than wastewater. Using this relationship a combination of treatment and other management options would need to achieve a 2.9 (maximum) or 1.6 (minimum) log reduction for protozoa and a 3.3 (maximum) or 2.3 (minimum) log reduction for viruses in urine and greywater to reach a 10^{-6} DALYs median annual risk per person based upon the total exposure volume. For faeces, however, the corresponding values would be about 5 logs higher.

The performance targets that apply to guarantee a technological safety and barrier effect against microbial hazards should ensure that the collection and handling of excreta and greywater is done so as to minimize exposure to untreated material, even if the relative risks are substantially lower in urine and greywater. Small communities have limited capacity and capability to run individual system assessment and management plans. Therefore, if necessary, competent authorities should support the implementation and function as reference points (see further Chapter 10, institutional aspects). Performance targets assist in the selection and use of control measures that are capable of preventing pathogens from breaching the technical and handling barriers. In addition, they should minimise overall exposure to untreated excreta. Simple design, handling practises and exposure control are central in this respect.

5.1.1 Exposure control.

A systematic survey of a local system can identify potential risk factors and suggest counteractions to avoid pathogen exposure, either by means of reducing contact with the material or ways to decrease the number (concentration) of pathogens in the material that will be handled. Reducing contact includes factors like closed systems and ensuring adequate storage times, wearing personal protection, using proper handling tools and reducing later contact in the field by working the excreta into the soil. General handling precautions are often defined as additional measures and not as proper barriers.

Treatment of exreta could be related to containment directly in the toilet in relation to defecation, e.g. by additives that will enhance the die-off of pathogens or prolonged storage, or by further treatment off-site in a controlled way with the purpose to reduce pathogen concentrations to acceptable limits. Esrey *et al*. (1998) stated that a combination of safe storage and fast destruction of the pathogens in excreta are needed in order to prevent contamination of the environment.

Inactivation of pathogens will also occur on agricultural land after application of the excreta as fertiliser and on crops that may have become contaminated by the application of fertiliser during crop development or from splashes from the soil during heavy rains. This inactivation over time and due to prevailing environmental conditions functions as an additional barrier against exposure from handling and consumption of crops and for humans and animals entering the fertilised field. The additional reduction with time, constituting a "barrier function in agriculture" is of additional importance, especially for crops that are to be consumed raw. Also for a safe handling of other crops and reducing cross-contamination during food preparation the withholding period (time between fertilisation and harvest) is of importance.

In the use of treated excreta, urine or greywater certain key risk points and exposure pathways need to be considered. These are elaborated later in this chapter. Furthermore, the risks are related to the degree of fecal cross-contamination of untreated faeces as well as the efficiency of treatment. The factors in table 5.1 apply for most systems, but are of major concern in larger systems where several units or users are involved. The handling is further dealt with in section 5.2.3 of this chapter.

Table 5.1. Major exposure points for the reuse of excreta and greywater.

Risk activity	*Major Exposure Route*	*Groups at Risk*	*Risk Management considerations*
Faeces Dry collection, (1) Faecal sludge (2) Wet systems (3) Urine (4) Greywater (5)			
Emptying the collection chamber/vessel (1-4)	Contact,	Entrepreneurs, Residents, Local communities	Provision of protective clothing and suitable equipment. Persons involved Training Facility should optimize on-site treatment Design of facility and selection of technology to facilitate safe emptying. Minimize spillage

Risk activity	*Major Exposure Route*	*Groups at Risk*	*Risk Management considerations*
Transportation (1-5)	Contact, Secondary spread through equipment	Entrepreneurs, Local communities	Avoid spillage Equipment not used for other purposes without proper disinfection/cleaning
Off-site secondary treatment facility (1-3) (5) Ponds	Contact (All) Vectors	Workers Nearby communities	Ensure treatment efficiency Protective clothing Facility should be fenced off. Ensure no access for children Consider and minimize vector transmission Ensure no recreational activity and consider vectors (5)
Application (1-3, 5)	Contact, Inhalation,	Entrepreneurs, Farmers, local communities	Use “close to the ground application”, Work the material into the soil directly and cover. Reduce access should be ensured if quality is not ensured. In such cases applications to parks, football fields or where the public have access should be avoided Protective clothing for workers, Minimum one month between application and harvest
Crops Harvest Processing Sale (1-5)	Consumption Handling	Consumers Workers Vendors	Crops eaten raw pose the most risk, Industrial crops, biofuels or crops only eaten after cooking less risks, Adequate protective clothing (gloves, shoes), Provide safe water in markets for washing and refreshing vegetables
Consumption (1-5)	Consumption	Consumers	Practicing good personal, domestic and food hygiene Cooking food thoroughly

This chain of events can further be illustrated with the example of fecal sludge emptying and use as a fertilizer in agriculture (Figure 5.1, [Strauss *et al.*, 2003]).

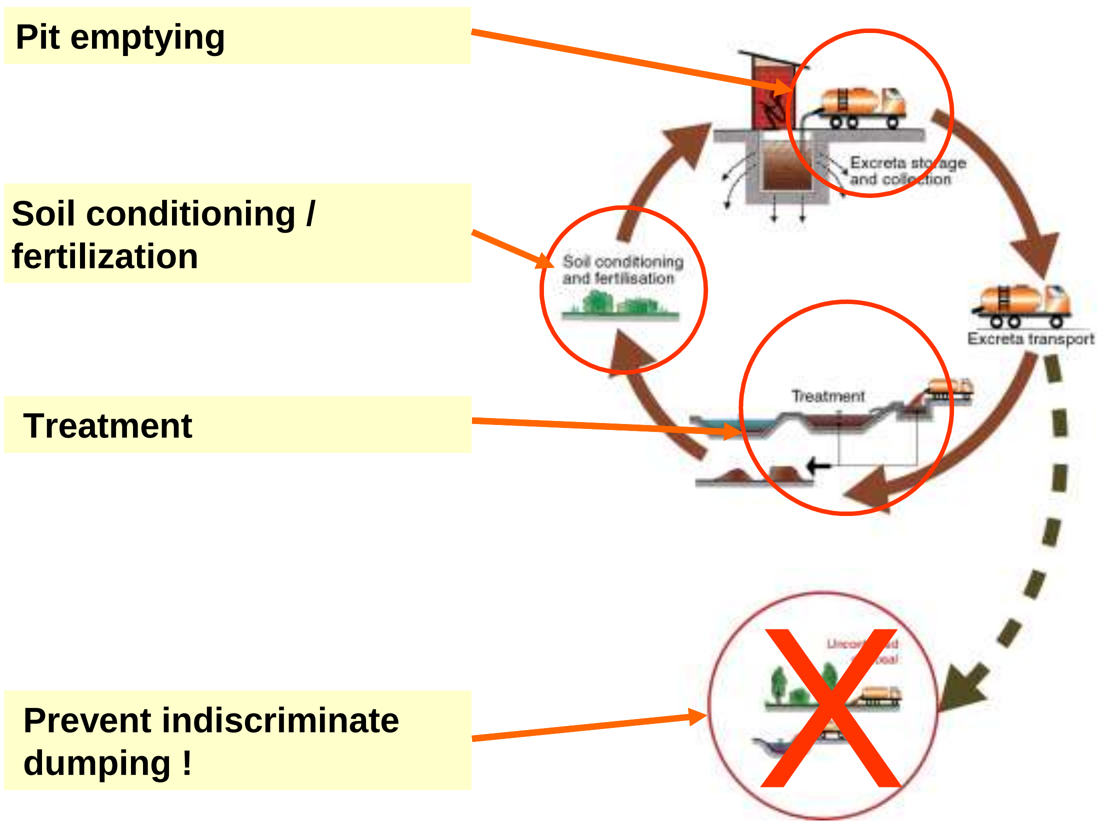


Fig.5.1Critical control points in preventing enteric disease transmission in faecal sludge management

5.1.2 Exposure control at agricultural sites or site of use.

Exposure control related to the field and the use of products relates to (1) crop restriction and (2) application techniques, (3) field workers, (4) the with-holding period (period between fertilisation and harvest), and (5) die-off of organisms before consumption. This section essentially follows the messages given in Vol 2 of the WHO Guidelines for the safe use of Wastewater, excreta and greywater with slight modifications.

(1) Crop restrictions.

- Restricted use does not normally need to be applied for treated urine and greywater, due to a low degree of faecal crop contamination. For treated excreta or faecal sludge crop restriction may be directed towards the use on non-food crops (e.g. cotton and "bioenergy" crops such as rapeseed or fast-growing woods, like Salix plantations used for biofuel). It may also be applied on crops processed before consumption (wheat); or crops that have to be cooked (potatoes). The exposed group comprises those who work in the fertilised fields. Crop restriction still normally requires that the excreta have been treated before use.
- If greywater may be heavily contaminated, vector breeding are likely to occur or pond treatment not feasible, subsurface horizontal irrigation in the rootzone of selected plants is a feasible option.

(2) Application technique.
The same application techniques as for wastewater are applicable for irrigation with greywater (Guidelines Vol 2). Localized irrigation both with greywater and with urine is estimated to provide an additional pathogen reduction of 2−4 log units, depending upon whether the harvested part of the crop is in contact with the ground or not (NRMMC & EPHCA, 2005). Urine should always be applied close to the ground and worked into the soil to minimize nitrogen losses, which further reduce the risks. Treated excreta or faecal sludge can essentially follow the local practices applied for animal manure. The material should however, be worked into the ground and topsoil both as a benefit for plant uptake and to reduce direct contact with any potentially remaining pathogens.

(3) Field workers.
Agricultural fieldworkers are at high potential risk especially for parasitic infections. The application of treated human excreta is often made on a small scale and should give a much better situation than indiscriminate open-air defecation. In larger scale applications, like the use of treated faecal sludge, exposure to helminth infection can be eliminated or reduced by an appropriate treatment combined with the use of appropriate protective clothing (i.e. shoes or boots for fieldworkers). These health protection measures have not been quantified in terms of pathogen exposure reduction but are expected to have an important positive effect. In larger scale applications fieldworkers should have appropriate sanitation facilities and water for drinking and hygienic purposes. Effective hygiene promotion programmes targeting fieldworkers, linked to agricultural extension activities or other health programmes is beneficial.

(4) Withholding period.
It is always recommended that a period of at least 1 month is applied between application of urine or treated excreta or faecal sludge. In the Vol 2, Vaz da Costa Vargas, Bastos & Mara (1996) is cited, showed that cessation of irrigation with wastewater for 1−2 weeks prior to harvest can be effective in reducing crop contamination by providing time for pathogen die-off. A further reduction will occur during a 30 day period. Risk calculations has been done for urine application to the field sowing that 1 month will be much beyond the risk level of 10^{-6} DALY for pathogenic bacteria, viruses and parasitic protozoa. (**page xxx**). Enforcing withholding also for treated excreta is normally no problem since the fertilization effect is best at planting or applied on seedlings.

(5) Die off of organisms before consumption.
The interval between final application of excreta as fertilisers and consumption reduces pathogens (bacteria, protozoa and viruses) substantially. In guidelines Vol 2 the study by Petterson & Ashbolt, (2003) are cited, where a substantial die-off is reported. The precise values depend upon climatic conditions, with rapid pathogen die-off in hot, dry weather and less in cool or wet weather without much direct sunlight (approximately 0.5 log unit per day). This reduction is even with more conservative calculations at least 4 log units during a month and will give adequate safety when combined with other health protection measures. Helminth eggs can remain viable on crop surfaces for up to 2 months, although few survive beyond approximately 30 days (Strauss, 1996).

5.1.3 Exposure control post harvest.

Vigorous washing of rough-surfaced salad crops (e.g. lettuce, parsley) and vegetables eaten uncooked in tap water reduces bacteria by at least 1 log unit; for smooth-surfaced salad crops (e.g. cucumbers, tomatoes), the reduction is approximately 2 log units (Brackett, 1987; Beuchat, 1998; Lang et al., 2004). Washing in a disinfectant solution (commonly a hypochlorite solution) and rinsing in tap water can reduce pathogens by 1−2 log units. Washing in a detergent (e.g. washing-up liquid) solution and rinsing in tap water can reduce helminth egg numbers by 1−2 log units (B. Jiménez-Cisneros, personal communication, 2005). Peeling fruits and root vegetables reduces pathogens by at least 2 log units. Cooking vegetables achieves an essentially complete reduction (5−6 log units) of pathogens.

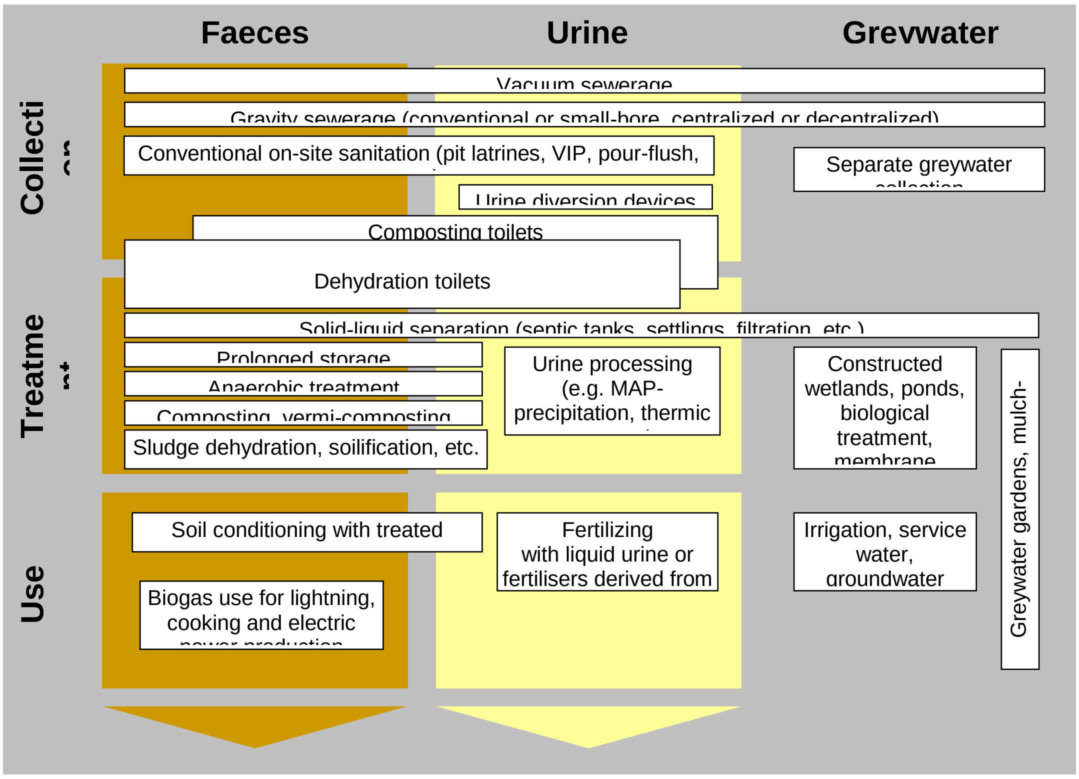
These reductions are reliable and can be used as references for risk calculations in combination with excreta treatment and other health-based control measures. Effective hygiene education and promotion programmes will be required to inform local food handlers (in markets, in the home and in restaurants and food kiosks) how and why they should wash wastewater-irrigated produce effectively with water or disinfectant and/or detergent solutions.

Food preparers are best protected by exposure control techniques such as rigorous personal and domestic hygiene, frequent hand washing with soap, the use of separate areas for food preparation and the subsequent handling of washed, disinfected and cooked food. Effective hygiene education and promotion are required.

5.2 Technical measures

Excreta and greywater treatment and handling systems are often decentralized and involves no or limited sewerage. Currently available technology allows design of such systems both in urban and rural areas in rich and poor countries (Jenssen et. al. 2004, Werner et al. 2004). In low-income countries, inhabitants in rural areas having access to sanitation facilities are mostly using on-site installations such as traditional pit, VIP or pour-flush toilets, and more recently, in selected areas, urine-diverting toilets. In contrast to industrialized countries, where the dominating urban sanitation system is centralized sewerage, the majority of urban dwellers in low and middle-income countries are served by on-site sanitation systems. Small-diameter gravity sewers or other low-cost sewer systems might also prove feasible in selected, mainly densely populated urban areas served by reliable water supply. It is unlikely, that sewerage will become a predominant sanitation option-of-choice in developing countries in the foreseeable future due to water scarcity, unreliability of water supply services, and for financial-economic and resource reasons, in the majority of places. Due to the growing stress on public health, environment and natural resources a variety of reuse oriented on- and off-site systems have been developed and implemented at an increasing rate (Werner et al. 2004). These comprise urine-diverting toilets, composting toilets, anaerobic (yielding biogas) and aerobic treatment of excreta, and separate greywater treatment systems. This section gives a brief overview of sanitation for low as well as in high-income countries where excreta and greywater are collected and treated for reuse in urban or peri-urban agriculture. This includes systems where excreta (urine and faeces diverted or combined) and greywater are handled separate and onsite or cluster systems that handle combined wastewater through septic tanks and small diameter sewers. Figure (5. 2) summarizes some technical options for excreta and greywater management based on the collection, treatment and use options.

Figure 5.2 Overview of technologies for management of excreta and greywater.



5.2.1 Onsite sanitation systems

Onsite sanitation is small systems often for one home or clusters a few homes. They comprise a range of systems from traditional septic tank or soil infiltration systems to the more recent source separating systems that are designed for recycling of resources from excreta and greywater (Fig 5.3). Systems where the excreta is treated and handled separate from the greywater are termed source- separating systems, with either two fractions, the excreta (urine and faeces) and the greywater, or three fractions urine faeces and greywater.
In order to collect excreta only, toilets that use no or very little water are the most feasible.

The toilet options used in the source separating systems range from pit toilets to modern urine diverting and vacuum toilet systems. The principle difference between the pit- and pour flush toilets and the other options utilise pits or soak-aways in natural soils which locally and due to the soil and groundwater conditions, may pose a threat to the groundwater quality and subsequently human health. The other options, collects all excreta for on- or off-site treatment and potential use and thus provide better protection of the local groundwater. The pit toilets constructed for disposal of excreta and not for use of the material, can also be excavated providing possibilities of recycling of phosphorus and organic matter but lose nitrogen. The composting or dry sanitation toilets loose nitrogen to the air while the urine diverting or low flush systems with holding tanks have very little loss of plant nutrients prior to agricultural application when handled properly. Fig.5.3 also indicates the separating options for greywater at the household level. Greywater treatment options are described in section 5.2.5.

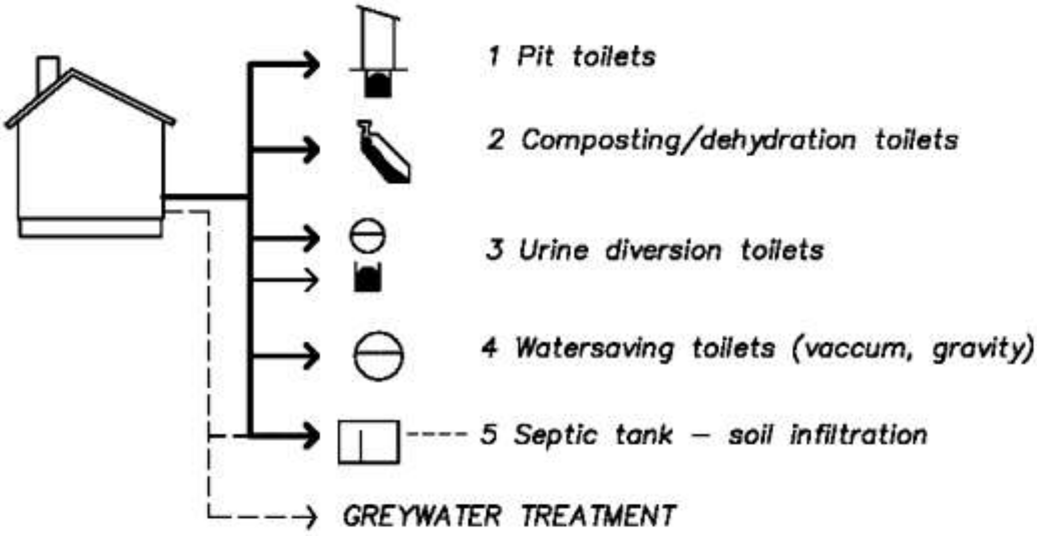


Fig. 5.3. Onsite sanitation options; 1-4 systems with sources separation, 5 traditional septic tank systems. For the systems with source separation greywater is handled in a separate system (see section 5.2.5).

5.2.1.1. Pit toilets

The pit toilets include the simple pit latrine, ventilated improved pit latrine (VIP-latrine) that do not require water for flushing and pour flush toilets where1 – 3 liters of water is used to flush the excreta to a soakaway. Traditionally pit latrines were dug quite deep with many examples of discharging their percolate directly into the groundwater. When pit latrines are used shallow pits should be recommended since these may limit the groundwater impact as well as being easier to excavate for reuse after ample storage.

The separation distance to the groundwater is an important hygienic barrier and should be maximized. It depends on several factors, such as the soil texture, structure, chemical composition and hydraulic loading. Normally finer grained soils (fine sand silt or finer) give better protection than coarser sands and gravel. Water should be limited to what is used for anal cleansing and cleaning of the toilet. The toilet should be constructed, so that no rain or surface water can flow into the pit neither when the toilet is in use nor when the pit is full and covered for maturation and hygienization of its content.
The ability of fly-breeding is reduced by a fly mesh at the ventilation pipe (VIP), the use of a toilet cover and frequent adding of bulking material or ash to reduce the possibility for flies to come in contact with fresh fecal material. Adding ash or lime will cause a rise the pH and enhance pathogen die-off.

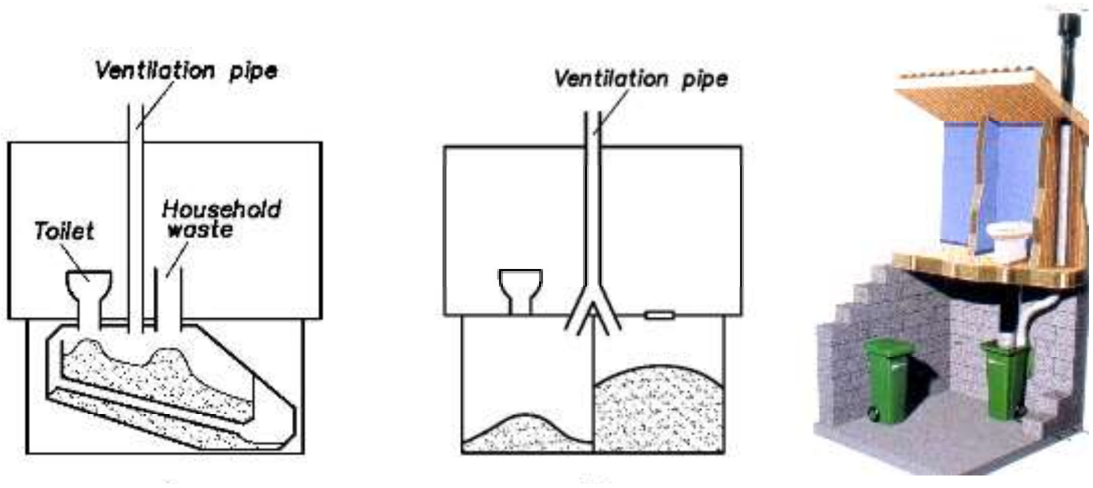
When the pit is full the waste should be covered with soil and the chamber sealed for two years. After two years of storage the decomposed waste could be safely used as a soil amendment (WHO 1996).

The pour-flush toilets use a pit for excreta disposal and have a special pan, cast into the cover slab and are preferably also equipped with a water seal for odour and fly control. The pour flush toilets may be equipped with one or two soakpits or discharge to septic tank systems (see below). Pour-flush toilets are not suitable for areas with cold climates and impermeable or very low permeable soils (WHO 1996). The potential risk for groundwater contamination is higher than for simple pit/VIP latrines due to the water use and pour flush toilets should be avoided in areas of shallow water tables. Pour-flush toilets are also inappropriate where the use of solid objects for anal cleansing is the custom as these may cause siphon blockage.

5.2.1.2 Composting toilets

Composting toilets (Fig.5.4) are built with a collection chamber where all excreta are confined. Composting systems should preferably be operated in a batch mode. In a batch operated system as the double vault system (B) one vault is used while the other matures or the collection containers (C) are changed when full and set aside for maturation and hygienization. This eliminates mixing of fresh and matured material and is safer for persons emptying the toilet. A batch operation also facilitates professional collection and secondary composting (Hanssen et al 2005). Secondary composting may be a way to ensure proper hygienization of material from composting toilets. The toilets can be designed with or without urine diversion. Composting toilets mainly rely on aerobic degradation of organic matter, resulting in a volume reduction of the excreta of 70-90% if properly designed (Del Porto and Steinfeld 1998). Adding dry bulking material is important, otherwise it will not function as a composting toilet, but be a collection chamber for wet excreta with potential problems with odor and fly breeding. Proper ventilation will add to the odor control.

The carbon to nitrogen ratio (C/N-ratio) of excreta (including urine) is 7-8 but for well functioning composting it needs to be raised to between 30 and 35 which can be done by adding bulking material such as paper, wood or bark chips, sawdust, ash or other similar substances. The bulking material also serve to cover the fresh faeces and thus lower the potential of fly contact and breeding, reducing the risk of disease transmission. Adding bulking material also helps mitigating odour problems. Organic household waste can also be added to a composting toilet through the toilet or in a separate chute (Fig.5.4 A). Adding



A **B** **C**

organic household waste will help to raise the C/N ratio.

Figure 5.4: Examples of a composting toilet systems A: Continous system, B: Batch system - dual compartment and C: Batch system - removable compartments**.**

Thermophilic composting of faecal material normallty gives a fast and substantial reduction of pathogens if elevated temperatures are reached. Experimentally a T_{90} values (i.e. 1-log_{10} reduction) of 6 minutes at 65°C and 1 hour at 52°C for *Salmonella* and *E. coli*. Enterococci express a slower die-off rate, requiring 3 days to reach a 4-log_{10} reduction (Holmqvist, et al., 2003) as well as viruses and helminth eggs. Due to its complexity however, the composting process may prove difficult to manage within the chamber, which will expand the pathogen persistence. Experience from temperate regions has shown that it is difficult to reach temperatures above 40 °C in the composting compartment. The normal operating temperature range is therefore often mesophilic or ambient which either may require long maturation times or a secondary composting (section 5.2.4) or storage period.

One of the critical handling points is when emptying composting toilets. Proper protection measures should be taken if the material is not fully sanitized, with personal protection when handling the material and that the material is further treated or stored out of reach for people until proper maturation times have been reached. In addition to protective clothing as gloves and boots normal hygiene and washing after the emptying operation is important (see also section 5.2.3 below).

5.2.1.3 Dehydration toilets

A dehydration toilet has the same basic constructed as a composting toilet with a collection chamber below the toilet. The aim, however, is to evaporate or dry out the excreta instead of optimizing the conditions for composting. In the dehydration toilet, the moisture content of the excreta is reduced. For efficient operation neither water nor urine should be added to the dehydration chamber. In different applications with the aid of heat (preferably solar), natural evaporation, ventilation and the addition of absorbent materials the moisture content can further be kept low. High temperature in the chamber, together with effective ventilation speeds up the desiccation process. Together with temperature and humidity the storage time and the pH all play an important role in the reduction of pathogens. The ventilation, which should draw air through the toilet and out through the vent pipe, as well as the absence of urine or other liquids helps to reduce odours. This technology is increasingly popular in arid areas where water is scarce and faeces can be effectively dried and reused as a safe fertiliser. After each use absorbents such as lime, ash, sawdust, or dry soil should be added to the chamber to absorb excess moisture and make the pile less compact. Addition of absorbents is also reported to reduce flies and eliminate bad odours. The use of alkaline absorbents, such as wood ash or lime, will result in an increase in pH of the pile and enhance pathogen die-off.

There are different studies reporting the pathogen die-off rate in dehydrating toilets. Early studies indicated that Ascaris eggs were particularly resilient to dehydration (Strauss and Blumenthal 1990,) but dependent on the temperature, moisture content and pH, 6-12 months in warm climates are usually sufficient to allow for the die-off of helminth eggs (Peasey, 2000). Investigations in Vietnam have shown that a 6 month retention period gave a reduction of resistant indicator viruses (8 log_{10} reduction) and no viable Ascaris eggs (Carlander and Westrell, 1999). The mean temperature ranged from 31-37°C (overall maximum was 40°C), the pH in the fecal material was 8.5-10.3 and the moisture content 24-55%. The inactivation was described as a combination of factors but pH for the virus indicator inactivation was shown to be statistically significant as a single factor (Carlander and Westrell, 1999; Chien *et al.*, 2001). Another study indicated that 12 months was needed to achieve a complete destruction of Ascaris eggs (Phi et al, 2004). In a Chinese study by Wang *et al.* (1999), plant ash was mixed with faeces in a ratio of 1:3 and yielded a pH of 9-10. A >7 log_{10} reduction of bacteriophages and fecal coliforms, and a 99% reduction of *Ascaris* eggs was recorded after six months even though the temperature was low (–10°C to 10°C), resulting in partial freezing of the material. Coal ash and soil addition led to a lower or insufficient reduction respectively. The coal ash gave an initial pH of 8. If such additives are chosen, the subsequent storage time should be prolonged to 12-18 months without new fecal additions (alternating collection chambers is recommended). According to Lan *et al.*, (2001) a pH >8 resulted in inactivation of *Ascaris* within 120 days.

Addition of a pH-elevating agent like lime or ash has the potential to enhance inactivation of pathogens. After alkaline treatment, the resulting fertiliser will have an elevated pH (>8). This is not of concern from a hygienic point of view and may be beneficial for many soils but may affect crop production in already alkaline soils. The conditions to achieve complete removal of pathogens may vary due to local circumstances. On a large scale, secondary treatment of collected material may function as an additional treatment barrier, resulting in a higher safety level, when the material is used as a fertiliser. High temperature (thermophilic) composting of the dehydrated faeces may in some instances be considered as a secondary treatment, particularly if the contents of the toilet is to be used on food crops (Peasey, A., 2000).

Table 5.2. Investigated microbial reduction in dry collection of faeces.

Area of investigation	**Type of toilet**	**Additive**	**pH, temp, moisture**	**Most important findings-Inactivation of pathogens and indicators**	**Reference**
Vietnam (during hot and dry season)	12 latrines, 2 of each type. All urine diverting, most double vault or multi bucket.	Ash from firewood and leaves. 200-700 mL per visit.	pH: 8.5-10.3 temp: 31.1-37.2°C moisture: 24-55% (mean values for each latrine)	**Controlled die-off experiments in challenge tests:** T_{90} for *Salmonella typhimurium* phage 28B varied from 2.4 to 21 days. pH most important factor for die-off. *Ascaris* viability 0-5% after 9 weeks (except in 2 latrines). pH in combination with temperature affect die-off.	Carlander & Westrell, 1999
South Africa (hot to cold climate)	Various urine diverting toilets.	Wood chips	pH. 8.6-9.4 moisture: 4-40%	**Organisms present in material:** After 10 months: All indicators present in high numbers (10^2-10^6/g). *Salmonella* present. After 12 more months: Fecal streptococci ~10^4/g, clostridia & coliphages present, *Salmonella* absent	Austin, 2001
South Africa	2 urine-diverting toilets.	Wood chips + turning	pH. 8.4-8.6 moisture: 4-9%	**Organisms present in material:** After 2 months: Indicators except coliphages present (~10^2/g). *Salmonella* absent.	Austin, 2001
El Salvador	118 double-vault urine diverting latrines.	Lime, ash or lime-mixed soil	pH: 6.2-13.0	**Organisms present in material:** Fecal coliforms inactivated after 500 days. pH most important factor.	Moe & Izurieta, 2003

	38 single vault solar latrines.			*Ascaris* inactivated after 450 days (pH >11), after 700 days (pH 9-11). Temperature strongest predictor for inactivation.	
China	2 latrines	Plant ash mixed with faeces in ratio 1:3	pH: 9-10 temp: -10-10°C	**Controlled challenge test and organisms present in material:** After 3 months: >7 $\log_{10}$ reduction of *Salmonella typhimnurium* phage 28B and fecal coliforms. 1% viability of *Ascaris.*	Wang *et al.* 1999*
China		No detailed information given	pH >8	**Controlled challenge test:** Inactivation of *Ascaris* within 120 days.	Lan *et al.*, 2001

* The other additives coal ash; sawdust and loess were also tested and resulted in lower pH and lower inactivation.

5.2.1.4 Urine diversion systems

Urine is the most nutrient rich fraction of the excreta (Chapter 1). The aim of urine diversion is to collect urine for reuse as a fertiliser and to eliminate euthrophicating discharge of nutrients into surface waters. Urine diversion may be practiced using both composting and dehydration toilets. This practice enhances the drying or composting process by keeping out liquids. The collected urine can then be used as fertilizer after an appropriate storage period (Chapter 4).

Urine diversion toilets

In the urine diversion toilets urine and faeces are collected separately. The technology has been adapted both as low, medium and high cost alternatives. The toilets come in both slab and sitting/pedestal toilet versions, where versions also exist for anal cleansing with water. Inserts for urine collection (Fig 5.5d) can be made from local material, but are also commercially available. In the later years toilets made especially for urine diversion are available and used on all continents. In commercially made urine diverting toilets the bowl/slab is divided into two compartments, a front one collecting urine and a rear one collecting fecal material (Fig 5.5 xx)**.**

(a) (b) (c) (d)

Figure5.5. Examples of urine diverting toilets; a) slab toilet, Guanxi province China b) double flush urine diversion toilet c) single flush urine diversion toilet, Sweden d) urine diverting insert to a bucket toilet.

Urine diversion toilets with flushing either apply a single flush for urine with < 0.5 litres or a double flush for either the urine or fecal matter < 4 liters. The single flush system requires a straight chute down to the faecal collection chamber (Fig 5. 6). The fecal matter is normally composted on site and the urine collected for use in agriculture (Winblad and Simpson-Hébert 2004). Within pedestal toilets, a pan generally located towards the front of the defecating area collects the urine. Additional urinals can be used to collect urine from male users. If urinals are used it is important to select models that use little water. In the last years several new waterless urinals have appeared on the market. They have been tested in airports, hotels and universities without odours problems if properly maintained.

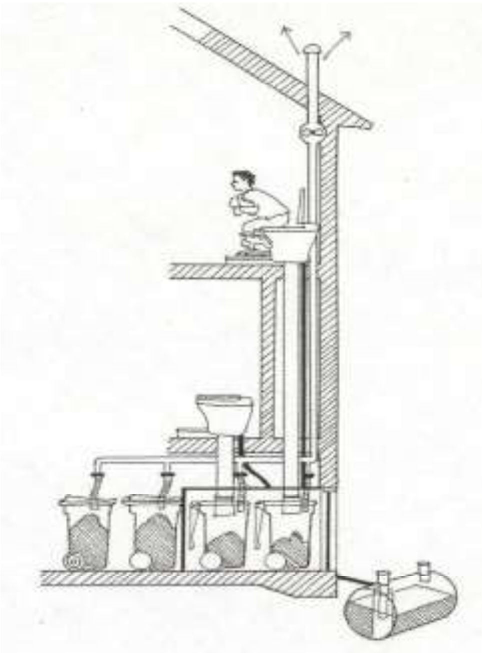


Fig 5.6. Technical layout of a single flush urine diversion system in a two storey apartment house (from Winblad and Simpson-Hébert 2004).

In the dual flush system (Fig 5.7) the fecal matter is flushed into a sewer system and the urine collected separately. Dual flush systems can be fitted in both new and existing urban areas with multi storey buildings e g with a gravity urine collection system.

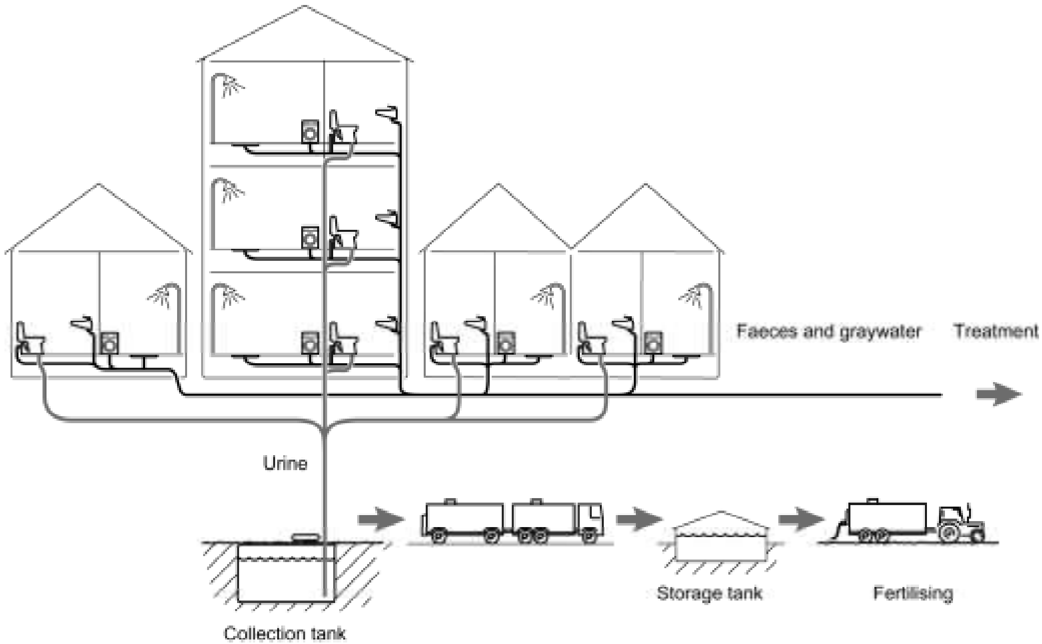


Figure5.7 Layout for a dual flush urine diverting system. The urine is collected for use in agriculture and the faecal matter is flushed away together with the greywater (from Jönsson et al. 2000)

When the urine is collected using a urine diversion toilet some fecal contamination may occur which may pose a potential risk when using urine. The cross-contaminating amounts are normally ≤ wastewater diluted 100-fold. Storage of the urine has shown to give sufficient treatment with respect to pathogen reduction **(**Höglund 2001**)**. The hygienization is attributed to a rapid conversion of urea to ammonia giving a raise in pH. The ammonia content together with the increase in pH has a hygienizing effect. Bacteria concentrations diminish quite quickly during storage, but prolonged storage is necessary in order to adequately reduce the number of viruses and protozoa (Chapter 4).

5.2.1.5 Vacuum and low flush gravity toilets

Vacuum and low flush gravity toilets are used to collect blackwater (urine and faeces together) as concentrated as possible for further treatment, processing and reuse in agriculture. Vacuum toilets use 0.5 – 1.5 litres per flush gravity toilets using down to 1 liter per flush also exist. Blackwater collected using 1-liter per flush toilets has a low dry matter content (Jenssen 2001). To treat the blackwater aerobically or anaerobically (section 5.2.4) additional organic matter must be added I e grinded organic household waste (Fig. 5.8).

The use of vacuum toilets provide a similar level of comfort as a traditional flush toilet, but is potentially more hygienic due to air sucked into the toilet when flushing and thereby avoiding aerosols. The system is completely closed and should a leak occur the negative pressure in the pipes reduce the risk of raw sewage spill. Vacuum toilet systems can be installed in multistory buildings in urban situations.

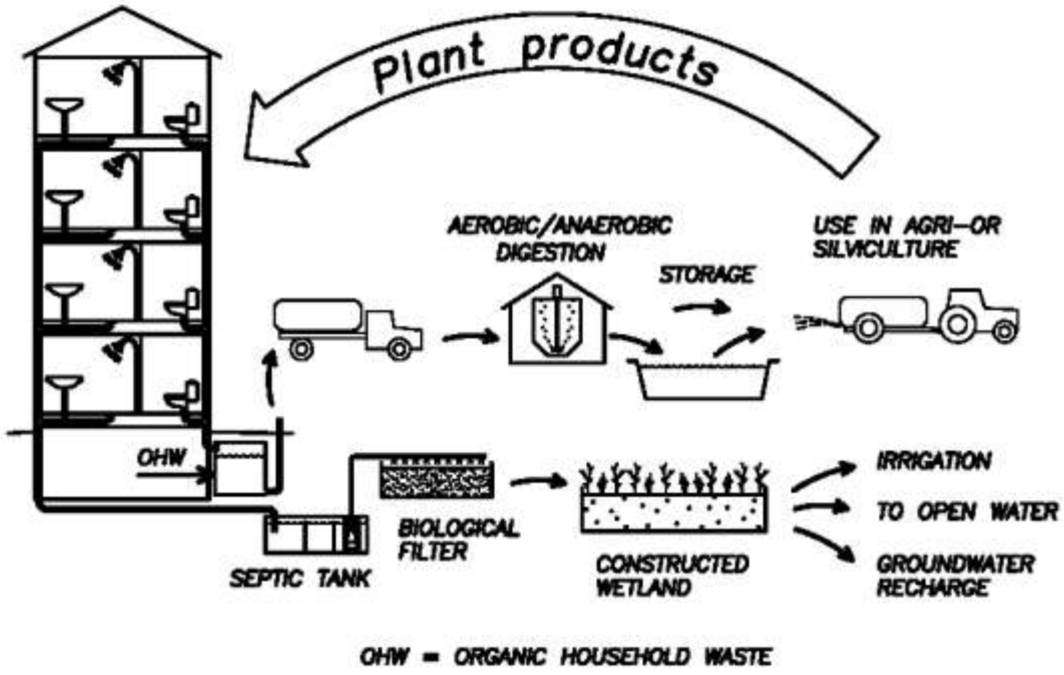


Figure 5.8. Example of a fully recycling system using vacuum or low flush gravity toilets for separate collection of blackwater and separate treatment of greywater. Other greywater treatment options are given in section 5.2.5 (From Jenssen 2001).

The collected blackwater must be hygienized prior to agricultural use. Hygienization can be achieved using aerobic or anaerobic (yielding biogas) processes. Some vacuum toilets are available with urine diversion.

5.2.1.6 Septic tank systems

Septic tank systems comprise all sanitation systems use a septic tank as the primary treatment step. In many developed countries septic tank followed by soil infiltration (leachfield or drainfield) constitute the major sanitation solution in rural areas. These systems normally treat combined wastewater (greywater and excreta). The pathogen removal in septic tanks is poor and bacteria and viruses remain present in both the liquid and the solid phase (Stenström 1986). The removal of helminth eggs can be expected to be < 0.5 logs but suspended solid removal can potentially be used to assess the efficiency. The septic tank is the most common pre-treatment unit for onsite combined wastewater (greywater and excreta) and greywater. For design of septic tanks the reader is referred to (Crites and Tchobanoglous 1998) or local codes.

Many of the inconveniences of conventional gravity sewers can be overcome through the use of small-diameter sewers transporting effluent from septic tanks, termed septic tank effluent gravity systems (STEG). Properly functioning septic tanks, ensures that the solids settle, and that the sewage network transports the liquid portion only. A planned program for emptying of the septic tanks is essential to successfully operate a small diameter gravity sewer system. This is due to particles entering the system when the solid storage capacity of the septic tanks is reached. An appropriate provision of manholes is also essential throughout the network for maintenance and emergency interventions. Small diameter gravity sewers are traditionally used for combined grey- and blackwater, but the same function is obtained using greywater septic tank effluent.

5.2.3 Handling and transport of excreta and sludge

Faeces and sludge need to be handled at various steps within sanitation treatment and reuse system. Handling and transport of faeces and sludge constitute a very critical point in a sanitation system from a health risk aspect, as people handling these materials may be exposed directly to pathogens and there is a risk for accidental spill or intentional dumping. Materials that need to be handled may be very variable in nature, depending in their origin:

- Dry materials from dehydration toilets or composting toilets, dried sludge and compost.
- Sludge from septic and settling tanks, filters, anaerobic digesters, etc., generally of liquid or semi-liquid consistency.
- Contents from pit latrines with a consistency ranging from solid to liquid, often also containing solid waste.

Different options are available for handling and transport of faeces and sludge.

- Manual handling through excavation or emptying using buckets, transport in buckets or simple carts
- Mechanical emptying and transport, by vacuum tankers, trucks, etc.
- Pumping and piped transport of liquid sludge.

Piped sludge transport is the safest way of transport but is only an option if transport distance is limited and pumps can be afforded and managed.

The classical technology for emptying of septic tanks, pits, etc. is by suction with a vacuum pump. A hose is introduced in the tank or pit and the content sucked out. Sludge removal by suction pumps significantly reduces the direct contact of the workers with the sludge and is therefore the safest technique available. The pump is usually connected to a truck-mounted tank of variable capacity. In this way the truck can access the plot, empty the facility and then directly transport the sludge to the disposal or treatment site. Tanks may be mounted on carts pulled by tractor or animals. Smaller units or vacuum tugs, consisting of smaller tanks and motor or hand-driven vacuum pumps may be used in situations where very narrow access does not allow large vehicles.

For blackwater tanks or urine tanks that contains no hard sludge or scum a pipe with a quick coupling may be fitted to the holding tank which reduce the time for emptying the tank and also spill and possible human contact with untreated excreta (Jenssen et al. 2005).

From the human health risk a basic distinction should made between sludges which, upon collection, are still relatively fresh or contain a fair amount of recently deposited excreta (e.g. sludges from frequently emptied, unsewered public toilets) and sludges which have been retained in on-plot pits or vaults for months or years and is virtually free of pathogens. Blackwater, constitute high-risk material and exhibits characteristics similar to sludges collected at short intervals e.g. from public toilets. Special care should therefore be taken against accidental contact and spill during emptying of latrine or toilet pits or vaults by vacuum trucks, where varying amounts of water or wastewater are collected alongside with the accumulated solids. The content of helminth eggs may here be in the range of 500 – 6000/L (Kone and Strauss, 2004) which is higher than what can be expected in tropical sewage; 20 – 1000/L according to Mara (1978).

Manual handling normally comprises the use of shovels and buckets and may demand that the workers have to step into the pit, thus exposing themselves to great health risks. Manual handling should be minimised if the material is not pretreated on-site. However, manual handling will still be the final option when the use of vacuum pumps is excluded. Manual handling can be acceptable if the health risk to workers is minimized. Use of adequate protection measures by workers is absolutely necessary. Protection measures for handling of sludge include the use of protection clothes such as gloves and masks and a good hygiene (washing hands after work etc.). Most important is that workers be aware of the nature of the health risks to which they are exposed and that they know how to protect themselves. Training and targeted information may therefore be the most successful measures in addition to on-site treatment.

5.2.4 Treatment of blackwater and septic tank/fecal sludge

5.2.4.1 **Low-cost treatment options**.

The faecal material collected from latrine or toilet pits may contain high numbers of pathogens, if it only has been stored for short periods of time (days or 1-2 weeks) prior to collection. Secondary treatment serves to inactivate these below the tolerable risk threshold and the related guideline values, respectively. The solids fraction constitutes a valuable soil conditioner and fertilizer when stabilised and treated to the required hygienic quality. In contrast to this, the undiluted liquid fraction will, in most cases, not be usable in agriculture due to excessive salinity.

The solids-liquid separation processes, applicable for pumpable sludges comprise settling and filtration and lead to a concentration, of the pathogens trapped in the solids fraction. The hygienization process for this fraction will therefore be crucial, as the pathogen concentrations will have increased several-fold compared to the raw faecal sludge. Fig 5.9 schematically depicts an array of FS treatment processes and options, which may be suitable for low or middle-income countries (Ingallinella et al., 2001).

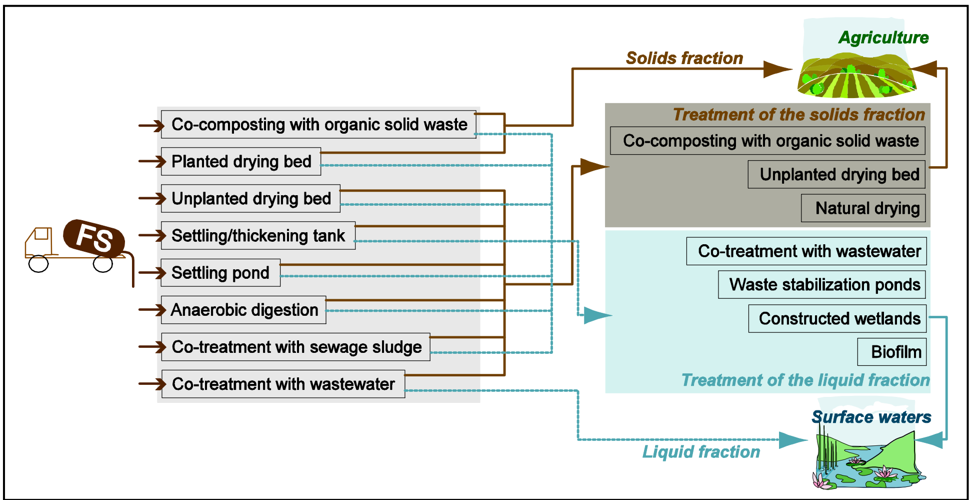


Fig. 5.9 Low-cost options for treating FS and blackwater (brown lines: solids fraction; blue lines: liquid fraction) (Ingallinella et al., 2001)

Settling-thickening tanks or primary ponds can be used for solids-liquid separation. The former provide a liquid retention time of a few hours (enough to ensure quiescent settling of settleable solids), while the latter cater for several days or a few weeks of liquid retention and, hence, also allow for further hygienization and anaerobic degradation of organics. Batch-operated settling tanks can typically remove 60 % of the suspended solids while removals in settling ponds is > 80 % (Koné and Strauss, 2004; Fernandez *et al*., 2004). Helminth egg removals will be of the same order of magnitude.

Conventional sludge drying beds used for dewatering and drying of faecal sludge and anaerobic digester residue will reduce the faecal sludge volume applied to 50 - 80 %. Sludge drying can reduce the water content to below 20-30%, which result in partial pathogen removal. The dried sludge still may contain pathogens, particularly helminth eggs, and should therefore receive further treatment, e.g. composting or prolonged storage before use in agriculture. The drained liquid requires further treatment (e.g. in facultative ponds or in constructed wetlands) prior to discharge into a receiving water body.

Planted sludge drying or “humification” beds with a gravel/sand/soil filter planted with wetland plants such as e g reeds, bulrushes or cattails have the advantage over unplanted sludge drying beds that the root of the plants create a porous structure in the accumulated solids, thus maintaining the dewatering capacity during several years in spite of an increased layer of accumulated sludge solids. Removal of accumulated biosolids is required at a much lower frequency reducing contact. The extended storage of biosolids allows for biochemical stabilization, and pathogen inactivation, resulting in a humus-like material, which is likely to require no or little additional storage to reach hygienic safety. Helminth egg viability in FS solids accumulated over three years in FS-fed planted drying beds were found to be < 2 % (Koottatep *et al*., 2004).

Waste stabilization pond (WSP) systems comprise pre-treatment units (tanks or ponds) for solids-liquid separation followed by a series of one or more anaerobic ponds and a facultative pond. Where FS are made up of substantial proportions (> 30 %) of sludges from unsewered public toilets ammonia levels might be excessively high. In tropical climate, the tolerable nitrogen level in the supernatant of primary settling units is 400 mg (NH_3 + NH_4-N)/L (Heinss *et al*., 1998). Where waste stabilization ponds exist to treat municipal wastewater, FS are often mixed into the wastewater for co-treatment. This may create problems because the wastewater ponds were usually not designed to co-treat major loads of FS. To avoid problems, FS may be pre-treated in primary settling-thickening ponds. Their effluent can then be co-treated with wastewater in facultative and maturation ponds. The FS settling ponds, which will also allow for anaerobic degradation of dissolved organics, enables to separate off the bulk of the solids and helminth eggs ahead of the main WSP system.

Co-composting, i.e. the combined composting of faecal matter and organic solids waste is practiced all around the world, usually in small, informal and uncontrolled schemes or on a yard scale. Most of this may proceed at ambient temperatures, with concomitant inefficient inactivation of pathogens. Thermophilic composting, however, can effectively hygienise and stabilize faecal sludge, faeces that have been pre-treated in a urine diversion toilet, or slurry from anaerobic treatment. If operating conditions required for thermophilic composting are adequate - moisture content = 50% - 60%, C:N ratio = 30 – 35 and mixing of bulking material to allow for sustained air passage - the temperature will rise to between 50 - 65°C. Such temperatures will effectively inactivate pathogens. Fresh faecal sludge is normally too wet and exhibits too low C:N ratio for optimal composting. FS has to be dewatered prior to co-composting. Admixing of a relatively dry, carbon-rich bulking material such as organic municipal waste is required. The end-product of the aerobic composting process is an odourless, stabilised material with good properties as a soil conditioner and as a slow-release P fertilizer. Due to the complexity of the composting process however, optimal thermophilic conditions throughout the composting mass can only be guaranteed if moisture content, bulking structure and C:N ratio are maintained and controlled throughout the thermophilic and maturation phases. Well operated thermophilic composting schemes can achieve close to 100 % pathogen destruction, notably very low helminth egg viabilities if regular turnings are done during the three to four weeks thermophilic phase. Small-scale composting on household level is less efficient and pathogen inactivation is incomplete as the temperature increases only marginally above ambient. Prolonged storage would be the method-of-choice in that case. Composting is therefore best suited as a secondary off-site treatment.

Anaerobic digestion is a biological process that takes place in absence of air. The organic material is broken down producing biogas (a mixture of methane, CO_2 and traces of other gases), water and remaining slurry. The slurry from the biogas reactor constitutes a valuable soil conditioner and fertilizer. This option is, in principle, suited to treat blackwater and higher-strength FS, which have not undergone substantial degradation. In India, in the order of 100 large-scale biogas plants are in operation treating highly concentrated, fresh FS from public pour-flush toilets. Small biogas digesters (Fig5. 10) serving one or a small number of households have become increasingly popular. The main goal of the household digesters is to produce biogas and provide the family with energy, mainly for cooking. The main input is animal manure from small household livestock while human excreta and other organic wastes usually constitute the smaller fractions.

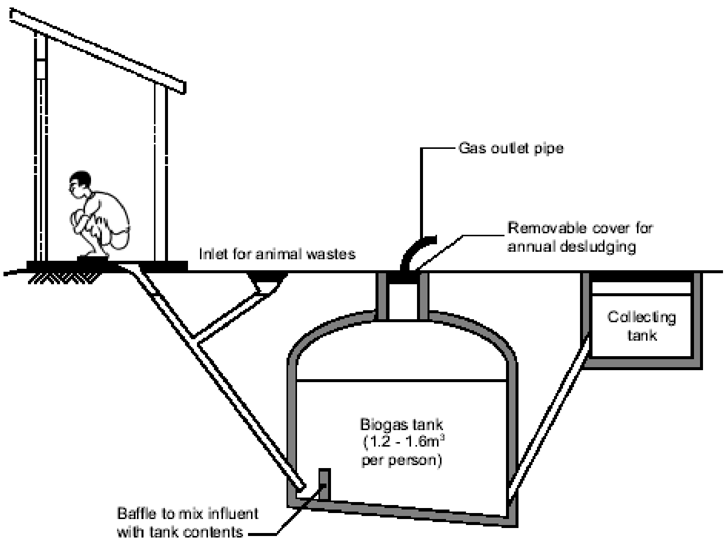


Figure 5.10Household biogas digester for treatment of animal manure and human excreta

Pathogen reduction in mesophilic digestion is usually modest, with, on the average, only 50 % inactivation or 0.5 log cycles reduction of helminth egg viability (Feachem *et al*., 1983; Gantzer *et al*., 2001). Post-treatment such as by sludge drying beds, thermophilic co-composting with organic bulking material or extended storage is required to achieve the hygienic quality compatible with the stipulated guideline value.

5.2.4.2 Criteria for selecting low-cost treatment options

There are no generally valid advantages or disadvantages for any of the treatment processes and options described above. Specific, local conditions and requirements as well as the type and relative quantities of the different sludges collected determine the choice of the "best" option among an array of options which might be found potentially feasible in the specific situation. Table 5.xx contains a semi-quantitative characterization of selected low-cost treatment processes and options/Due to formatting problems this table is sent as a separate file/Thor Axel/. Criteria categories comprise operation and maintenance and performance aspects as well as requirements for polishing treatment of solids and liquids

5.2.4.3 High-cost treatment of FS and blackwater

In industrialized countries, treatment of faecal sludges or blackwater is largely based on established technologies. Frequently used options include extended aeration, anaerobic digestion, mechanically stirred sludge thickeners, or chemical conditioning followed by centrifuging or filter pressing. Complete pathogen removal can be achieved either in thermophilic processes or by processes especially designed for hygienization, e.g. pasteurization or high alkaline treatment.

Large-scale biogas digesters are common for treating agricultural or organic municipal waste. Domestic wastewater or excreta from on-site sanitation systems or decentralised wastewater collection systems can also be co-treated in such digesters. Gas yields allow for the combined production of electricity and heat and digester residues are used as fertilizers. Large digesters are usually heated and use mechanical agitation to maximise gas yields. The digestion process can be mesophilic or thermophilic. Thermophilic digestion yields higher gas production, allows for higher sludge loading rates and enables complete pathogen removal but require more capital-extensive technology, higher energy inputs and higher operating skills. The residual liquid from thermophilic digesters can be safely used as a soil conditioner-cum-fertilizer, whereas slurries from mesophilic digesters have to be subjected to a separate hygienization process such as pasteurization, high alkaline treatment, drying bed treatment, or extended storage (see Chpt. 5.2.4.2). Recent developments in biogas technology tend to combine anaerobic digestion with membrane filtration, allowing compact reactor volumes and complete pathogen removal. However, those technologies are still in the stage of development.

Aerobic treatment of liquid organic waste is also termed liquid composting. It is based on slurry aeration, which induces a microbial degradation process by aerobic organisms, mainly bacteria. The process is exothermic, which means that the process generates heat. In a properly constructed and operated system, thermophilic temperatures are reached without additional heat sources, provided the relative organic content is sufficient The wastes are handled as liquids (dry matter content between 2 and 10 %) and stabilised in the reactor at thermophilic temperatures between 55 and 60 °C with a hydraulic retention time of 5 - 7 days (Skjelhaugen, 1999). The process is run semi-continuously and is characterised by high oxygen utilization, low ammonia loss and no odour release (Skjelhaugen, 1999). Experimental investigations have shown that the pathogen removal is high and fulfill guideline targets (Nordin et al, 1996).

5.2.4.4 Pathogen removal performance of treatment options and processes

Table 5.3 lists orders of magnitude removals of helminth eggs for selected processes and low and high-cost options for treating faecal sludges and blackwater. As expected and by the nature of the processes involved – viz. heat or high alkaline treatment – high-cost options are more effective in helminth egg removal, i.e. more log-cycle reduction can be achieved in shorter retention time than with low-cost treatment options. This is in exchange for higher investment and higher energy input.

Table 5.3. Helminth removal in different treatment processes for faecal sludge.

Treatment option or process	**Helminth egg log reduction**	**Duration**	**Reference**
Low-cost			
FS settling ponds	3	4	Fernandez *et al.*, 2004
FS reed drying beds (constructed wetlands)	1.5	12	Koottatep *et al.*, 2004
Drying beds for dewatering (pre-treatment)	0.5	0,3 - 0,6	Heinss *et al.*, 1998
Drying beds for drying	2,0 - 3,0	1	
Composting (windrow thermophilic)	1,5 - 2,0	3	Koné *et al.*, 2004
pH elevation > 9	3	6	
Anaerobic (mesophilic)	0.5	0,5 - 1,0	Feachem *et al.*, 1983; Gantzer *et al.*, 2001
High-cost			
pH elevation > 12	3		
Thermophilic, in-vessel (aerobic/anaerobic)	3	1 - 5 days	

Pasteurization	3	Hours	
Thermal hydrolysis	3	Hours	

5.2.5 Greywater

Greywater makes up the largest volume of the waste flow from households, with low nutrient and pathogen content. Simple treatment techniques such as soil infiltration, gravel filters, constructed wetlands or ponds may result in a pathogen reduction meeting the HBTs. More complex methods as activated sludge, rotating biological contactors or membrane filtration may also be used. The effluent, normally aimed for irrigation of agricultural crops in water scarce regions, can also be used for groundwater recharge, industrial or urban reuse or discharged into surrounding watercourses (Werner et al, 2004).

Source control and water conservation are part of the general management of greywater. This relates to the use of environmentally friendly household chemicals and reducing faecal input as well as reducing the amount of water to be treated. Progressive planning can calculate on a mean amount of 80 litre greywater per person and day (Ridderstolpe et al 2004). In industrialised countries excess amounts of detergents are responsible for substantial BOD input as well as grease and oil in general for food preparation. Grease may also constitute a problem in areas where cooking oil is extensively used. If used for irrigation, liquid soaps containing potassium is preferred since hard soaps often contain sodium which increase the risk of soil salinisation. More information on greywater volume and composition is given in Chapter 1.

Greywater collection is normally based on a pipe system, where smaller diameter pipes can be used compared to combined wastewater and equipped with ventilation for air and odour evacuation and water traps. The final discharge or use of the water determines the extent of treatment needed. Before discharge to streams or the use in irrigation or groundwater recharge, the treatment should safeguard the hygienic quality. For ground water recharge substantial reduction of BOD and suspended solids is normally needed to prevent clogging of the recharge basins or wells. For domestic reuse more sophisticated tertiary treatment may be necessary.

A range of treatment alternatives is available for onsite or small scale decentralized greywater treatment (Fig. 5.11). The most common options are briefly described below. These can also be used for treatment of combined wastewater, but have to be designed accordingly.

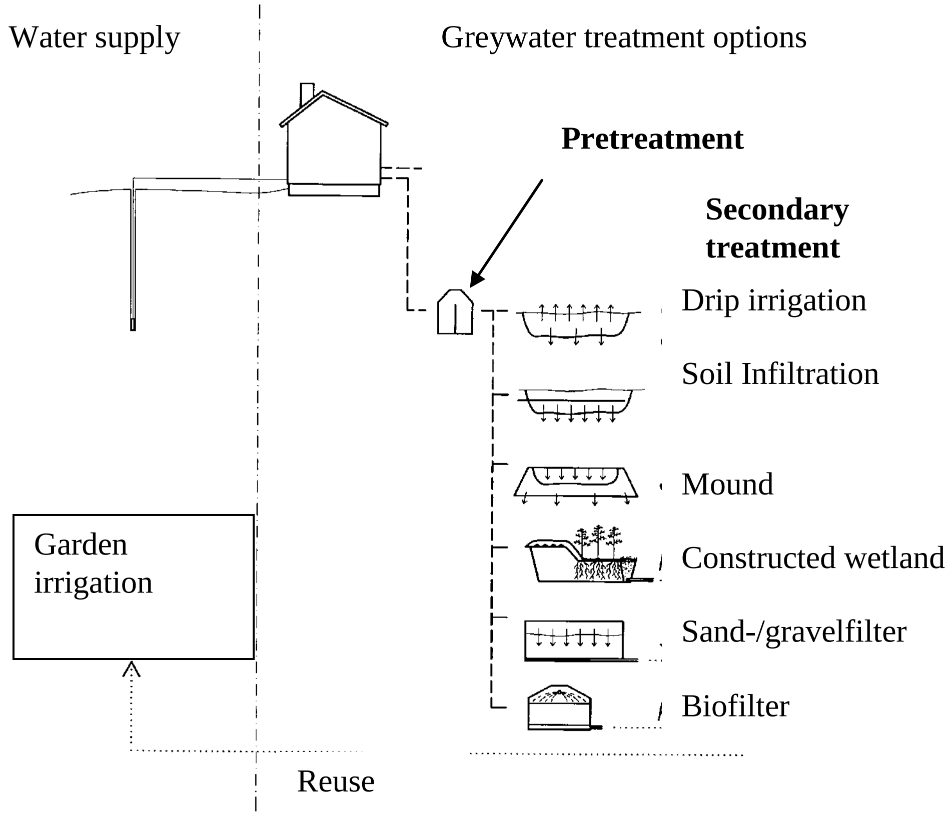


Fig. 5.11 Greywater treatment options.

5.2.5.1 Pretreatment/ solid-liquid separation

Pre-treatment is always needed to avoid clogging of the subsequent treatment. It consists of a solid-liquid separation that reduces the amounts of particles and fat in the effluent by septic tanks, settling tanks, ponds or filter systems such as filter bags.

The most common pre-treatment unit for greywater as well as for treatment of combined wastewater (greywater and excreta) onsite is a septic tank (see section 5.2.1.6). The pathogen removal in septic tanks is, poor (normally <0.5 log) and depends on the efficiency of particle removal. A regular (yearly) inspection is recommended to prevent problems with particle overflow.
For small systems as a single dwelling, alternatives to the septic tank may be filterbags from natural or synthetic material that produce the same effluent quality. A homeowner can remove such bags, however with proper personal protection against exposure to the material, which may contain pathogens. The natural fiber bags can be composted together with their content or dried and reused if the bag is of synthetic fabrics.

Home made screens or filters constructed of fine gravel, straw or branches may also be appropriate prior to soil infiltration in small-scale domestic systems in hot climates. In small systems direct use of greywater is also possible i. e. to a mulch bed where water is used for growing plants or trees.

5.2.5.2 Soil infiltration

Soil infiltration is a simple and suitable method for onsite greywater treatment, where comprehensive experience exists regarding both separated greywater and combined wastewater. It is for example the primary system for onsite and decentralized wastewater treatment in the U S. The treatment efficiencies are high and normally > 2 logs for both bacteria and viruses and > 3 logs for parasitic protozoa, thus giving a similar reduction efficiency as a traditional wastewater treatment plant (Siegrist et al. 2000).

After the pre-treatment the effluent is distributed to the soil through open ponds or shallow trenches or infiltration basins (Fig. 5.12).

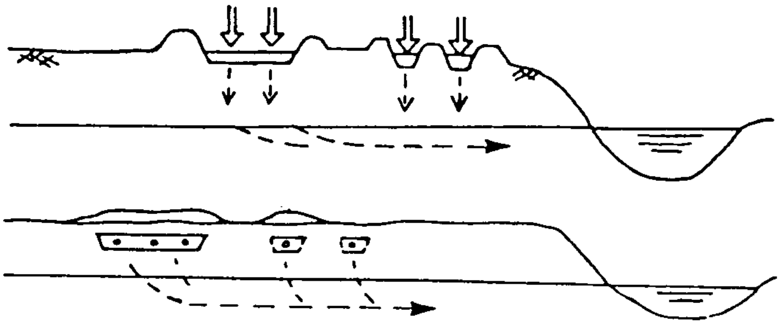


Fig.5.12 Infiltration in open basins/ponds (above) and in buried shallow trenches (below) the percolation down to the groundwater and subsequent flow towards a stream is indicated.

The water percolates down through an unsaturated zone to the groundwater (saturated zone). Most of the treatment occurs in the unsaturated zone. The size and load of the system needs to account for the local soil conditions to keep the flow unsaturated, which assures optimum conditions for filtering of pathogens. Unsaturated flow also assures aerobic conditions that generally promote a more rapid die-off of pathogens.

Soil infiltration systems should not be used where the groundwater quality may be endangered. The necessary separation distance to groundwater varies depending on soil type and system design (Siegrist et al. 2000). Virus and bacteria removal, as well as phosphorus sorption is enhanced by soils rich in iron and aluminium oxides (brown and red color soils). Disposal systems should always be down-slope and as far as possible from water wells will better protect possible water supplies from contamination. Impermeable soils, shallow rock, shallow water tables, or very permeable soils such as coarse sand or gravely soils are normally considered unsuitable sites. For permeable soils a layer of sand 30-50 cm in the bottom of the infiltration trench will enhance the retention capacity for microorganisms. Elevated systems (mounds) can also be designed to overcome limitation in the local soil conditions (USEPA 2002). For information on siting and design the reader is referred to Jenssen and Siegrist 1990 and 1991, Siegrist et al. 2000 and USEPA 2002.

5.2.5.3 Drip irrigation

Drip irrigation is a shallow soil infiltration system where the plant uptake of water and nutrients is optimised, thus minimizing vertical percolation to the groundwater. The system may be simple or advanced with pressurized distribution of the liquid. Localized irrigation is estimated to provide an additional pathogen reduction of 2−4 log units, depending upon whether the harvested part of the crop is in contact with the ground or not (WHO guidelines for the safe use of excreta, wastewater and greywater, Vol 2) (NRMMC & EPHCA, 2005).

5.2.5.4 Ponds

Wastewater stabilization ponds (WSP) are developed for combined wastewater treatment but are also suitable for greywater. Waste stabilization pond treatment systems usually consist of a number of ponds linked in series and should be designed to minimize hydraulic short-circuiting. For greywater treatment, an anaerobic stage is usually not required. The design criteria for helminth egg and *E. coli* removal is discussed in WHO guidelines Vol 2. A properly designed series of WSP can easily reduce faecal coliform numbers from 10^8 per 100 ml to $<10^3$ per 100 ml. In tropical environments (20−30 °C), well designed and properly operated WSPs can achieve a 2–4 log unit removal of viruses, a 3–6 log unit removal of bacterial pathogens, a 1–2 log unit removal of protozoan (oo)cysts and a 3 log unit removal of helminth eggs; the precise values depend on the number of ponds in series and their retention times (Mara & Silva, 1986; Oragui et al., 1987; Grimason et al., 1993; Mara, 2004). The removal is mainly by sedimentation for protozoan (oo)cysts and helminth eggs while viruses are removed by adsorption onto solids and bacteria by inactivation by several mechanisms like temperature, pH and light intensity (Curtis, Mara & Silva, 1992).
Effluent storage reservoirs can also be used for greywater treatment arid and semi-arid countries. Due to the organic load a pre-treatment may be needed. Effluent storage and reservoirs may if properly designed, operated and maintained, give a pathogen removals within the same range as waste stabilization ponds.

5.2.5.5. Constructed wetlands

Artificial shallow ponds vegetated with macrophytes are normally termed constructed wetlands. If the pond is filled with a porous media it is termed a subsurface flow constructed wetland (Fig 5.13) and where the porous media can be sand, gravel, light weight aggregate, or other, suited to support the macrophytes and to have a sufficient hydraulic conductivity to transport water horizontally through the root zone. Fine grained soils as silt or clays are not suited due to low hydraulic conductivity and consequently a high risk for surfacing of flow and short-circuiting of the system resulting in poor treatment performance.

The geometry of subsurface flow constructed wetland is based on hydraulic calculations. In cold climate where the plants are seasonally dormant, aerobic pre-treatment is recommended (Jenssen et al. 2005) to achieve high removal of BOD and nitrogen during the cold period and deeper systems are used to allows for the upper part to freeze while the water still flow lower down. In cold temperate climate 1m deep systems are recommended, while in warm climate 0.4 – 0.6 m depths are the most common.

Constructed wetlands with subsurface flow are well suited for greywater treatment. Constructed wetlands give a high reduction of BOD and total nitrogen, while phosphorus removal is dependent on the sorption capacity of the media (Zhu 1998). Constructed wetlands can reduce the pathogen load significantly and in produce an effluent with < 1000 thermotolerant coliforms/100ml (Jenssen and Vråle 2004, Jenssen et al. 2005). Normally the reduction, also of somatic coliphages, depends on the type and size of the porous media and the retention time. The macrophytes may also enhance the removal (Francey et al, 1992). When using iron rich sand and allowing a residence time of more than one week a removal of 3 logs of indicator bacteria and a substantial virus removal has been achieved.

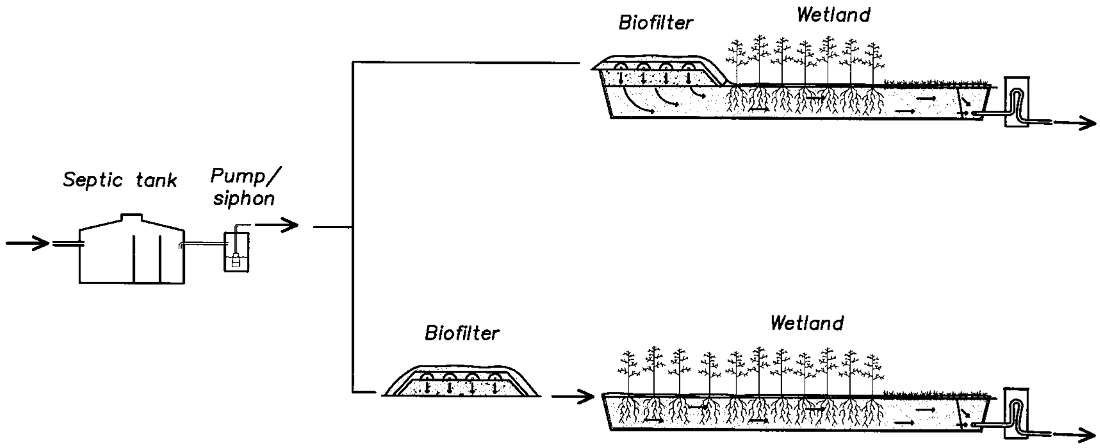


Figure 5.13 A subsurface flow wetland with and without integrated biofilter (From Jenssen and Heistad 2000)

In warm climates and if the area is not restricted a greywater treatment wetland can be constructed without a pretreatment biofilter and the dosing system (pump/siphon) can also be omitted. However, with a biofilter more compact systems can be made (Jenssen and Vråle 2004) for urban applications.

5.2.5.6 Sand filters/vertical flow constructed wetlands

The sand filter is a well-proven method for wastewater purification, which over the last two decades has been used with plants (often termed vertical flow wetland) and is well suited for greywater treatment. The water flow is a vertical unsaturated flow (as in unplanted sand-filters) and the treatment equal to the unsaturated zone in a soil infiltration system. The purification performance is as for soil infiltration systems dependent on the hydraulic loading and the sand texture and surface chemistry of the sand grains. Typical loadings are in the range of 2 – 10 cm/d. In fine and medium sands more than 3 log reduction of indicator bacteria can be expected, the BOD removal is $> 80\%$ and effluent suspended solids (SS) $<$ 5mg/l (Jenssen and Siegrist 1990). Bacteria, virus and phosphorus removal is enhanced when using sand rich in iron oxides. Aeration is improved and short-circuiting avoided if the filter is constructed with sloping sand walls on the sides of the gravel or distribution layer (Fig.5.14).

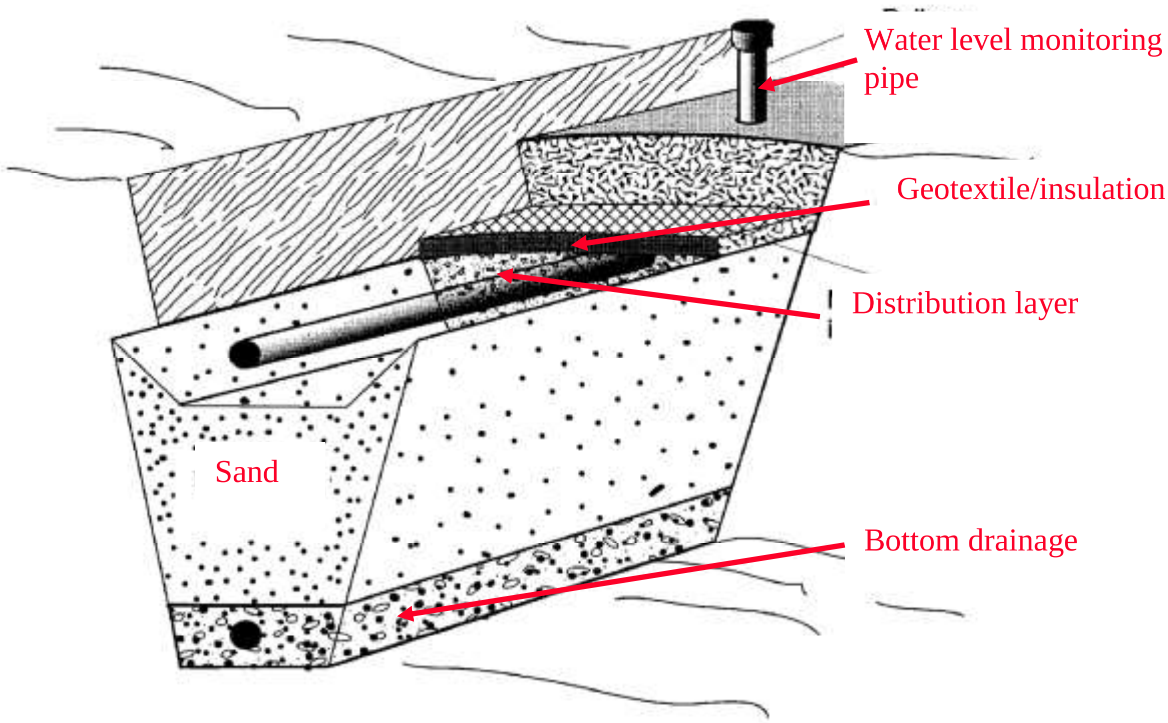


Fig: 5.14 Sandfilter design with sloping sand walls at the level of the distribution pipe.

5.2.5.7 Biofilters

Single pass vertical flow biofilters as pre-treatment to constructed wetlands use light weight aggregates of 2 - 10 mm grain size, but other media that can act as support for the biofilm with maintained performance for BOD reduction (Jenssen et al 2005). In Malaysia crushed coconut shell is suggested as biofilter media. High removal of indicator bacteria have been observed during intermittent filtration with hydraulic loading rate, media grain size and retention time being the most important factors (Stevik et al., 1999a; Stevik et al., 1998;). Pretreatment in a biofilter aerates the greywater and reduces BOD and bacteria, so higher loading rates can be obtained for the subsequent wetland or infiltration system (Heistad et al , 2001). For greywater loading rates up to 110 cm/day a > 70% removal of BOD and ~5 log reduction of indicator bacteria has been achieved (Jenssen and Vråle 2004). A uniform distribution of the water over the filter surface can be obtained using siphons, tipping buckets or a pump and a spray nozzle.

5.2.5.8 Mulch beds and greywater gardens

Dishpan dump, drain mulch basins and similar simple applications of direct use do not need pre-treatment. The mulch bed may be constructed beside trees or berry bushes and the bed excavated and filled with gravel, bark or wood chips. The application and design aim to secure that water is spread evenly over the area and is based on the plant needs. Normally water is applied by gravity but a pressurized system can also be used.

Greywater gardens are a similar technology, where greywater is treated in a planted constructed wetland. Contrary to mulch beds that need to be replaced when the organic material is decomposed, greywater gardens are permanent installations. Pre-treatment is recommended to avoid clogging and sub-surface application minimise the exposure for workers in the gardens,

5.2.5.9 Activated sludge

Activated sludge systems have not been extensively used for greywater treatment. It is assumed that the treatment efficiency will be low if greywater is low in biodegradable carbon, which was shown by Gunther (2000). Activated sludge systems must generally be succeeded by additional treatment to achieve more than 3 log reduction of fecal indicators.

5.2.5.10 Rotating biological contactors

In Germany a successful system using rotating biological contactors has been developed. The system is compact and can i. e be located in the basement of an apartment building. In order to achieve a reduction of fecal indicators > 3 logs the system is equipped with UV-disinfection.

5.2.5.11 Membrane filtration

Membrane processes use a semipermeable membrane and osmotic or lower pressure differential to force water through the membrane as permeate, with dissolved solids or other constituents captured as retentate. Membranes are often made of organic polymers, but new types of inorganic polymers as well as ceramic and metallic membranes are under development. The basic membrane systems include microfiltration, ultrafiltration, nanofiltration and reverse osmosis (RO), each of which retains a different range of particle sizes. Problems with operation and maintenance with membrane treatment may occur through fouling as a result of material build-up, blocking fluid flow across the membrane. Reverse osmosis is particularly susceptible to blockage and therefore requires pre-treatment. However, membrane filtration offers a > 6 log removal of microorganisms and may be applied for upgrading of treated greywater to meet requirements for in-house use.

6. Monitoring and system assessment

This chapter presents information on monitoring and system assessment. Monitoring has three different purposes: validation, or proving that the system is capable of meeting its design requirements; operational monitoring, which provides information regarding the functioning of individual system components related to health protection measures; and verification, which usually takes place at the end of the process (e.g. treated excreta and greywater, crop contamination) to ensure that the system is achieving the targets and validation.

The most effective means of consistently ensuring safety in source-separating systems and the final deposit or use of the end-products in agriculture is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the system, from the generation and use of excreta and greywater to the consumption of the fertilized product. This approach is captured in the Stockholm framework. Three components are important: system assessment; identifying control measures and methods for monitoring them; and developing a management plan. System assessment and its components are discussed in section 6.2.

The combination of health protection measures adopted in a particular system requires monitoring to ensure that the system continues to function effectively. Monitoring, in the sense of observing, inspecting and verifying, is not sufficient on its own but needs arrangements so that the collected information provide feedback to those who implement the health protection measures. The system structure is site specific and may vary in size and functions, but may in planning and operation be concentrated around simple questions, like:

1. What information should be collected?
2. How often and by whom?
3. To whom will this monitoring information be given?
4. What decisions will be taken on the basis of the monitoring information?
5. How can those decisions be implemented?

This requires operational guidelines and verification procedures with which the monitoring results can be compared. Decisions can either be implemented on the user or community levels or by an implementing or operating agency for corrective actions or enforcement. In the case of surveillance by an enforcement agency (for instance a Ministry of Health), the agency has legal powers to enforce compliance with quality standards and other legislation.

6.1 Monitoring functions

The three functions of monitoring are each used for different purposes at different times as briefly summarized in Table 6.1. Validation is performed at the beginning when a new system is developed or when new processes are added. Operational monitoring is used on a routine basis to indicate the system is working as expected. Monitoring of this type relies on simple measurements (e.g. use, storage time, functionality) so that decisions can be made to remedy a potential problem. Verification is used to show that the end product (e.g. excreta, crop contamination) meets microbial quality specifications. Information from verification monitoring is mainly relevant in large collection systems and should not be applied as a household verification. When collected periodically from larger systems it will usually not prevent a hazard break-through but can indicate trends over time (e.g. the efficiency of a specific process or system).

Table 6.1. Definitions of monitoring functions

Function	Definition
Validation	Obtaining evidence that the measures employed to control the hazards are working, (e.g., that the excreta treatment and other barrier functions selected is capable of inactivating faecal pathogens to meet the HBTs). The assessments should take place when a new system is developed or the treatment changed.
Operational monitoring	The act of conducting a planned sequence of observations or measurements to assess whether a control measure is operating within design specifications. Emphasis is given to quick and simple assessments to indicate if the system is functioning properly.
Verification	The application of methods, procedures, tests and other evaluations, in addition to those used in operational monitoring, to determine compliance with the system design parameters and/or whether the system meets specified requirements (e.g. microbial testing for *E. coli* or helminth eggs).

Source: Adapted from NRMMC/EPHC (2005).

6.2 System assessment

In developing a risk management plan, the input from a multidisciplinary team of experts with a thorough understanding of different aspects of the system for recirculation of excreta or greywater as resources are valuable. Typically, such a team would for example include agriculture experts, engineers, environmental health specialists and public health authorities. In most settings, the team would include members from several institutions, and there should be some independent members, such as from universities.

Effective management of the excreta/greywater system requires a comprehensive understanding of the range and magnitude of hazards that may be present and the ability of existing processes, barriers and infrastructure to manage actual or potential risks. It also requires an assessment of capabilities to meet targets. When a new system or an upgrade of an existing system is being planned, the first step in developing a risk management plan is the collection and evaluation of all available relevant information and consideration of what risks may arise. Figure 6.1 illustrates the consecutive steps in the development of a risk management plan.

The assessment and evaluation of an excreta/greywater system could be enhanced through a flow diagram including the identification of sources of hazards and health protection measures. This should be validated by visually checking the diagram against features observed on the ground. Identification of the potential occurrence of hazards in the system combined with information concerning the effectiveness of existing controls form a base for an assessment of whether health-based targets can be achieved with the existing health protection measures or improvements thereof. All elements of the system should be considered concurrently as well as the interactions and influences between elements and their overall effect.

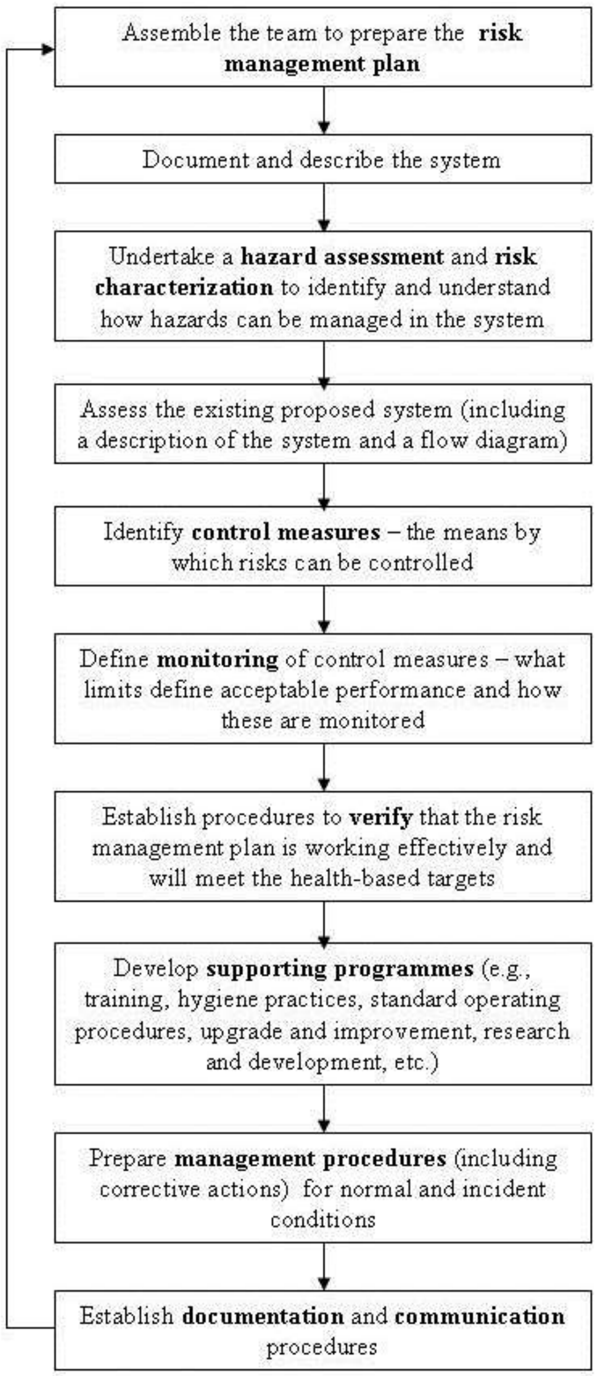


Figure 6.1 Development of a Risk Management Plan. Source: WHO 2004

6.3 Validation

Validation is concerned with obtaining system evidence on the performance of control measures to ensure the capability of meeting specified microbial reduction targets and design criteria. It should be conducted before a new risk management process is put into place (e.g. for greywater and excreta treatment, application and crop harvest), when system components are upgraded (e.g. new toilet collection design) or when procedures (e.g. composting or pH elevation of excreta; irrigation regimes of greywater) are added. It can also be used to test different combinations of processes to maximize process efficiency. Validation of an on-site excreta treatment/storage system could provide data on die-off of different enteric pathogens under existing treatment conditions (e.g., temperature, moisture content, after addition of lime, etc.).

Validation can be conducted at the facility scale or on a test scale starting with considering existing data on-site, from other facilities, from the scientific literature, regulation and legislation departments and professional bodies, historical data and supplier knowledge. These data may be compared or supplemented with laboratory or pilot-level evaluations of the components and overall system under the prevailing conditions accounting for seasonal variations. Validation is not intended for day-to-day management, thus parameters that may be inappropriate for operational monitoring can be assessed or used (WHO, 2004a).

6.4 Operational monitoring

Control measures are actions implemented in the system that prevent, reduce or eliminate contamination and are identified in system assessment. They include, for example, on-site excreta treatment/storage facilities, and use of personal protection during emptying, waste application techniques and adequate time between application and harvest. If collectively operating properly, they would ensure that health-based targets are met.

Operational monitoring is the conduct of planned observations or measurements to assess whether the control measures in a system are operating properly. It is possible to set limits for control measures (like minimum storage time, temperature and conditions during composting etc), monitor those limits and take corrective action in response to a detected deviation before the contamination passes through the system. Operational monitoring should take place around system parameters that indicate the potential for increased risk of hazard break-through. It is facilitated by simple measurements that can be taken quickly. These type of controls can easily be performed within a community, by village committees, community workers etc. Examples of parameters that can be monitored are presented in Table 6.2.

The frequency of operational monitoring varies with the nature of the control measure. If monitoring shows that a limit does not meet specifications, then there is the potential for a hazard break-through. For the treatment of excreta, storage time and temperature can be monitored to indicate pathogen inactivation. The emptying process, either for on-site units or for faecal sludge, the transportation system as well as the withholding time on the fields are other examples of simple monitoring. For a greywater system the faecal cross-contamination and following adequate treatment is central. Open greywater systems should be controlled for mosquito breeding. For faecal sludge the indiscriminate dumping of chemicals may warrant control. In most cases, operational monitoring will be based on simple and rapid observations or tests rather than complex microbial or chemical tests. These instead may be a part of validation and verification activities rather than of operational monitoring.

Figure 6.2. : Elements of an excreta-monitoring system

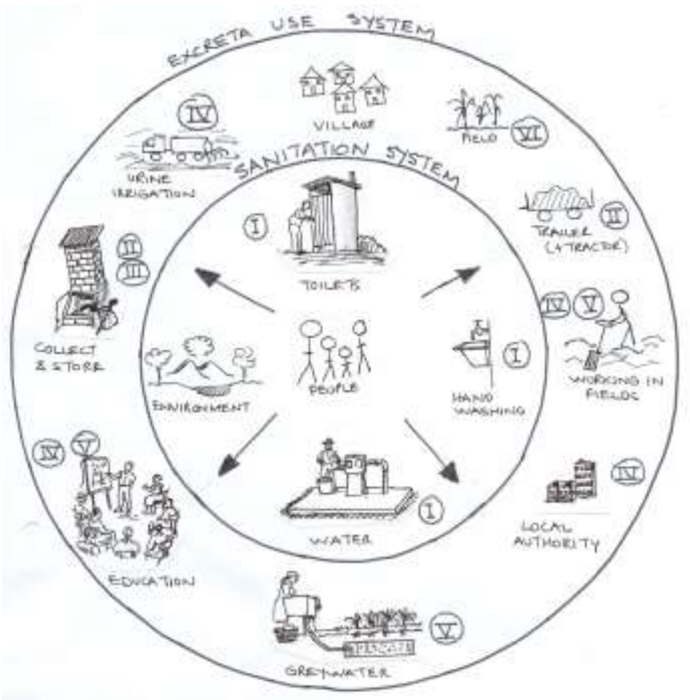


Table 6.2: *Validation, operational and verification monitoring parameters for different control measures*

Control Measures (numbers refer to control points in Fig 6.2)	**Validation Requirements**	**Operational Monitoring Parameters and Technical measure**	**Verification Monitoring**
Excreta and greywater treatment	Effectiveness of treatment processes at inactivating/removing pathogens and indicator organisms (*E. coli*, trematode eggs other helminths, e.g., *Ascaris*)	Parameters ensuring sufficient treatment, design, limiting vector transmission and secondary transmission and reducing personal contact.	For Faeces and Greywater *E. coli* Helminth eggs (*Ascaris*) For urine: Faecal cross-contamination
I. Toilet	Reduction efficiency against enteric bacteria, viruses and parasites.	Design that facilitate cleaning, Elevated and/or lined collection chamber (no seepage to groundwater or environment), Fly control measures (tight fitting lid, ventilation pipe with screen. Clean water and soap for hand washing available;	Ensure appropriate construction and use.
II. Primary handling – collection and transport	Reduced direct contact with insufficiently treated material.	Adequate storage time in double vault toilets. Ash, lime or other means of reducing microorganisms at toilet; informed persons collecting and transporting mechanisms that reduce contact, e g removal containers; Gloves; washing hands; Personal protection.	Ensure adequate handling and adequate treatment.
III. Treatment	Reduced direct contact with insufficiently treated material and environmental contamination	Suitable choice of location; treatment in closed systems; information signs in place. Wearing gloves and protective clothing; washing hands; avoid contact in treatment areas	Ensure adequate handling and adequate treatment.
Health and hygiene promotion	Testing of promotional materials with relevant stakeholder groups	Local programmes in operation Promotional materials available Promotion included in school curriculum	Increased awareness of health and hygiene issues in key stakeholder groups Improved practices
IV. Secondary handling – use, fertilising	Reduced direct contact with insufficiently treated material and environmental contamination	Wearing gloves; washing hands; the equipment used	Informed farmers using excreta; special equipment available.
V. Fertilised field	The amount of time needed for pathogen die-	Working excreta into the ground; information and	Analyse plant contamination

	off under different climatic conditions and for different pathogens/ indicators between waste application and crop harvest to ensure minimal contamination	signs. avoid over-fertilization	
VI. Fertilised crop Produce restriction	Survey of product consumers to identify species always eaten after thorough cooking Analysis of marketability of different species/crops Economic viability of growing products not for human consumption Harvesting, transport and trade; Consumption; contamination of hands, kitchen utensils, food	Harvesting and transport practices. Withholding time between fertilisation and harvest Types of crops grown in excreta use areas Crops cooked before eating	Testing of excreta/greywater to ensure that it meets WHO microbial reduction targets Proper preparation and cooking of food products; domestic and food hygiene; hand washing.

6.5 Verification monitoring

Verification is the use of methods, procedures or tests in addition to those used in operational monitoring to determine if the performance of the greywater/excreta use system is in compliance with the stated objectives outlined by the health-based targets and/or whether the system needs modification and revalidation.

For microbial reduction targets, verification is likely to include microbial analysis. This mainly relates to the faecal/faecal sludge fraction and greywater is source separating systems, but not directly to the urine fraction, since the later usually result in a to rapid die-off of *E coli* to serve its monitoring purpose. The other fractions involve the analysis of faecal indicator microorganisms; in some circumstances, it may also include assessment of specific pathogen densities (e.g. helminth ova). Verification of the microbial quality may be undertaken by public health agencies or other assigned control bodies. Approaches to verification include testing either after treatment or at the point of application or use. Verification of the microbial quality of the wastes often includes testing for *E. coli*. This organism has limitations and its absence will not necessarily indicate freedom from other pathogens. Under certain circumstances, it may be desirable to include more resistant microorganisms, such as *Ascaris* or bacteriophages (viruses that infect bacteria), as indicators for other microbial groups and relate this to a microbial risk assessment of the system.

6.6 Small systems

Validation, operational monitoring and verification monitoring are important steps to identify and eventually mitigate public health issues that might be associated with use in agriculture. However, in some situations, it can be difficult to monitor because it mostly takes place at the subsistence level with small facilities spread out in many locations or is practiced indirectly and informal (e.g. informally in urban areas or in small-scale operations). Additionally, and in comparison, open defecation frequently occurs and much of the wastewater use in agriculture that is practised is indirect and informal (e.g. irrigation with faecally contaminated surface waters). Countries and local authorities may have limited budgets for validation and monitoring and thus will need to develop validation and monitoring programmes based upon the most important local public health issues, the availability of professional staff and access to laboratory facilities.

With many household-level units the national health or food safety authority may chose to validate health protection measures at a central research site and then disseminate information to relevant stakeholders, i.e., through the development of locally adopted guidelines; through public health outreach workers; community comities, "health clubs" or through local stakeholder workshops. For small systems operational monitoring should focus on visual inspections and safety audits without requiring difficult or expensive laboratory testing.

Verification monitoring may be easier to conduct. Data from public health surveillance for faecal–oral diseases, schistosomiasis, intestinal helminth infections and other locally important diseases should be used to adjust health protection measures as necessary.

6.7 Other types of monitoring

Periodically, the microbial contamination of fertilised crops could be tested. Products should be tested for *E. coli*, and helminth eggs where they are a hazard.

Direct measurement of specific health outcomes (e.g. diarrhoeal disease, intestinal helminth infections, schistosomiasis and vector-borne diseases) is possible and can be assessed periodically in exposed populations. This is discussed in the context of the Stockholm framework in chapter 2.

CHAPTER 7. SOCIO-CULTURAL ASPECTS OF EXCRETA AND GREYWATER USE

Human behavioural patterns are a key-determining factor in the transmission of excreta-related diseases. The social feasibility of changing certain behavioural patterns in order to introduce excreta or wastewater use schemes, or to reduce disease transmission in existing schemes, can be assessed only with a prior understanding of the cultural values attached to practices that appear to be social preferences yet which affect disease transmission. Cultural beliefs vary so widely in different parts of the world that it is not possible to assume that any of the practices that have evolved in relation to excreta and wastewater use can be readily transferred elsewhere: a thorough assessment of the local sociocultural context is always necessary. However, there does appear to have been a positive correlation between the occurrence of traditional 'waste' use in societies and their population density, which has been called the "nutritional imperative". Societies that use excreta or have used it in the recent past in agriculture or aquaculture are the most densely populated: Europe, India, China and Southeast Asia (Edwards 1992).

Culture varies and every social group has a norm for excreting; which will vary with age, marital status, sex, education, class, religion, locality, employment and physical capacity (Tanner 1995). Attitudes and norms are often under pressure of change i.e. due to what is being considered modern or fashionable or what customs are possible to retain in new environments (Drangert 2004). Norms and attitudes are also related to existing technical devices and management arrangements. Socio-cultural aspects of excreta and greywater use are outlined in the Sections below.

7.1 Perceptions of excreta and greywater use

Human society has evolved different sociocultural responses to the use of untreated excreta, ranging from abhorrence through disaffection and indifference to predilection. Most religions provide recommendations how to manage excreta and have shaped peoples perceptions. Also, cultural, physical, and social aspects condition the views of use.

In Africa, the Americas and Europe, use of fresh excreta is generally regarded with disaffection. However, conditioning makes caretakers perceive faeces of children and elderly as inoffensive, and the same applies to ones own faeces. Products fertilized with raw excreta are regarded as tainted or defiled but large agricultural areas in many countries are fertilized with raw sewage, and the products find consumers (See WHO Guidelines for the safe use of wastewater in agriculture). Negative views are less articulated in relation to excreta-derived composts or wastewater sludge commonly used in agriculture, horticulture and land reclamation schemes.

In contrast, fresh human excreta have been used in agriculture and aquaculture in Asian countries for thousands of years. This practice is in social accord with the Japanese and Chinese traditions of frugality and reflects an economic appreciation with soil fertility. This has evolved in response to the need to feed a large population with limited land availability, and has necessitated the use of all fertilising resources available. However, access to cheap chemical fertilizers has changed the practices in Japan (Ishikawa 1998). The use of fresh excreta as fertilizer is often combined with the practice to always cook the food, and avoid eating raw vegetables, thus reducing potential disease transmission.

In Islamic societies direct contact with excreta is abhorred, and according to Koranic edict it is regarded as containing impurities *(najass*a). Its use is permitted only when the *najassa* have been removed (Faruqui, Biswas, and Bino 2001). Thus the agricultural use of untreated excreta would not be tolerated, and any attempt to modify this view would be futile. On the other hand, excreta use after treatment would be acceptable if the treatment is such that the *najassa* are removed – for example, after thermophilic composting which produces a humus-like substance that has no visual or odorous connection with the original material. Wastewater may be used for irrigation provided that the impurities *(najass*a) present in raw wastewater are removed. Untreated wastewater is in fact used in some Islamic countries, principally in areas where there is an extreme water shortage and then generally from a local wadi (ephemeral desert stream), but this is clearly a result of economic need and not of cultural preference.

In many countries the task of collecting urban fresh excreta and sanitation facilities that produce this, such as bucket latrines, are being replaced by those that do not, for example pour-flush toilets. Many government are promoting programmes to replace bucket latrines with pour-flush toilets, VIP toilets and urine-diverting toilets, not only for reasons of improved health but also because of "society's demand for doing away with the degrading practice of human beings carrying nightsoil loads" (Venugopalan 1984). From the viewpoint of excreta-related disease control, this is welcomed as the risk to health, is substantially reduced. Perceptions of urine are rarely documented, but most people entertain a fairly relaxed attitude towards it. Urine has traditionally been used to smear wounds or as an insecticide to kill banana weevils in East Africa. In contrast to raw faeces, dried and composted faecal material has a distinctly different appearance similar to ordinary soil and is more acceptable. It is odourless and has a soil-brown colour that reminds people of soil conditioner and less reported cultural avoidance of handling well-processed composted faecal material.

Use practices and perceptions of greywater have hardly been studied. Generally, the view of greywater disposal is relaxed and little thought is devoted to its management. The interpretation is that the user has been in touch with it in the shower, sink or washbasin before it is discharged, and therefore it might be dirty but not harmful. Greywater only contain minor amounts of faecal excreta, unless diapers have been washed or ablution washing is practised, and differs from ordinary wastewater and is not regulated by religious edicts.

A common practice in areas with flush toilets but recurring water cuts, is that residents collect greywater from washing machines and showers and use it for flushing the toilet. In water scarce areas residents sometimes unplug greywater taps and use this water for gardening in periods of watering restrictions. In the case of villagers in India some bring along the day´s greywater to the person who has milk cows as partial payment for the milk.

Treated excreta and greywater are much less objectionable in appearance than untreated and from a socio-aesthetic viewpoint more suitable for agricultural use. Therefore, farmers, residents, and utilities, may take measures to treat or manage urine, faeces and greywater, or a mix of these.

Technical design may minimize contact and smell or visibility of excreta and greywater. Design and technical development of on-site sanitation arrangements can make them odourless, invisible and socio-culturally acceptable. Greywater may be discharged in the yard in a mulch bed or sub-soil irrigation pipe. Urine may be stored in a tank that is connected to a hose-pipe for watering the garden. Faecal matter and paper may be composted.

Generally, farmers seem to have a positive view of the fertilizing value of urine and faecal material and they may select to use it on crops that are not sensitive to market reactions.

The management structure may have built-in incentives for residents and/or caretakers to fulfil supervision and operational maintenance. There is a need to strike a balance between making the system invisible and giving incentives for proper use and sustainability. Use of excreta and greywater can be made safe and acceptable through a combination of technical and management (routines) arrangements. The purpose is to have a system that is simple to run correctly and, ideally, that makes it difficult to abuse. It should be easy to follow the right procedure and difficult to do the wrong one.

7.2 Food related determinants

Perceptions of food are related to beliefs, culture, taboos, and traditions and are increasingly influenced by mass communication. Food habits are formed under particular social and economic conditions. When adapted by individuals or groups to other settings, they may be unsuitable or can even be harmful to health. For example, rural or indigenous peoples moving to urban areas or migrant workers, tourists, or refugees living in foreign communities often maintain their food habits although the conditions for food production, preparation, or processing may be inappropriate or inadequate (WHO 1995).

The sensory properties of a food, the anticipated consequences of ingestion and knowledge of the nature or origin of the food all interact to influence food choice, but the hedonistic response – like or dislike – is the major determinant (WHO 1995).

7.3 Behaviour change and cultural factors

The rapid growth and increased sophistication of consumer goods from detergents to pharmaceuticals make it increasingly difficult for people to know what they discharge after use. End-of-pipe treatment is not always capable of reducing pollution to acceptable levels and is often expensive. The European Commission is developing a procedure aimed at making manufacturers prove that their products are not harmful to humans or the environment (EU Reach Programme 2005). This is different from the current administrative system where the burden of proof is with authorities. To simplify treatment and improve the quality of the resources recovered separate collection and treatment of different liquid and solid waste streams is commonly practiced. In the case of sanitary systems it generally requires a change in behaviour among the users. Where these changes have occurred it has been a result of the users immediate needs and expectations. Attempts to minimize health risks by altering the established excreta use practices are likely to meet with social acceptance and success if the changes are minor and socially unimportant. Any attempts to alter a social preference are likely to fail.

Ingrained routine behaviour may be difficult to change. For instance, disposing wash water from diapers on the lawn may be hard to abandon if there is no feasible instant alternative for the person doing the washing. However, as is often the case, a simple technical improvement such as letting the wash water into a mulch bed can help to solve the contamination problem.

Studies of alternative sanitation in housing areas show that residents are willing to take on new responsibilities for environmental reasons. Among users, criteria such as privacy, convenience, cost and ease of construction or maintenance are often considered more important in system selection than the protection of human health or the environment (Holden et al 2003; Guzha and Musara 2003). The absence of flies and smell in correctly maintained urine diversion toilets, and their permanent structures, allowing them to be built directly on to a house, has proven to be an important factor in their widespread use in areas of South Africa, where they are seen as a modern sanitation alternative (Drangert 2003).

Behavioural change regarding toilet use has occurred rapidly when local conditions have created an imperative for the recovery and use of excreta and/or greywater (Wirbelauer et al 2003), such as a need for improved sanitation or the products, as fertiliser, soil improver or biogas. Physical conditions, such as high water table, regular flooding as well as rocky areas with high cost for digging trenches in the area may prevent conventional sanitation solutions, where instead dry urine-diverting toilets represent an affordable alternative to improve sanitation. Coastal estuaries as well as waterlogged areas occupied by the urban poor may find technical solutions, which are accepted. In dry areas with poor soils use of greywater and treated excreta may become a driving force for improved sanitation since application will make urban agriculture possible, as in West Africa.

Improved public health should always be combined with promoting better domestic and personal hygiene through education and behaviour change. In excreta use systems the people most at risk are those who apply the excreta to the fields, their families, produce handlers, consumers of produce and people with access to the areas where excreta is being used (Kochar 1979). There is a whole range of behaviours that can be targeted to better protect public health.

Improving sanitation facilities and convincing people to use them properly is the first step. It is also important to demonstrate the public health benefits of adequately treating/storing before its use as fertilizers. Information for residents and farmers has a better chance to be effective if it provides 'facts' about what will happen if advice is followed, and if they receive feedback on routine changes. The information provider should make sure that the focus is effective measures to achieve the stated purpose, and to do this 'right thing' in the right way (efficiency).

Educational efforts can be directed at school children, for example inform communities about helminth infections, their lifecycles and preventive measures against transmission, where these are prevalent. Encouraging workers to use protective gear (e.g., rubber boots and gloves) while harvesting or handling crops/products will reduce exposure to infectious agents and improving hygiene practices during produce handling, transport and produce preparation for consumption is very important. Hand-washing with soap is important. Communities should educate people about the risks associated with the contact of untreated excreta. Direct work with farmers/aquaculturalists to restrict the types of produce grown in excreta fertilized fields is advocated.

In many cases it will be possible to tie educational and hygiene behaviour changes to current agricultural extension and health outreach activities (Blumenthal et al. 2000). However, health interventions should focus on a few key specific behaviours and may work better if social and cultural reasons for changing hygiene practices are emphasized rather than exclusively focusing on health benefits (Curtis and Kanki 1998; Blumenthal et al. 2000). The acceptance of a change in sanitary practices are facilitated when users have been given the opportunity to examine and identify their own problems and are offered a wider choice of sanitation systems. "Seeing is believing" has also proved important in overcoming reservations concerning the use of certain systems, particularly when people have had the opportunity to visit them in the homes of neighbours or peers. The equipment and treatment used, the necessary maintenance and the recycled resources available and their form have to be both economically affordable and socially and culturally acceptable in their given context. This can best be achieved with the active participation of all relevant stakeholders in planning processes.

The willingness of communities and individuals to collect, treat and use greywater and excreta vary enormously from country to country, and also within societies. Where poor farming households lack access to fertilizers, the use of excreta in agriculture is often well known and acceptable, but when civil servants working in cities are presented with the concept these may have difficulty regarding acceptance, often supported by their argument that the people would not accept it.

7.4 Convenience factors and dignity issues

Convenient use and operation has proven to be of crucial importance for users including the level of comfort, privacy and security as well as the cost to construct and maintain installations. Many users who have changed to urine diverting systems from pits, or VIPs have appreciated a level of comfort, which they have compared to water toilets. When permanently installed in the house they are more convenient for use day and night, and provide security for women and girls against the risk of sexual harassment when visiting external toilet facilities. Permanent in-house structures receive a greater deal of attention, and have therefore become status symbols in some areas. They can also be adapted to accommodate different anal cleaning practices (Drangert 2003).

One of the greatest perceived inconveniences is the handling of faeces where exposure should be minimised. This handling has implications on the esteem in which the community at large sees those engaged. In some parts of southern Africa the collection and use of someone else's excreta is not seen favourably. However, an example from South Africa shows that when this is linked to economic incentives it may be accepted. In this case, a contractor collects the dry faeces and is paid by the residents for this service. The residents view him as a service provider. He in turn runs a successful company, recovering the nutrients and selling the treated product back to the residents.

The handling of excreta is closely linked to issues of human dignity. In some societies those working with excreta or wastewater may be perceived as "unclean" and the work is often a task reserved for those living on the margins of society in the weakest of social positions. One example of this can be seen among the Dhalits in India, although most states have outlawed the practice since the 1980s. One of the jobs ascribed to them is the manual disposal of human excreta. For conventional sanitation systems, a similar handling of fresh, untreated faeces or wastewater occurs which may pose risk to the health of those working in this sector. This may involve emptying buckets or pits or unblocking sewage networks, frequently without appropriate protective clothing. Systems aimed at using on-site treatment approaches for excreta, may reduce exposures to untreated faeces and create better conditions for those working in this sector.

Additionally, the privacy and convenience of the installations are often seen as protecting and promoting human dignity, by providing safe, private toilet facilities. Care should be taken in the design to ensure that they meet the needs not only of the majority of the adult population but also that sanitation facilities are accessible and useable for small children, the elderly and the disabled, and that their dignity is protected. In house facilities can help to ensure that these goals are achieved.

7.5 Gender aspects on use of excreta and greywater

While men in most areas construct the latrines, women are usually responsible for keeping them clean and useable. Women assist children, the aged and the sick with their hygiene and sanitation needs. Women also take responsibility for socializing children into the use of latrines and providing them with health/hygiene education. Women's perceptions, needs and priorities in relation to sanitation can therefore be quite different from men's. Research in East Africa indicates that safety (particularly for children) and privacy were the main concerns of women. What men want in relation to sanitation has never been specifically assessed. Men's interests, needs and priorities in relation to sanitation may well be as neglected as women's.

A rural case from India exemplifies differences in perception. Open defecation forces women and girls to enter the demarcated area for defecation outside the village. They are vulnerable to abuse or rape, particularly in the evening. Their choice is often to either to use a “pottie” in the house, or refrain until morning. Fathers are protective of the girls and prevent pre-marriage affairs, but this does not appear to be a compelling factor for installing a toilet in the house. There is no outspoken societal norm requesting men to do so despite the fact that their daughter may be hurt. This highlights the need to translate the male task of constructing toilets into a societal non-negotiable norm.

Another indication of deviation from male responsibility in East Africa relates to the placing of the urine-diverting toilet inside the house or in the backyard. Male head of households often opt to have the toilet in the yard, while female heads suggest the toilet to be indoors. This reflects the benefits of the indoor toilet for women’s household chores, while men tend to undervalue female benefits and they rather talk about the risk of bad smell. Also, men generally have more options for excreting; they work outside the home more often and can use the facilities at the workplace or elsewhere. The gender perspectives on sanitation systems, which intentionally recover and use excreta and greywater, have not yet been specifically explored. Women are actively involved in food crop production and concerned about food security. They would be directly affected by increased access to soil nutrients provided by such systems. Access to a ready supply of fertilizer will help to increase food production and facilitate the development of small vegetable gardens and fruit trees close to homes.

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 such systems on the basis of health gains. Women's support would also be critical for the success of different methods to treat faeces and ensure a sufficient reduction in pathogens. Since women have the responsibility for tending the cooking fires, their involvement could be used to ensure a supply of ashes to be used in the latrines. Men, on the other hand, construct the latrine and it could be assumed that they would appreciate not having to construct a new latrine and pit each time the old pit is filled. The possibility of simply emptying the toilet chamber and continuing to use it must be positive from a labour expenditure point of view. However, this task has to be done on a regular basis, which is different from male household tasks generally. Both women and men need access to cash incomes and would be assumed to welcome the potential economic benefits of excreta and greywater use, if the opportunities for small-scale entrepreneurship in construction of sanitary facilities and starting small market gardens are made available to both women and men. In India the fertilizer value of a family´s excreta can pay for the investment in a urine-diversion toilet within four years (Jönsson pers comm).

It has long been established that lack of adequate sanitation facilities, in particular from a privacy perspective, has implications for the education of girls. Parents are reluctant to send their girls to school in some parts of the world where school sanitation is inadequate. Experience from Tanzania in the 1980s revealed that parents sometimes took their girls out of primary school altogether because of poor sanitation facilities. In other cases girls' schooling was irregular because they could not go to school during menstruation, due to inadequate facilities. For girls such systems can therefore contribute to their schooling by providing access to appropriate and adequate sanitation.

Women retain most of the sanitary tasks for cleaning the latrine or toilet in the home. They are often involved in gardening and responsible for feeding the family. Therefore, the potential use of urine and grey water in fertilizing and watering the garden - be it a lawn, trees or vegetables - does not require a change of responsibilities between men and women in the household. By contributing to urban agriculture treated excreta and greywater could help families save money by growing their own fruit and vegetables and/or selling some of the produce. Women often have a great need for increased sources of income but are often confined to the informal sector. Urban agriculture, as a means of ensuring greater food security and potential supplementary income, is particularly attractive to women as it allows them to work close to their homes and facilitates the carrying out of other important roles, such as care of children, elderly and the sick. The importance of ensuring that women, as well as men, are involved in planning and decision-making on urban agriculture initiatives and have equitable access to training and extension services should be emphasized.

Evidence from systems in South India reveals that in areas with high water-tables where other forms of sanitation are not feasible, sanitation systems that facilitate excreta and greywater use provide huge benefits to women and girls. Without access to sanitation the alternative for poor households is that all members of the households have to walk to open defecation sites (separate sites for women and men), sometimes up to a distance of 0.5 km from the household. The health risks at the defecation sites are considerable. There are additional problems for women and girls as they are only able to use these sites to urinate and defecate at dawn and dusk. The toilet in use in South India requires much less water than the more expensive alternative, the water flush toilets, which reduces the work burden for women in drawing and carrying water for the toilets.

Experience from Zimbabwe indicates that women in rural areas prefer the sanitation alternative offered by the arbor loos (An ”arbor loo” is a simple form of latrine with a shallow pit, with a light, moveable slab. When the pit is three-quarters full a new is dug and the slab and superstructure is moved to the new site. The old one is covered with topsoil in which a fruit-tree is planted) to the conventional pit latrines, as they can be built closer to the house. Women expressed appreciation of the gains in terms of privacy and safety, particularly for children, in night use. Women also consider the use of the filled pits for planting fruit trees beneficial. Having the fruit trees close to the house enhances the potential for tending them properly, particularly in terms of being able to use the grey water from bathing and dish washing for watering. Men expressed appreciation of the arbor loos because the pits are smaller than conventional pit latrines and building them requires less labour. These findings are, however, not based on well-documented empirical data but on the observation of practitioners working in the communities.

When sanitation alternatives are being considered it should be ensured that women are involved in all decision-making processes, even if traditionally they are excluded from decisions seen as being outside of the family, connected with the allocation of finances or are concerned with ’technical measures’. It should be remembered that if these systems fail, women would usually be the group most severely affected.

Addressing gender issues implies taking a closer look at social relationships and examining the different roles of community members and the social structure between women and men, girls and boys. Considering gender is therefore not just a matter of involving women in a sanitation project; the first goal is to make gender roles and interdependencies visible and to include this in the implementation process. The roles of men and women with regard to decision making, choice of technology, hygiene, food security, financial security, crop production and health issues should be determined in order to involve the correct groups in an appropriate manner.

The involvement of all stakeholders should therefore have a clear perspective on gender. The involvement of men and women as a single group will not be enough. Participation should be used to define the various roles of the different stakeholders, to describe different expectations and avoid unrealistic hopes (Werner et al., 2003).

8. ENVIRONMENTAL ASPECTS OF EXCRETA AND GREYWATER USE

The use of excreta and greywater has the potential for both positive and negative environmental impacts. The resource value of excreta and greywater has been largely described in Chapter 1. This chapter present an overview on environmental assessment of the use of urine, faeces and greywater and the potential environmental impacts. The environmental impact of the use of human excreta and greywater differ depending on the situation at the outset. It is outside the scope of these guidelines to give specific recommendations on how to manage environmental impact, but rather discuss it in its context.

The intention with the direct use of excreta and greywater is to minimize the environmental impact both in the local and global context. For large-scale implementation, environmental impact assessment (EIA) is a useful tool for the analysis. A procedure for measuring the environmental impacts of different sanitation approaches involves the analysis of material flows (short case example in Box 8.1) or a life-cycle analysis for the production of different crops, which may also lead to a better understanding of the environmental impacts of different agricultural practices (short case example in Box 8.2).

Box 8.1 Example of environmental assessment through material flow analysis.
A practical case study conducted in Viet Tri, Viet Nam allowed an estimation of nitrogen flows related to excreta and organic solid waste management in Viet Tri by applying the method of material flow analysis (Montangero et al, 2004). The results indicate that 60% of the nitrogen delivered to the households in the form of food is finally discharged with the excreta in surface water, fishponds or on the soil, resulting in water pollution. The impact of potential measures including increasing the proportion of households using urine diversion latrines from 5 to 25%; treating 25% of the effluent from on-site sanitation systems in duckweed ponds; and treating 25% of the sludge from on-site systems in constructed wetlands was quantified. The proposed measures lead to a 30% reduction of the nitrogen load into soil and surface water.

The environmental impact of different sanitation systems can be measured in terms of the use of natural resources; discharges to water bodies; air emissions; resources; and the impacts on soils. Table 8.1 summarize the types of impacts that may be considered in an EIA (Kvarnstrom et al, 2004). The environmental impacts of most relevance to the use of excreta and greywater are their potential impacts on soil or water contamination.

Table 8.1 Criteria for measuring environmental impacts of sanitation systems (Kvarnstrom et al, 2004).

Criteria	**Unit**
Use of natural resources, construction, operation and maintenance	
Land	M^2/person
Energy	MJ/person
Construction materials	Type and volume
Chemicals	Type and volume
Fresh Water	
Discharge to water bodies	
BOD/COD	g/person, year
Impact on eutrophication	g/person, year of N and P
Hazardous substances: heavy metals, persistent organic compounds, pharmaceutical residues, hormones, Pathogens	mg/person, year; number/unit
Air emissions	
Contribution to global warming	Kg of CO_2 equivalents
Resources recovered	
Nutrients	% in to the system
Energy	% consumption within the system
Organic materials	% in to the system
Water	% in to the system
Quality of recycled product released to soil	
Hazardous substances: heavy metals, persistent organic compounds, pharmaceutical residues, hormones, pathogens	mg/unit; number/unit

Box 8.2 Life-cycle analysis of wheat production using human urine as fertiliser

Life cycle analysis is another tool for monitoring environmental sustainability. In a study the environmental consequences of introducing urine as a fertiliser to cereals was evaluated (Tidaker, 2003). Conventional production of spring barley with a chemical fertiliser was compared with the same production using urine as fertiliser. If the collection system and handling was optimized and well functioning, the energy use decreased by 27% when urine was used as fertilizer. Eutrophication of surface waters was substantially lowered due to lower discharge of nitrogen and phosphorous, but a higher release of ammonia to the atmosphere occurred. The environmental impact was dependent on decisions made on farm level, highlighting the need for monitoring the reuse system from toilet all the way to the field.

8.1 Impacts on Soil

Relevant substances to consider regarding environmental impacts on the soil are salts, heavy metals, persistent organic compounds, hormones, and nutrients. Pathogenic microorganisms are the main focus of these guidelines and not further discussed in this chapter. Table 8.2 presents a description of contaminants found in different types of fertilizers and their potential for impacting soils.

Table 8.2 Contaminants in different fertilizers and potential relative impacts on soils

	Urine	Faeces	Grey water	Faecal sludge	Wastewater	Farm yard manure	Chemical fertiliser
Heavy metals	X	X	X	X	XXX	X	XX
Toxic organic compounds			XX		XXX		
Pharmaceutical residues	X			X(X)	XX	X	
Salts	XX		XX		XX	XX	XX
Hormones	XX			XX	XX	XX	

8.1.1 Metals

The contents of heavy metals are generally low or very low in excreta, as compared to other impacting sources, and depend on the amounts present in consumed food products. Urine reflects the metabolism and the levels of heavy metals in urine are very low (Jönsson et al., 1999; Vinnerås, 2002; Palmquist et al., 2004). The content of these substances is higher in faeces compared to urine but the concentrations are lower than in chemical fertilizers (e.g. cadmium) and farmyard manure (e g. chromium and lead). The main proportion of the micronutrients and other heavy metals passes through the intestine unaffected (Fraústo da Silva & Williams, 1997). Greywater is the liquid household flow with the highest content of metals due to potential misplacement.

Table 8.3 *Concentrations of heavy metals in urine, faeces, wastewater and in source diverted kitchen waste, compared with farmyard manure*

	Unit	Cu	Zn	Cr	Ni	Pb	Cd
Urine	µg/kg ww	67	30	7	5	1	0
Faeces	µg/kg ww	6667	65000	122	450	122	62
Black water	µg/kg ww	716	6420	18	49	13	7
Kitchen waste	µg/kg ww	6837	8717	1706	1025	3425	34
Cattle org. FYM	µg/kg ww	5220	26640	684	630	184	23
Urine	mg/kg P	101	45	10	7	2	1
Faeces	mg/kg P	2186	21312	40	148	40	20
Black water	mg/kg P	797	7146	20	54	15	7
Kitchen waste	mg/kg P	5279	6731	1317	791	2644	26
Sewage sludge	mg/kg P	13360	19793	1072	617	1108	46.9
Cattle org. FYM	mg/kg P	3537	18049	463	427	124	16

Sources: Steineck et al, 1999; Vinnerås, 2002,

Regardless of the metal content of the excreta and greywater, a metal will not impact plant uptake unless it first reaches a threshold concentration in the soil and the metal is in a mobile phase (e.g. dissolved in the soil solution and not adsorbed to soil particles). Metals are bound to soils with pH above 6.5 and/or with high organic matter content. If pH is below this value, organic matter is consumed or all feasible adsorption soil sites are saturated, metals become mobile and can be absorbed by crops and contaminate water bodies. The plant roots acts as an efficient barrier against uptake of non-essential metals. Therefore, impacts on soils from heavy metals are usually noted on soil microbiology before observed for plants or ultimately humans (or animals). Impacts of heavy metals on crops are complex, because there may be antagonistic interactions that affect their uptake by plants (Drakatos et al., 2002).

One important heavy metal is cadmium, which is a non-essential element that can pass through the root barrier, due to its resemblance to zinc. Cadmium is toxic to humans and needs to be limited in the inflow to agricultural land. Heavy metal concentrations in excreta and greywater generated at the household or small community level will rarely be high enough to threaten the environment.

8.1.2 Persistent organic compounds

Excreta and greywater normally have low contents of persistent organic compounds. However, greywater can, dependent on the household use, contain as many as 900 different organic compounds, but most of these substances will be found at very low concentrations (Eriksson et al, 2002). Collected faecal sludge may also contain a range of different organic chemicals if the toilets have been used dumping these in the households. Therefore, information to system users regarding the importance of correct handling of household chemicals is vital.

If excreta and greywater are treated prior to use in agriculture, the concentration of many of these compounds will be reduced by adsorption, volatilization and biodegradation. Absorption of these substances by plants through roots is not likely to occur due to the large size and high molecular weight of many of these compounds, which reduces their mobility in soil and water (Pahren *et al.*, 1979). It is possible that these chemicals can be transferred to the edible surfaces of crops but concentrations are likely to be low. These substances may be associated with soil that remains on the crops after harvest. Washing produce thoroughly prior to consumption will remove a large percentage of this contamination.

Synthetic organic compounds, organochlorides are adsorbed and biodegraded with time in soil. Cordy *et al.*, (2003) studied the removal of 34 organic compounds that can be found in excreta and greywater, and did not detect any of them after 3 m of infiltration through desert soils with a retention time of 21 days. Removal of endocrine disruptors such as steroidal hormones detected in treated and non-treated wastewater through infiltration in soils has been demonstrated (Mansell, Drewes & Rauch; 2004).

A variety of pharmaceutical residues or their metabolic by-products can be detected in excreta and sometimes greywater. Most of these substances are at the highest concentrations in urine. A number of biologically active pharmaceuticals and their metabolites have been identified in ground and drinking water samples (Heberer et al 2002). The effects of these substances on the ecosystem and animals are not yet known, but negative effects on the quantity or quality of crops is assumed to be negligible. Furthermore, the amount of hormones in manure from domestic animals is far larger than the amount found in human urine or faeces. Thus, even though theoretical estimations based on effects on fish have indicated an ecotoxicological effect from oestradiol, fertiliser experiments with urine or faeces and comparative assessments with manure strongly indicate that the risk is very limited.

Urine and faecal fertilisers are mixed into the topsoil, with a high biological activity. Usually the substances are retained there for months. The dominant removal mechanism for these substances is adsorption. Removal efficiencies are greater in soils containing higher contents of silt, clay and organic matter. Some may be transported through the soil matrix to groundwater and two drugs (carbamazepine and primidone) did not show significant reductions even after six years of passage through the soil aquifer treatment system (Drewes et al 2002). Additional attenuation, to below the detection limit, occurs by biodegradation, regardless of aerobic or anoxic conditions or the type of organic carbon matrix present (hydrophobic acids, hydrophilic carbon vs. colloidal carbon). A variety of pharmaceutical residues or their metabolic by-products in low concentrations can be detected in wastewater, which may either reflect their excretion in urine and faeces or that they are flushed away in the toilet.

Endocrine disruptors (interfere with hormone functions) have also been found and may not degrade quickly in the environment. Mansell, Drewes & Rauch (2004) found that 17-α-estradiol, estriol and testosterone are not sensitive to photodegradation (i.e. less than 10% destruction after 24-h exposure to ultraviolet light). Thus, these compounds could remain on the surface of crops irrigated with greywater if present there. The concentrations of these compounds are usually extremely low, and to date only effects on animals in direct contact with polluted water have been demonstrated. Effects on humans have not been shown.

Regarding the excreta, some substances with endocrine disrupting properties such as hormones (from humans, like 7-ethinylestridiole or from plants, like 17□- alpha- estradiol estriol) and pharmaceuticals may be present in low concentrations - especially in diverted urine. These substances can interfere with hormone functions in marine animals - particularly if the substances are discharged directly into surface waters. It should be noted that animal manure also contains residues of pharmaceuticals used, in many cases preventive medication resulting in high amounts of especially antibiotics. The soil system is generally better equipped than watercourses for degradation of the pharmaceutical residues present in the fertilisers.

There are many indications that pharmaceutical substances have less impact in the agricultural system than when a waterbody is used as a recipient. Additionally, the human use of pharmaceutical substances is small compared to the amount of pesticides used in agriculture, which also represent biologically active compounds, as the pharmaceutical substances.

8.1.3 Salinization

Salinity effects are, in general, only of concern in arid and semi arid regions where accumulated salts are not flushed regularly from the soil profile by rainfall. The use of urine and greywater can accelerate the process of soil salinisation due to its higher salt content. However, fertilisers containing organic materials will help to buffer the negative effects of the salts in the soil profile.

There are four ways in which salinity affects soil productivity:

1) It changes the osmotic pressure at the root zone.
2) It provokes specific ion (sodium, boron or chloride) toxicity.
3) It may interfere with plant uptake of essential nutrients (e.g. potassium and nitrate) due to

antagonism with sodium, chloride and sulfates.

4) It may destroy the soil structure by causing soil dispersion and clogging of pore spaces. This results in an increased lateral drainage but may also affect the oxygenation. Both low-salinity waters and high sodium concentrations in the water in relation to calcium and magnesium concentrations in the soil exacerbate the effects.

Salinization is measured through a combination of parameters. Depending on the type of soils and the washing and drainage conditions, salinity problems can occur with conductivities > 3 mS/m, dissolved solids > 500 mg/L (being severe if > 2000 mg/L), and sodium absorption ratio > of 3 - 9 (Ayers and Wescott, 1985). Soil salinization, is also affected by inefficient drainage, climate and type of soil Practices to limit salinization include soil washing, appropriate soil drainage in addition to the salt inputs.

8.2 Water bodies

Application of excreta and greywater to agricultural land will reduce the direct impacts on water bodies. However, as for any type of fertiliser the nutrients may percolate to groundwater, if applied in excess or be flushed into surface water after excessive rainfall. This impact will always be less than the direct use of water bodies as the primary recipient.

The impact of reuse of human excreta and grey water on groundwater quality depends on factors like: agriculture application rate, the type of irrigation water, the soil type, aquifer vulnerability, the agricultural practises and the type of crops as well as the recharge and groundwater use (Foster *et al.,* 2004).

In order to avoid negative effects of using excreta and greywater as agricultural fertilizers the following should be considered (Foster *et al.,* 2004):

- Improve agricultural practices;
- Establish criteria to operate wells used to supply water for human consumption in the surroundings (establish safe distances to the agriculture site, depth of extraction and appropriate construction); and
- Routinely monitor ground water.

Surface water bodies are affected by agriculture drainage and runoff. Impacts depend on the type of water body (rivers, agriculture channels, lakes or dams) and their use, as well as the hydraulic retention time and the function played within the ecosystem.

A high organic load will independently of the source affect the dissolved oxygen levels, thus impacting aquatic organisms. Additionally the nitrogen or phosphorous washed into water bodies will lead to eutrophication and subsequent oxygen depletion and facilitate the growth of toxin producing algae (Chorus and Bartram, 1999).

Organic chemicals originating from excreta and greywater will only minimally impact surface water bodies due to their adsorption to soil particles after application. The soil will act as a filter before the respective pollutants reach ground and surface waters (see Table 8.4).

Table 8.4 *Contaminants in different fertilizers and potential relative impacts on ground and surface waters*

	Urine	Faeces	Grey water	Faecal sludge	Wastewater	Farm yard manure	Chemical fertiliser
Heavy metals*							
Toxic organic* compounds			X		XX		
Pharmaceutical residues	X			X	X	X	
Salts	X		X		X	X	X
Hormones	X				X	X	
Eutrophication	X	X	X	X	X	X	X

Nitrogen can contaminate ground and surface water bodies by infiltration and agricultural run-off. The amount of nitrogen leached depends on crop demand; hydraulic load due to rain and agriculture water; soil permeability; and, nitrogen content in soils. Agricultural runoff containing phosphorous can cause eutrophication in surface water bodies (reservoirs and lakes). Biodegradable organic matter can consume dissolved oxygen in lakes and rivers if runoff contains high levels of organic matter.

Phosphorous is an essential element for plant growth and external phosphorous from mined phosphate is usually supplied in agriculture in order to increase plant productivity. Soil P contents varies with parent material, texture and management factors such as rate and type of P applied and soil cultivation (Sharpley, 1995). It is usually present in soils in relatively important quantities. World supplies of accessible mined phosphate are diminishing. It is predicted that phosphate carrying rocks/mineral reserves will run out in 60 - 130 years. The mining of phosphate causes environmental damage because it is often removed close to the surface in large open mines leaving behind scarred land. Moreover, phosphate-carrying rocks/minerals also contain varying amounts of non-desired elements, such as cadmium. Approximately 25% of the mined phosphorous ends up in aquatic environments or buried in landfills or other sinks (Tiessen 1995). The discharge into aquatic environments causes eutrophication of water bodies leading to more environmental damage. Moreover, to reduce eutrophication from phosphorous in wastewater discharged into surface waters, wastewater treatment plants require additional P removal treatment processes, that add to costs and complexity of wastewater treatment.

Urine alone contains more than 50% of the excreted phosphorous from humans. Thus the diversion and use of urine in agriculture can aid crop production and reduce the costs of and need for advanced wastewater treatment processes to remove phosphorous from the treated effluents (EcoSanRes 2005).

9. ECONOMICS AND FINANCE

Economic factors are especially important when the viability of a new scheme for the use of wastewater and excreta is being appraised, but even an economically worthwhile project can fail without careful financial planning.

Economic analysis and financial considerations are crucial for encouraging the safe use of excreta and greywater. Economic analysis seeks to establish the economic feasibility of a project and enables comparisons between different options. The cost transfers to other sectors, e.g. the health and environmental impacts on downstream communities, also need to be included in a cost analysis. This can be facilitated by the use of multiple objective decision-making processes.

Financial planning looks at how the project is to be paid for. In establishing the financial feasibility of a project it is important to determine the sources of revenues and clarify who will pay for what. The ability to profitably sell products grown with excreta or greywater or to sell the treated greywater and excreta themselves also needs analysis. Section 9.3 discusses the assessment of market feasibility.

9.1 Economic feasibility

Economic analyses seek to establish whether a project is affordable. There are different methods that can be used to analyse a project and its implementation at the macro-economic level.

9.1.1 Cost-benefit analysis

Within the framework of a cost-benefit analysis monetary values are assigned to all expected costs and benefits of the project whenever possible to determine the feasibility of the project in relation to the economy of the country. The economic appraisal of an excreta and greywater use project is undertaken to determine the cost effectiveness of the project and whether it is worthwhile to proceed with it (Squire and van der Tak 1975; Gittinger 1982). This requires a calculation of the marginal costs and benefits of the project, that is, the differences between the costs and benefits of the project and the costs and benefits of the alternative. For a scheme to be economically viable, its marginal benefits should exceed its marginal costs.

When used to analyse sanitation schemes, cost-benefit analyses have the advantage of producing comparable data for a range of different sanitary options, which can be used for decision making. As part of the overall costs, appraisals should therefore explicitly include those of the system hardware but also for other components such as planning, administration etc., hygiene promotion campaigns, and the health and environmental impacts on downstream communities associated with different sanitation options.

9.1.2 Costs and benefits

One difficulty of traditional economic appraisals for sanitation systems however is that the setting of the system boundaries often leads to many important costs or benefits being completely overlooked. An example of how far these costs can actually reach can be seen by considering a centralized wastewater treatment works which discharges treated effluent to a surface water body. In addition to the investment, reinvestment and operation and maintenance costs of the sewer network and treatment plant, and the expected health benefits for those connected to the system, the environmental problems arising in the receiving water must be considered, as should the social loss of a recreational area, the possible effect on subsequent drinking water treatment, the loss of natural habitats and effects on coastal areas, and the costs of using drinking water to flush the system. Each one of these external costs may in turn incur further costs.

For systems using excreta and greywater these additional costs may include the necessary transformation costs to adapt the existing sanitary infrastructure, additional awareness raising activities to ensure its proper use, and the need for continued research and development of the system. However there are also a large number of direct additional benefits when excreta and greywater are safely used, including;

- Preserving high quality water sources for high priority uses such as drinking-water supply (through the possible use of treated greywater for irrigation water and by not discharging effluents to water sources);
- an improvement of soil structure and fertility;
- increased access to fertiliser, particularly for poor, subsistence farmers (thus increasing harvests);
- reduced energy consumption (both in the treatment works, but also for fertiliser production);
- possible energy production, and resource conservation; and
- creation of small and medium sized businesses, selling technologies or services associated with the collection, treatment and/or marketing of the products.

In order to account for all these costs and benefits the boundaries used when evaluating sanitary systems need to be much broader than they are at present.

Further economic considerations that are of note when choosing sanitation systems for the safe use of excreta and greywater:

- Sewerage systems are expensive to build, operate and maintain - systems that can reduce the infrastructure needs can be much less expensive e.g., on-site dry sanitation (with or without urine diversion);
- The cost of pumping greywater or transporting excreta can be substantial - greywater and excreta treatment facilities should be planned where the greywater and excreta can be cost-effectively used with minimal transport (e.g., neighbourhood biogas digestors could be used to treat excreta from on-site systems in urban areas);
- Low-cost effective greywater and excreta treatment technologies are available;
- Combinations of different treatment technologies (e.g., composting toilets plus post composting with organic material) can increase pathogen removal efficiencies at low cost and provide flexibility for upgrading treatment facilities;
- Users of greywater and excreta may be willing to pay for access to the greywater and excreta;
- Greywater and excreta tariffs may help to foster cost-recovery and/or the sale of crops at a central facility can also raise revenues;
- Differential prices for treated greywater and excreta and freshwater or agricultural inputs may entice farmers to use greywater and excreta instead of high quality freshwater sources or expensive imported fertilisers;

Excreta and greywater use systems can influence both the individual and the national economic status. If excreta and greywater are treated and managed properly, health risks are significantly reduced. On the individual (household) level the means and money spent on caring for or curing a sick person can be allocated to other tasks and time gained through reduced illness can be used for education or income generating activities. On the national level monetary and professional resources are relieved from treating cases of faecal-oral diseases and can be concentrated in other areas.

9.1.3 Multiple objective decision making processes

The information from economic appraisals form an important part of decision making processes but should be used in conjunction with other information that allows other factors and externalities to be taken into account. In order to be able to objectively compare different sanitation systems there is a need for full dynamic, integrated, cost/benefit or multi-criteria analyses of all types of sanitation systems performed over system life cycles or planning periods. This can be achieved using multiple objective decision making approaches. These involve establishing a range of criteria, which consider all key aspects of the system (for example health, environmental, socio-cultural, economic and technical aspects) and using these to form a basis for decision making.

A range of different quantification methods can be used in multiple criteria approaches outside of estimated monetary values, with perhaps DALYs being used to measure health effects, and a palette of different measurable indicators (such as the use of natural resources, discharge to water bodies etc.) for the environment. Socio-cultural aspects, such as the appropriateness of the system or its legal acceptability can be qualitatively assessed, as can technical issues such as system robustness or its compatibility to existing systems. The appraisal of a specific project should also involve not only comparing one system with another, but also comparing possible variants of the same scheme for instance, the use of greywater for different purposes (irrigation, industrial, non-potable uses).

9.1.4 Empirical examples of cost effectiveness studies for reuse systems

One of the difficulties in considering the economic appraisal of sanitation systems that use excreta and greywater is that very few studies have so far been carried out, and that when information is available it is mainly from pilot or demonstration projects, and thus have additional expenses (for example for technology introduction costs, limited, small scale fabrication of system elements, awareness raising activities etc.). Such studies have also tended to consider only a particular aspect of the system rather than adopt a broader view. However within studies, which have only considered investment, reinvestment and operation and maintenance costs, systems designed to use excreta and greywater have been seen to have an economic advantage over more conventional systems (see Box 9.1).

BOX 9.1 Examples of investment and operation and maintenance cost comparisons

1) Germany:

In Brandenburg near Berlin, Germany cost comparisons have been made for three different sanitation concepts for a planned new housing estate, where the population is expected to increase from 672 to 5,000 inhabitants within 10 years. The three systems analysed were:

- Gravity sewer system, consisting of: flush toilets, normal gravity sewer system, pumping station with transport sewer to the existing sewer network, system operated by the public supplier.

- Source separation concept I (gravity, composting of faeces) consisting of: Gravity separation toilets, collection and storage of urine, transport and agricultural use on a nearby farm, faeces transported in gravity sewer with aerobic treatment in a compost separator, utilisation of compost in horticulture, transport of greywater in gravity sewer system, treatment in a constructed wetland, transport to the receiving water.

- Source separation concept II (vacuum, digestion of faeces) consisting of: Vacuum separation toilets, gravity urine transport, storage of the urine and agricultural use on a nearby farm, faeces transported by vacuum sewerage, common treatment with organic waste in a biogas plant, biogas used to produce energy, transport of the digested sludge to nearby farms and utilisation in agriculture, transport of greywater in gravity sewer system, treatment in a constructed wetland, transport to the receiving water.

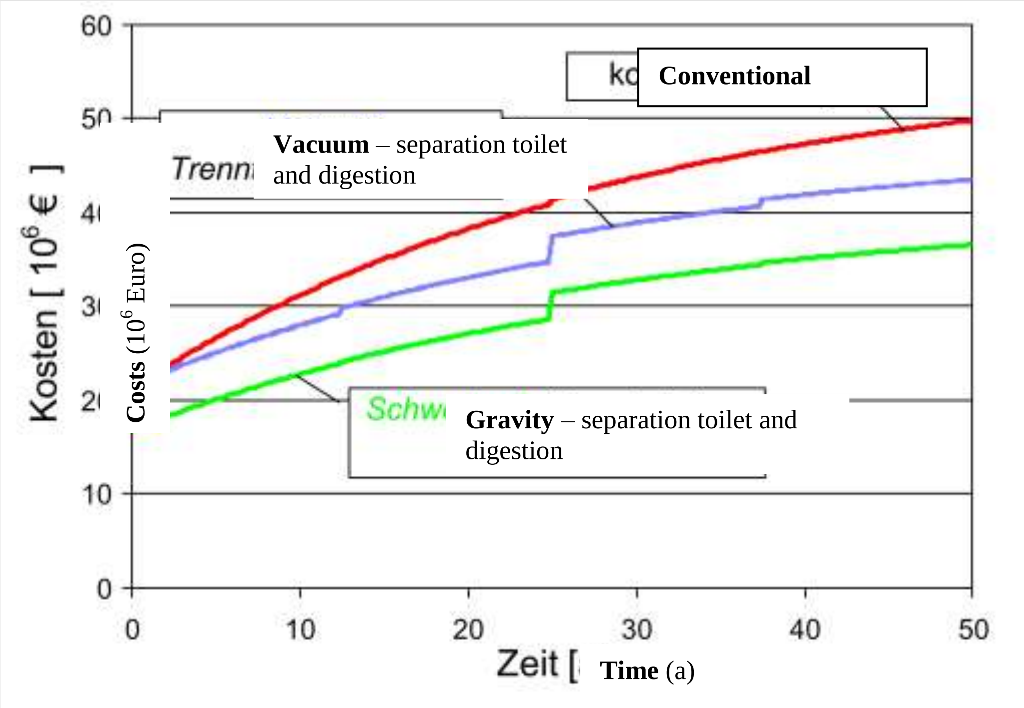


Figure 9.1: Cost comparison for the installation, operation and maintenance of the three systems for a population of 5000

The three systems were calculated over a lifetime of 50 years, with an annual interest rate of 3.5% p.a. The results of this cost comparison can be clearly seen in Figure 9.1, for the situation where 5000 inhabitants are served and the local Berlin water company is responsible for the operation of the system. Other service scenarios have been calculated with different population numbers and operational models, which also revealed a significant price advantage for the use oriented systems over the system lifetime.

2) Uganda

In Kalungu Girls Secondary School in Uganda existing sanitation facilities were jeopardizing the groundwater, the main source of potable water. In 2003 a project was implemented to renew and improve both water supply and sanitation facilities at the school. Additionally a training programme aimed to ensure an understanding and proper use of the new facilities was implemented.

Prior to deciding on the sanitation scheme a detailed cost comparison was conducted and served as one instrument in the decision making progress. Two alternative sanitary solutions were compared:

- Option 1: Source separation concept: dry urine diversion toilets, sewer line for greywater and a horizontal subsurface flow constructed wetland. The treated products from the toilets are to be used to water gardens within the school grounds.

- Option 2: Conventional concept: flush toilets for the students, separate sewer system for wastewater, mechanical pre-treatment, pumping station and a vertical subsurface flow constructed wetland.

The comparison considered investment and reinvestment and operating costs. The calculation was carried out over a 50 year time frame, with reinvestments depending on individual system parts and an interest rate of 8% per annum.

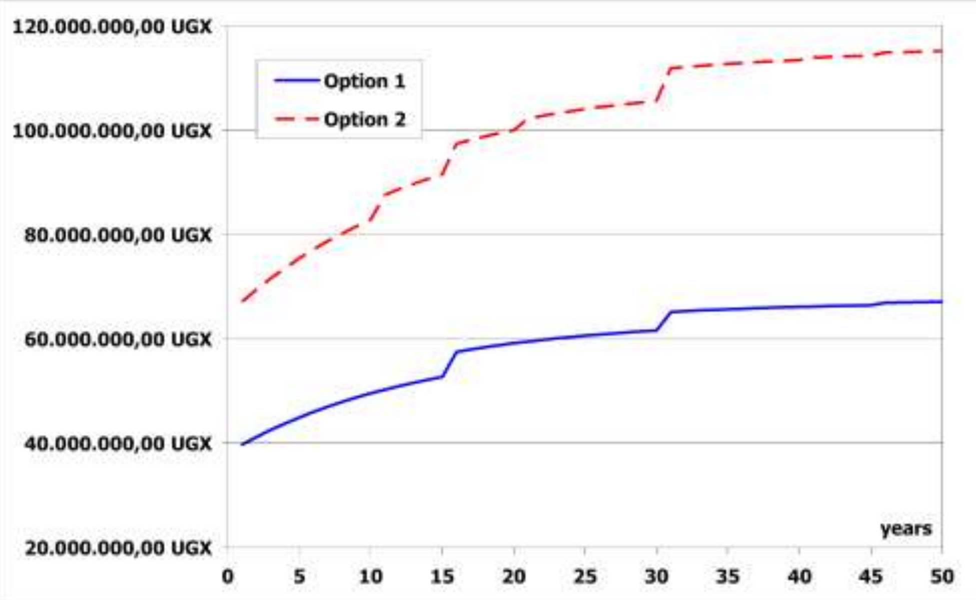


Figure 9.2: Cost comparison for the installation, operation and maintenance of the two systems for the school (exchange rate as of 22 September, 2004: 1€ = 2060 UGX).

The cost comparison in Figure 9.2 clearly shows that the safe use option is significantly less expensive. The main difference results from the significantly smaller wastewater treatment system for this option and the pumping station additionally required for the conventional option.

9.2 Financial feasibility

To ensure sustainable services and cost recovery of excreta and greywater use systems, appropriate financing mechanisms are needed. In drawing up such financing mechanisms allowances should be made not only for the investment, reinvestment, and operation and maintenance of the system but also for the opportunity and environmental costs as well as the systems external impacts on individuals and communities (Cardone and Fonseca, 2003).

Funds are also needed to ensure institutional capacity building and skills training, monitoring and assessment, and policy and the development of an enabling environment for sanitation. The latter includes awareness raising campaigns, hygiene promotion etc. Most of these activities are of a public nature with both the broader community and the individual households benefiting. Financing for sanitation however mainly comes from two sources: the individual or household, and an external source such as government (Evans, 2001). Trying to mobilize individual household financial resources for activities targeted to the broader community has however proven difficult. This raises one of the main challenges of developing financing mechanisms for sanitation: How can the needs, interests and finances of individuals and households be effectively co-ordinated and reconciled with those at the community / national level? Ideally this should be achieved in a way to recover costs, but also to ensure equitable access to sanitation, particularly to poorer members of society.

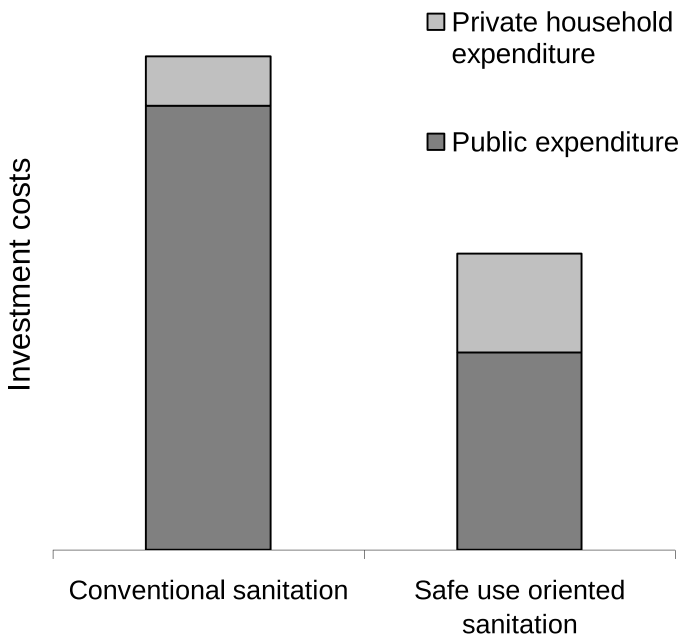


Figure 9.3: The cost structures of conventional and safe use oriented sanitation systems (Werner et al., 2004)

Sanitation systems that recover and use excreta and greywater generally have a different cost structure and appropriate financing mechanisms may be needed to support private households in their decision to install them. As shown in Figure 9.3, the total costs to install such systems tend to be lower than for more conventional sanitation systems. In comparison to traditional decentralised sanitation (such as pit latrines or VIPs), they normally provide permanent solutions, and thus do not have to be replaced when full, representing a significant saving over time. However, although the overall costs are less, those to be covered by the private household may be higher as a result of having to replace or transform domestic sanitary facilities (for example by installing a urine diversion toilet).

Innovative financing alternatives including start-up funds, community based finance programmes, micro-credit programmes or targeted subsidies, which are easily understood by households, may therefore be required. These should put particular emphasis on the possibility to finance the users investment for on-site and neighbourhood systems. Unlike rural areas, the systems for densely populated urban areas can often not be left to the individual choice of the households. Generally a common, acceptable solution must be found, which may even be stipulated in legislation. Financial mechanisms may also be necessary in such cases to ensure a uniform system can be adopted. Financing mechanisms should explicitly target the poorest as they often pay higher costs for services than middle class families (Mehta and Knapp, 2004). A sensitive use of these instruments is essential to ensure proper support is given.

Experience from projects around the world has shown, that simply subsidising sanitation facilities does not guarantee their proper use and maintenance. Often the opposite is true and toilets are converted into store rooms, households do not connect to sewers and wastewater treatment plants fail to work properly (Mehta and Knapp, 2004). These instruments should therefore be focused towards assisting households to provide themselves with sanitation facilities that they need and use, and should not become an end in themselves. As described in Chapter 1 it is often more sustainable to spend more money on promotional efforts (including hygiene promotion) than it is to subsidize sanitation hardware (WSSCC 2005).

It is generally expected that households will be willing to pay up to 3% of household income for improved sanitary services, assuming that the household sees the service as necessary and that it actually does represent an improvement in the current situation (Rogerson, 1996). This expenditure also depends on other factors such as who controls the household finances, ownership of the property where the family live, and the range of sanitary facilities on offer. Understanding what conditions encourage households to invest in sanitation and designing a range of options that respond to their wants and needs may help mobilise finance at the household level. Experience has shown that household interest in sanitation may not be driven by health concerns, with comfort and convenience, prestige, permanence of the structure and of course cost often being seen as a much greater motivating factor in the choice of sanitary system. The additional benefits accruing from the safe use of products also has proved attractive to families engaged in agriculture or horticulture. Adopting a demand responsive approach to sanitation should therefore assist households to choose the system they want and can afford.

Where treated excreta and greywater are distributed by a separate agency from that which collects and treats it, a charge of some sort may be payable. Charges may also be levied when the wastes are distributed to individuals.

The level of these charges should be set in the planning stage. The responsible authorities must decide whether they should be set to cover only the operation and maintenance costs or set higher to recover the capital costs of the scheme as well. While it is of course desirable to ensure the maximum recovery of costs, an important consideration is to avoid discouraging the use of the excreta and greywater. Some prior investigation of the willingness and ability to pay is therefore essential, not only in determining the level of charges but also the frequency, timing and means of payment. For instance, an annual charge payable after the harvest season may be the easiest to collect.

If the products are to be used in agriculture farmers may sometimes be willing to share in the investment in treatment works that are a prerequisite to obtaining use permits. Their contribution may be in cash or in the form of land for treatment and storage facilities. Experiences in Peru have indicated that farmers may sometimes be willing to perform operational and maintenance tasks associated with treatment, storage and conveyance of wastewater, as in-kind contributions to the running costs of the scheme.

The possibilities for private sector participation in sanitation systems that safely recover and use excreta and greywater are considerable (see Boxes 9.2 and 9.3). These range from construction of facilities and providing specific elements for them (e.g. urine separating toilets), the logistics of safely collecting, transporting and treating the products, through to their marketing and use. These market openings can also be stimulated and thus create business opportunities particularly for small and medium-sized enterprises.

Municipalities may also be able to operate profitable service providers for the management and treatment of faecal sludge in urban centres (see Boxes 9.2 and 9.3).

Box 9.2 Private Sector Providers of Sanitation Services

Factors influencing pits latrines and septic tanks emptying service delivery
When the pits of on-site sanitation systems are full, they are emptied by cesspit trucks or manually. The financial, institutional and regulatory framework determines largely where and how the faecal sludges are deposited. To spare cost, the truck drivers in many places sell the sludge to local farmers or dump the product on open spaces or into the drainage systems at the shortest possible distance.

Private cesspit emptying companies are often not legally recognized by the local authorities, even though they may constitute the only initiative catering for FS collection and disposal. In most cases, a fee structure and money flux has become established without any legal control, resulting in emptying fees affordable to only a few and in indiscriminate dumping of FS. Experiences in the field have shown that the emptying service is cost-effective. Proper regulatory mechanisms, private sector competition and the development of economic incentives could help make the collected sludge be delivered to a designated treatment site.

Faecal sludge emptying and haulage: a private sector "stewardship" business
Where the business opportunity exists, small-scale private entrepreneurs owning one or a few cesspit trucks the faecal sludge emptying and haulage service is dominated by . They often hold a share of > 70 % this business in spite of the lack of legal status. The Table below highlights the importance of small-scale sanitation stewardship entrepreneurs, with examples from Ghana, Nepal, Senegal and Viet Nam and illustrates the profit potential for FS removal services. The potential for strengthening the roles of private entrepreneurs in the safe management of faecal sludge exist. The policy framework should facilitate their role in providing safe services.

Table Importance of small scale private sanitation stewardship in faecal sludge management*

	Kumasi	**Dakar**	**Hanoi city**	**Kathmandu**
Population (millions)	1.3	2.1	1.5	0.8
Share of population on onsite sanitation	60	60	90	-
Share of installations emptied mechanically (%)		70	90	64
Number of cesspit trucks in	14	± 100	40	8

operation				
Share of private business (%)	80	75	66	70
Total volume of FS hauled per day (m3)	300 – 400	550	300-400	30-50 m3
Average emptying cost per trip	30-40 €	30-40 €	20-30 €	16-22€
Yearly turnover/truck	30 – 60 k€	20-30 k€	10-20 k€	10 -15 k€

Source: data compiled from field survey by Sandec and its partners (CREPA, CEETIA/Viet Nam, ENPHO/Nepal) Prepared by Doulaye Koné and Martin Strauss, Sandec/Eawag

Box 9.3 Innovative money flux for improved faecal sludge management

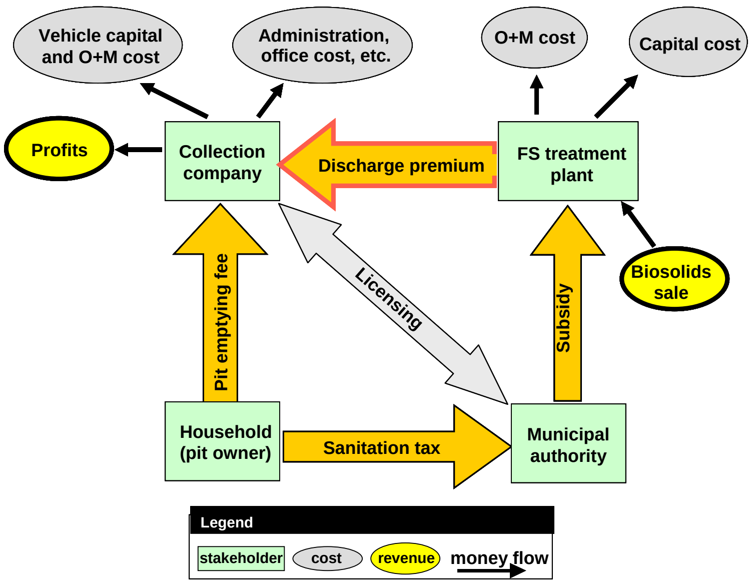


Figure 9.3 Innovative money flux scheme in FS management

Sustainable environmental sanitation may be achieved or enhanced only by applying appropriate financial incentives and sanctions (Wright 1997). Hence, municipalities must devise an effective sanctioning system (e.g. by imposing fines or non-renewal of FS collection contracts with entrepreneurs), and an incentive-based policy by, among others, paying entrepreneurs for delivering FS to the legally designated treatment or disposal site.

The potential business opportunity is shown in Fig. 9.3. It is based on a rigorous economic analysis of the business opportunities and potential of existing and expected future key players. It analyzes conditions under which, each player can make a profit, based on their operation and maintenance costs, capital costs, margins of profit and potential for improving the service delivery. The development of the money flow model present in Figure 9.3 implies a participatory consultation with key stakeholders (households, entrepreneurs, authority representatives, Technical services, farmers, etc.). Hence the project development process should be guided by a thorough stakeholder analysis study and stakeholder involvement process study.

Figure 9.3 illustrates such a financial scheme, the most crucial element of which is the payment to collectors for FS brought to the treatment site (discharge premiums). The flux reversal principle is about to be introduced in the city of Danang, Viet Nam. The city of Ouagadougou, Burkina Faso, is planning to pay collectors the equivalent of € 3.70 per standard truck load upon delivery of FS to the new wastewater/FS treatment scheme to reduce illegal and illicit dumping of FS or use of untreated FS in agriculture. For FS management to function on a sustainable basis, national or municipal governments must consider providing subsidies, recoverable partly by surtax on water, wastewater or sanitation charged to households. The rationale for such a policy is to render pit emptying affordable to all urban dwellers, to enable entrepreneurs to operate FS services with adequate profit margins, and to keep prices for biosolids usable in agriculture competitive. Intensive information, awareness raising and social/commercial marketing campaigns are needed to render new money flux procedures acceptable by the urban customers and to induce the demand of farmers for biosolids.

Sources: CREPA-Senegal, 2002; Strauss et al. 2003; Wright 1997.

9.3 Market Feasibility

In planning for greywater and excreta use it is important that the market feasibility be assessed. Market feasibility may refer to the ability to sell (treated) greywater and excreta to producers or it can refer to the products produced (see Table 9.1). For selling treated greywater and excreta it is important to have an idea of how much people are willing and able to pay. Assessing the market feasibility is particularly important when produce restriction in agriculture is being considered as a partial health protection measure. Producers should be consulted as to which products can be restricted. If farmers or market gardeners can not make a suitable return on the products that they are allowed to raise, then produce or waste application restrictions are likely to fail. Equally, if the excreta are to be used for gas or energy generation, it should also be ascertained if this could be achieved at a competitive price.

Any product derived from the treated greywater and excreta (e.g., fish, plants, biogas, etc.) must also be acceptable to the consumers. If the public perception of these products is negative, even if the quality meets WHO or national performance criteria, then producers still may not be able to sell their wares. If agricultural products will require post-harvesting processing the cost and availability of these services need to be considered. In some cases, it will be necessary to market products to increase demand and profit potential. Currently, however, most treated excreta and greywater is being managed decentrally, often at household level, and being used in subsistence rather than market agriculture and horticulture.

Table 9.1 Market Feasibility - Planning Questions

Product for sale	**Key Questions**
Greywater and excreta	• What is the price for the treated greywater and excreta which people are willing and able to pay? • What is the demand in the project area for treated greywater and excreta? • Are there extra costs required to get the treated greywater and excreta to the where it will be used (e.g., pumping costs, transport, etc.)?
Produce	• Are products (plants, biogas, fish, etc.) acceptable to

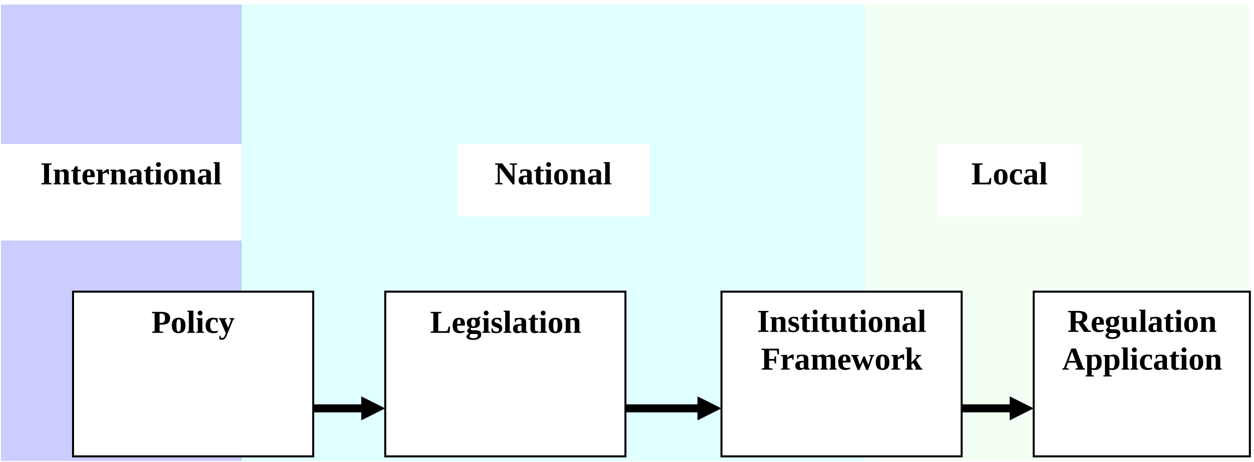
	consumers? • Can producers earn acceptable returns with restricted application and produce? • Is the project capable of supplying products that meet market quality criteria (e.g., microbial standards for products to be exported)?

10. POLICY ASPECTS

The safe management and use of excreta and greywater is facilitated by the appropriate policies, legislation, institutional framework and regulation at the international, national and local levels. In many countries these frameworks are lacking or are inappropriate to the context. This chapter looks at different policy and institutional aspects that help encourage the safe use of excreta and greywater. It also gives some country specific policy/legal/regulatory examples. A policy framework should be based on a holistic approach that maximizes the public health protection and environmental benefits from the point of excreta and greywater generation, through application and final product consumption.

Policy is the overall framework that sets national development priorities. It can be influenced by international policy decisions (e.g., MDGs, Commission on Sustainable Development), international treaties or commitments (e.g. the United Nations Environment Programme's Global Programme of Action for the Protection of the Marine Environment from Land-based Activities) or multilateral development institutions. Policy leads to the creation of relevant legislation. Legislation establishes the responsibilities and rights of different stakeholders - that is, the institutional framework. The institutional framework determines which agency has the lead responsibility for creating regulations (often as part of a consultative process) and who has the authority to implement and enforce the regulations (Figure 10.1).

Figure 10.1 Policy Framework



10.1 Policy

Policy is the set of procedures, rules and allocation mechanisms that provide the basis for programmes and services. Policies set priorities and often allocate resources for their implementation. Policies are implemented through four types of policy instruments (Elledge 2003):

1) *Laws and regulations:* Laws generally provide the overall framework. Regulations provide the more detailed guidance and may be developed at the national, regional or local level by different authorities as set out in legislation. Regulations are rules or governmental orders designed to control or govern behaviour and often have the force of law. Regulations for excreta and greywater use can cover a wide range of topics, including the practices of service providers, design standards, tariffs, treatment requirements, targets

and monitoring requirements, crop restrictions, environmental protection and contracts. These regulations, especially treatment and operational monitoring, have to be adapted to local condition.

2) *Economic measures:* Examples of economic measures are user charges, subsidies, incentives and fines. User charges, or tariffs, are charges that households and enterprises pay in exchange for the removal of human excreta and greywater. Subsidies are allocations in cash or kind to communities and households for establishing recommended types of sanitation facilities or services. Fines are monetary charges imposed on enterprises and people for unsafe disposal, emissions and/or risky hygienic behaviours and practices, which are a danger to people and the environment.
3) *Information and education programmes:* These programmes include public awareness campaigns and educational programmes designed to generate demand and public support for efforts to expand sanitation and hygiene services and encourage the safe use of excreta and greywater.
4) *Assignment of rights and responsibilities for providing services:* National governments are responsible for determining the roles of national agencies and the appropriate roles of the public, private and non-profit sectors in programme development, implementation and service delivery.

The legislation resulting from policies for the safe use of excreta and greywater should establish a clear functional framework of how the sanitary system should operate. It should be directed explicitly at the household level and make clear provision for all types of sanitation systems (from centralised to on-site systems). Local government have a key role in implementing and enforcing such legislation.

10.1.1 International Policy

International policy may affect the creation of national greywater and excreta use policies. Countries agree to treaties, conventions, International Development Targets, etc. that may commit them to carry out certain actions. For example countries may have commitments with respect to the Millennium Development Goals (Chapter 1), the Commission on Sustainable Development or in relation to reducing the use and/or contamination of water resources that cross international boundaries (e.g., by requiring less freshwater abstraction or wastewater and excreta discharges to be treated to higher qualities to reduce basin-wide contamination). Another major issue is the worldwide export of food. Food products raised in compliance with the WHO *Guidelines for the safe use of wastewater, excreta and greywater* are internationally recognized as being developed within an appropriate risk management framework. This can help to facilitate international trade in food products produced with wastewater and excreta.

10.1.2 National greywater and excreta use policies

Policy priorities for each country are necessarily different to reflect local conditions. National policy on the use of excreta and greywater in agriculture needs to consider issues including:

- Health implications of excreta and greywater use in agriculture (requirement for a health impact assessment (HIA) prior to large-scale project implementation);
- Water scarcity
- Wetland, coastal zone ocean impact and biodiversity;
- Resource recovery and recycling;
- Resource availability;

- Socio-cultural factors that influence practices and acceptability of excreta and greywater use;
- Ability to effectively treat excreta and greywater;
- Ability to implement health protection measures to safely manage excreta and greywater use;
- Impacts if excreta and greywater are not used;
- Impacts on household nutrition, food security and local economy;
- Numbers of people dependent upon excreta and / or greywater use in agriculture for their livelihoods;

- Trade implications of crops grown using treated excreta and/or greywater.

Excreta and greywater use is often poorly anchored in existing policy and institutional structures. It may be divided arbitrarily between institutions working in public health, water resources management, rural development, or between town municipalities, and regional and national governments. This may result in incoherent approaches and strategies, without an overall institutional responsibility. As most of the excreta and greywater management issues are likely to occur either at the household or community levels, policies should be clearly based upon a household centered approach. Policies developed for sanitation also apply to the safe use of excreta and greywater, and are best enforced by local governments and authorities.

In addition to public health aspects, environmental concerns are important in developing excreta and greywater use policies. National policies can strive to reduce environmental damage by requiring appropriate treatment chains and may also encourage the beneficial recycling of water and nutrient resources. This is essential in relation to phosphorus, an important nutrient in excreta and greywater and indispensable for crop development in agriculture but also a major cause of eutrophication if it ends up in fresh water.

10.1.3 Greywater and excreta in integrated water resources management (IWRM)

In many arid and semi-arid countries, the renewable freshwater resources available are already heavily exploited. IWRM is a process, which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.
Greywater and excreta management are increasingly being viewed in this greater context of integrated water resources management. Greywater may represent a reliable water source with constant flows even in the dry season, and excreta a constant source of organic material, nutrients and energy. The productive use of greywater and excreta should figure prominently in water resources management as it enables communities to reserve and preserve higher quality water resources (i.e., groundwater or uncontaminated surface waters), as well as to improve soil structure and fertility. Excreta and greywater use policies emphasize approaches that reduce environmental contamination and promote safe resource use. Commercial fertilizers might not be an option for many farmers, due to high costs, while plant nutrients present in excreta and greywater are readily available. This also reduces dependency on commercial fertilizers for crop production, which is important in the local context as well as on a policy level.

10.2 Legislation

Legislation may facilitate technical incentives and financing mechanisms. In addition legislation define responsibilities and cooperation between relevant stakeholders including the private sector; allocate financial resources to capacity building and training, and to monitoring, implementation and maintenance. It facilitates enforcement of consistent standards for excreta and greywater related to other sectors (e.g., education, housing construction, workplace safety, etc.). Effective legislation/regulations both have incentives for complying and sanctions for not complying with the requirements (WHO 2004).

Often it may be sufficient to amend existing legislation, but sometimes new legislation is required. The following areas deserve attention:

- define institutional responsibilities or allocate new powers to existing bodies;
- establish roles and relationships between national and local governments in the sector;
- create rights of access to and ownership of greywater and excreta, including public regulation of its use;
- establish land tenure;
- develop public health and agricultural legislation: greywater and excreta quality standards, produce restrictions, application methods, occupational health, food hygiene, etc.

Box 10.1 Legislation promoting or preventing?

The Swedish Environmental Code (SFS 1998:808) contains an example of legislation where the use and saving of resources is in focus. The Objective (ch1 §1) states: *The purpose of this Code is to promote sustainable development, which will assure a healthy and sound environment for present and future generations. …*

The Environmental Code shall be applied in such a way as to ensure that: /…/ 5. reuse and recycling, as well as other management of materials, raw materials and energy are encouraged with a view to establishing and maintaining natural cycles

.

This aim is underlined in **Chapter 2. General rules of consideration etc.** ***2 ch 5 § states:*** *"Persons who pursue an activity or take a measure shall conserve raw materials and energy and reuse and recycle them wherever possible. Reference shall be given to renewable energy sources."*

This article ensures that the aim of conserving raw materials and resources is as important as the aim of minimizing emissions of pollutants etc. Recycling of nutrients is now stipulated in the provisions for example for small wastewater plants for single family houses.

The German legislation gives an example of counterproductive legislation. Soil protection guidelines, public health protection guidelines, fertilizer use legislation, etc. are rarely developed in parallel to each other, which can create contradictions concerning excreta and greywater use. It might be very difficult to establish how permission can be obtained to use excreta and greywater legally. One example of this would be the case of urine use in the Federal Republic of Germany, where by definition urine is not considered as wastewater and is therefore not regulated for use as a fertilizer, making agricultural use of urine difficult.

10.2.1 Institutional Roles and Responsibilities

Enabling legislation may be required to establish a national coordinating body for excreta and greywater use and to set up local bodies to manage individual schemes. These will require a certain degree of autonomy from central government and the ability either to charge for the excreta and greywater they distribute or to sell any produce. Working within an existing institutional framework may be preferable to creating new institutions.

At national level the safe use of excreta and greywater is an activity that touches the responsibilities of several ministries or agencies. Normally, the development of policies to encourage the safe use of excreta and greywater would involve a consultative process between different agencies/institutions with overlapping responsibilities. Examples of ministries or agencies that have jurisdiction over the use of greywater and excreta might include:

- ***Ministry of Agriculture and Fisheries****:* overall project planning; management of state-owned land; installation and operation of irrigation infrastructure; agricultural and aquacultural research and extension, including training; control of product marketing.
- ***Ministry of Environment****:* sets excreta and greywater treatment and effluent quality standards based on environmental concerns, establishes practices for protecting water resources (both surface and groundwaters) and the environment; establishes monitoring and analytical testing protocols.
- ***Ministry of Health****:* health protection, particularly establishment of quality standards (for treated excreta and greywater, products; health protection measures), monitoring methods and schedules for treated excreta and greywater; health education; disease surveillance and treatment.
- ***Ministry of Water Resources****:* integration of excreta and greywater use into water resources planning and management.
- ***Ministry of Energy****:* integration of the energy generated from the anaerobic treatment excreta and greywater into national energy plans.
- ***Ministry of Education****:* develop school curricula concerning: sanitation and personal and domestic hygiene and safe practices related to the use of excreta and greywater
- ***Ministry of Public Works/Local Government****:* excreta and greywater collection, treatment and use.
- ***Ministry of Finance and Economic Planning****:* economic and financial appraisal of projects; import control (equipment, fish feed); development of financing mechanisms for excreta and greywater conveyance and treatment and use infrastructure.

Other ministries and government agencies, for example those concerned with land tenure, rural development, cooperatives and women's affairs, may also be involved.
Co-operation between the relevant agencies is required, particularly between the technical staff involved. Some countries, especially where there is water scarcity, may find it advantageous to establish an executive body, such as an interagency technical standing committee, under the aegis of a leading ministry (Agriculture or Water Resources), or possibly a separate organization (with both government and private funding sources), to be

responsible for the development, planning and management of excreta and greywater use projects.

In many countries a simple *ad hoc* committee may be sufficient. Alternatively, existing organizations may be given responsibility for the sector, or parts of it: for example, a National Water Board might be made responsible for the use in aquaculture / agriculture / energy generation. Such an organization should then convene a committee of representatives from the different agencies having related responsibilities. Setting up an interagency or inter-ministerial committee will help to inform others of the challenges/opportunities in developing safe approaches for the sector.

For example, in Uganda an Inter-Ministerial Steering Committee (IMSC) was set up as a policy and strategy making body to oversee activities related to water supply, sanitation and hygiene. It was made up of the Permanent Secretaries and Directors from the Ministries of Health, Water, Lands and Environment, Gender, Labour and Social Development, Local Government, Education and Sports, Finance Planning and Economic Development. The role of this committee was to review the overall sector policy; co-ordinate and promote convergence between sector agency activities; and promote appropriate changes in policies for sector programs and projects.

In countries with a regional or federal administration, such arrangements for interagency collaboration will be important at the regional or state level. Whereas the general framework of greywater and excreta use policy and standards may be defined at the national level, the regional body will have to interpret and add to these in the light of local conditions.

The local body managing a scheme, or at least the agency collecting the greywater and excreta, will often be under municipal control. If greywater and excreta use is to be promoted in the context of a national policy, this implies careful coordination and definition of the relationship between local and national government. On the one hand, it may be necessary for the national government to offer incentives to local authorities to promote safe greywater and excreta use, but at the same time, sanctions of some sort may have to be applied to ensure that schemes are implemented without significant risk to public health.

Local governments should be given the authority to develop their own regulations. For example, they should have the ability to collect fees for greywater and excreta treatment or other services, issue permits, conduct inspections, develop produce restrictions, inspect markets, develop decentralized greywater and excreta treatment and use facilities, etc.

Local authorities should have the ability to issue permits for the use of excreta and greywater from a public conveyance network. Permits may be issued by the local agriculture or water resources administration, or by the body controlling the greywater and excreta distribution system. Provision of such permits for greywater and excreta use could be made conditional on the observance of sanitary practices regarding application methods, produce restriction and exposure control.

It is also common for the body administering the distribution of greywater and excreta to deal with the landowners through users' associations, which may develop from traditional institutions. Permits to use greywater and excreta can then be issued to the associations, which simplify the administrative task of dealing separately with a large number of small users and also delegates to the associations the task of enforcing the regulations which must be complied with for a permit to be renewed.

A joint committee or management board, which may include representatives of these associations, as well as any particularly large users, the authorities that collect and distribute the greywater and excreta, and also the local health authorities, is required. Even in small-scale organizations, some arrangement such as a committee with community representatives is important for the users to participate in the management of the project. In some cases farmers will be able to directly negotiate contracts for a specified supply of treated greywater and excreta with the utility that treats it.

10.2.2 Other Roles and Responsibilities

The number of stakeholders that may be involved in safe use sanitary systems can be quite large, and may include individuals, groups, institutions or organisations with different needs and concerns. A detailed stakeholder analysis is normally carried out at the start of activities to identify those that will be of relevance and how large stakeholder groups may be effectively addressed and represented.

The stakeholder analysis given below provides an overview of the possible stakeholders in excreta and greywater use programmes.

- ***Users of sanitation facilities:*** Most often the individual households. In rural areas the households are usually the final decision makers, responsible for the construction and maintenance, as well as the collection and treatment of the excreta and greywater, whereas in urban areas households may be marginally involved, with service providers collecting the excreta and greywater, for further secondary off-site treatment, generally against payment. The households can help drive the process forward by adopting good sanitation and hygiene practices; innovating, taking action, talking to the neighbours about solving local problems, and encouraging local political representatives to support locally developed solutions.

- ***Users of the treated excreta and / or greywater:*** These may be the users of the sanitation facilities themselves or in urban areas like beneficiaries of urban agriculture, market gardeners, or the communities for use in municipal areas.

- ***Community Based Organizations (CBOs) and self-help groups:*** support the households by organizing the delivery of the different services needed (such as maintenance of the facilities, or the collection and treatment of the final treated products) and the use of the produced fertiliser at the level of the CBO/ neighbourhood-groups.

- ***Non-Governmental Organizations:*** providing information and raising awareness among potential users. They also often advise the households on the use of sanitation systems, and support (poor) households in the contact with e g. financing institutions and municipalities.

- ***Service providers:*** encompasses a group of diverse stakeholders, engaged in public or private market oriented activities of service provision. These include planners, consultants, producers / suppliers, construction companies, utilities providers, and companies involved in excreta and greywater collection, transport, and treatment. Farmers also act as service providers by collecting and treating excreta from the users of the sanitary facilities.

- ***Developers and investors:*** Either from private or public may initiate the construction of residential units. The decision of developers and investors to introduce systems that safely use excreta and / or greywater is often tightly related to the premises demand. They are often actively involved in the planning and implementation process of an entire programme.

- ***Financial institutions:*** The introduction of new infrastructure generally requires that the investment and operation costs be secured.

- ***Research institutions:*** These may be universities or other research oriented institutions or organizations that can fulfil different tasks by providing advice to programme initiators, developers, municipalities and NGOs.

- ***International organizations:*** can ensure that external funds for sanitation hardware are bundled with appropriate hygiene promotion and sanitation marketing activities; encourage governments to consider appropriate, cheaper and more sustainable sanitation systems; finance local sanitation research; develop guidance and tools for facilitating good practice; disseminate information; actively endorse the idea of flexible technical norms and standards to allow for innovation where excreta and greywater use is promoted; and offer support in adopting the legislative and regulatory framework to facilitate safe use and resource efficiency as part of sanitation systems.

Table 10.1 presents some of the factors that may either encourage (motivating factors) or discourage (constraints) different stakeholders to adopt safe use systems. A participatory approach is essential where the stakeholders have the possibility to voice their motivations and reservations. Equally important is to deal with the constraints raised. To map the motivations and constraints is a useful task, which should be adapted during the course of the project, becoming increasingly specific with time.

Table 10.1 Different factors for stakeholders to adopt safe use systems

Principal Stakeholders	**Examples of Motivating Factors**	**Examples of Constraints**
I. Users of sanitation facilities: households, neighbourhoods, tourists, pupils, employees, …	No smell, hygiene improvement, structural stability, local physical factors (high groundwater table, rocky ground…), reduced costs, increased comfort, improvement of quality of life, greater security (in-house construction), interest in treated products, prestige, ecological reasons, water scarcity, unreliable water supply, …	Habits, taboos, hygiene concerns, unfamiliarity, fear of loss of comfort, unavailability of structural elements, legislative restrictions, economic factors (e.g. for start-up etc.), …
II. User of treated products	Economic reasons, local and reliable availability of agricultural inputs (water, nutrients, organics), increase of crop yields for either the market or for family needs, improvement of self sufficiency, ecological reasons, …	Habits, taboos, lack of logistics, fear of negative consumer perception, fear of negative long term effects on soil, …
III. CBOs and self-help	Failure of conventional / existing sanitation	Habits, taboos, lack of information,

Principal Stakeholders	Examples of Motivating Factors	Examples of Constraints
groups	system, local improvement of quality of life, Agenda 21, interest in treated products, reduced costs, local physical factors (high groundwater table, rocky ground…)	insufficient financing, inappropriate legislation, influence of interest groups, hygienic concerns, …
IV. NGOs	Failure of conventional / existing sanitation systems, economic reasons, ecological reasons, agricultural reuse of treated products, improve quality of life, …	Habits, taboos, lack of information, insufficient financing, inappropriate legislation, influence of interest groups, hygienic concerns, …
V. Local authorities, governmental institutions	Political reasons, economic reasons, ecological reasons, Agenda 21, failure of conventional / existing sanitation system, possibility of financial support, sustainability of system, support regional self-sufficiency, promotion of (urban) agriculture, job (and income) creation, long-term security of social services (water supply etc.), …	Habits, taboos, lack of information, lack of start-up funds / insufficient financing, monitoring of treatment / handling etc., more difficult for decentralised system, distrust of alternative systems, not recognised as state of the art technology, reluctance to change status quo, contradiction of existing legal framework / long term plans, powerful lobby from conventional centralised sanitation industry, corruption, …
VI. Service providers: Planners / consultants, constructors (builders), maintenance service providers, producers of equipment, providers of collection, treatment, transport and marketing of the treated products	Increased profit, opening up of a potentially huge new market, request / need for particular product, further develop their own know-how, ethical / ecological reasons	Absence of technical knowledge, absence of products, inappropriate legislation, lack of suitable tools, economic interest of (waste) water monopolies, fear of failure (economic risk), not yet recognised as state of the art, reluctance to make the necessary increase in effort, lack of experience in decentralised planning / participation, lack of start-up funds, fear of reduced profit margins in smaller / decentralised projects, regulatory obstacles …
V. Local authorities, governmental institutions	Political reasons, economic reasons, ecological reasons, Agenda 21, failure of conventional / existing sanitation system, possibility of financial support, sustainability of system, support regional self-sufficiency, promotion of (urban) agriculture, job (and income) creation, long-term security of social services (water supply etc.), …	Habits, taboos, lack of information, lack of start-up funds / insufficient financing, monitoring of treatment / handling etc. more difficult for decentralised system, distrust of alternative systems, not recognised as state of the art technology, reluctance to change status quo, contradiction of existing legal framework / long term plans, powerful lobby from conventional centralised sanitation industry, corruption, …
VII. Developers & Investors	Increase attractiveness of developments (eco-label), safe and secure "management" (especially in tourist areas), user satisfaction, economic reasons, legal requirements …	Absence of service logistic, habits, taboos, lack of information, lack of start-up funds, monitoring of treatment / handling etc. more difficult for decentralised system, distrust of alternative systems, not recognised as state of the art technology, reluctance to change status quo, contradiction of existing

Principal Stakeholders	Examples of Motivating Factors	Examples of Constraints
		legal framework / long term plans, powerful lobby from conventional centralised sanitation industry, corruption, less« commission »for projects, …
VIII. Financial institutions	Economic reasons, failure of existing / conventional systems, improving sustainability, guarantee repayment of credit, …	Absence of specific financing instruments, not recognized as state of the art technology, need for research and development, …
IX. Research institutions	Need for research and development, availability of research funds, ecological reasons, …	Availability of research funds, prestige, …

10.2.3 Rights of access

Farmers will be reluctant to install infrastructure or treatment facilities, unless they have some confidence that they will continue to have access to the greywater and excreta. Permits and dependent on efficient or sanitary practice by the farmers may regulate this access. Legislation may therefore be required to define the users' rights of access to the greywater and excreta and the powers of those entitled to allocate or regulate those rights.

10.2.4. Land tenure

Security of access to greywater and excreta is worth little without security of land or water tenure. Existing tenure legislation is likely to be adequate for most eventualities, although it may be necessary to define the ownership of virgin land newly brought under cultivation. If it is decided to amalgamate individual agricultural area under a single management, powers of compulsory purchase may be needed.

10.2.5 Public health

The area of public health includes rules governing crop restrictions and methods of application, as well as quality standards for treated greywater and excreta, which may require an addition to existing regulations. It may include application requirements or required withholding periods between application and harvest. It also covers other aspects of health protection, such as the promotion of hygiene and other health issues, occupational health and food hygiene, which are unlikely to need any new measures. Consumers also have the right to expect safe products.

Legislation on the use of excreta and greywater, intended for the protection of public health, should be based upon the health-based targets and health protection measures discussed in Chapters 4 and 5 of this Volume of the Guidelines.

10.3 Regulation

Regulations are the rules that specify actions that need to be performed by the users (can be individuals or communities, etc.) of excreta and greywater. Regulations are usually created through a consultative process led by an administrative authority, with a delegated responsibility in legislation. Regulations governing the use of excreta and greywater should be practical and focus on protecting public health (other issues will also be relevant e.g., environmental protection). Regulations should also establish permitting requirements, specify the risk management approaches that will be required in different settings, describe water quality/produce monitoring requirements, create disease surveillance requirements, and develop financing mechanisms. Most importantly, regulations should be feasible to implement given the local circumstances. Box 10.2 provides an example of regulations that affect the use of excreta and greywater in South Africa and Box 10.3 the development of municipal regulations through consultation with various stakeholders in Tepoztlán, Mexico.

Box 10.2 National Building Regulation in South Africa

The National Building Regulations (NBR) states that waterborne sewage and chemical closets are the only acceptable indoor toilets. The assumption is that municipalities will automatically be able to treat the sewage and safely discharge it to the environment. The safe use of excreta and greywater could be incorporated into the standards by allowing the choice of different technologies, e.g. different types of toilets or storage and treatment systems that facilitate the safe use of excreta and greywater. The NBR could allow the use of different systems if, for example, the owner of the building and/or the municipality can demonstrate that they can comply with system operation and treatment requirements.

A framework of regulations could be set up around the different health protection measures (i.e., excreta and greywater treatment, use restriction, application, exposure control). Regulations may already exist for some of the protective measures. Without some complimentary measures, e.g., regulations that control market hygiene (e.g., availability of adequate sanitation and safe water supplies and market inspectors,) safe food products grown in compliance with the excreta or greywater regulations could easily become re-contaminated in the market, mitigating any impact of previous public health protective measures that have been implemented (see table 10.2 for examples of activities that might require regulations).

Table 10.2 Examples of activities that might be covered in regulations

System components	Regulatory considerations
Greywater and excreta	Access rights; tariffs; management (e.g., municipalities; communities, users groups, etc.)
Conveyance	Responsibility for building infrastructure and operations and maintenance, pumping costs, delivery trucks
Treatment	Treatment requirements depending upon final use; process requirements
Monitoring	Types of monitoring (e.g., process monitoring, analytical, parameters), frequency, location, financial responsibilities
Greywater and excreta application	Fencing, need for buffer zones
Produce Restrictions	Types of produce permitted not permitted, enforcement, education of users/public
Exposure control	Access control for use areas (e.g., sign posting, fences), protective

	clothing requirements, provision of water and sanitation facilities for workers, hygiene education responsibilities
Market hygiene	Market inspection, provision of safe water and adequate sanitation facilities at markets
Financial authority	Mechanisms for charging tariffs, collecting fines
Enforcement	Mechanisms for ensuring regulatory compliance

Box 10.3 Developing a Municipal regulation for the city of Tepoztlán in Mexico
The content of a regulatory framework for a municipality with regard to sanitation is being proposed for the municipality of Tepoztlán in Mexico. The regulations will be developed after extensive consultation with key local and national stakeholders and in parallel with proposals for appropriate institutional reforms to assure their effective application. This municipal regulation will contain the following specifications:

a. Basic principles and rules taking into account particularities of the municipality.
b. Inclusion of rules for construction permits and new urban developments.
c. Policy and procedures regarding water management and sanitation, including assessment and monitoring.
d. Specify concrete measures and actions regarding sanitation that should be undertaken by the municipality
e. Adapting local regulations to federal and regional legislation to avoid conflicting jurisdictions and to promote concurrent jurisdictions.
f. Institutional mechanisms of participation of the local population in the process of municipal management in specific affairs of importance such as sanitation, with specific emphasis on surveillance.
g. Definition of minimal norms of quality of the public services offered by the municipality.
h. Requirements for housing development to fulfil the regulation in relation to sanitation and other issues.
i. Establishing proper incentive systems for conversion and retrofitting of conventional technology towards alternative sanitation technologies that facilitate the safe use of excreta and greywater.
j. Implementation of registers and inventories of waters and soils.
k. Improving the tariff system collection

A bottom-up strategy is thus proposed, where appropriate regulation for a municipality, in this case Tepoztlàn, could serve as a model for other municipalities and gradually influence regulation at other levels of government.

10.4 Development of a National Policy Framework

In developing a national policy framework to facilitate safe use of excreta and greywater in agriculture, it is important to define the objectives of the policy, assess the current policy environment and develop a national approach.

10.4.1 Defining objectives

The use of greywater and excreta can have one or more of several objectives. Defining these objectives can help to start the planning and implementation process (Mills and Asano, 1998). The main objectives might be:

- To increase national or local economic development;
- To increase crop production;
- To increase energy production
- To augment freshwater supplies and otherwise take full advantage of the resource value of greywater and excreta;
- To manage of greywater and excreta in a cost-effective, environmentally friendly manner; and
- To improve household income, food security and/or nutrition.

Where greywater and excreta is already used sub-objectives might be to incorporate health and environmental safeguards into management strategies or improve produce or yields through better practice.

10.4.2 Analysis of the existing policy framework

The right formal and informal policy framework can facilitate the safe use and managing of excreta and greywater. Existing practices, habits and customs need to be integrated to understand what actions that should be taken to reduce risks and maximise benefits.

An existing policy framework facilitates, impedes or is neutral towards the safe use of excreta and greywater. The most practical approach is from a "what is not strictly prohibited" rather than from "what is specifically allowed?" perspective[i]. This analysis should include the whole handling chain, from point of household generation, through conveyance, storage, treatment, use, and product consumption. Coordination of many authorities/agencies at community level will be helpful, and the analysis of the existing framework should have that objective in focus.

As legal, institutional, cultural, religious contexts differ it is not possible to prescribe a specific methodology for institutional analysis that functions globally. The questions in table 10.3 should be seen as examples for a structured approach with the aim to identify the system. Is the purpose to use the excreta and greywater at the household level and then to delegate responsibility to individual households? Or, is the system to be operated by a municipality? What permits are necessary? Is it possible for local farmers to sell their crops after using these substances? The framework should not be a technology-prescriptive but based more upon the principles of maximizing public health and environmental protection and to identify the necessary changes within the existing institutional framework. Once an analysis is completed, it will be helpful to develop an action plan.

Table 10.3 Structured questions providing input for an institutional analysis of excreta and greywater use (adapted from Elledge et al. 2002)

Questions regarding ……	**Examples of relevant questions**
…The legal framework	Does the existing legal framework adequately govern excreta and greywater use? Are existing regulations appropriate? Or do existing regulations conflict with desired outcomes for the use? Are national policies within the sector based on appropriate levels of legality? Are there barriers

Questions regarding ……	**Examples of relevant questions**
	or obstacles resulting from the legal basis of excreta or greywater use? Are these policies sufficiently comprehensive to allow institutions to develop strategies and action plans to act upon them? Are these national policies compatible with other relevant national policies and regulations, for example, environment, public health, education, and decentralization? Are the policies more appropriate for one or more target groups or areas (e.g., urban areas, small towns, rural areas)? Do laws or bylaws cover responsibilities of landlords for providing adequate storage or treatment facilities for tenants? What challenges and possibilities exist within the spatial planning and building codes? How are construction permitted or restricted? What is stated in technical norms and standards?ii The neighbour's rights - to what extents can neighbours have opinions on land use? Do these rights pose challenges? Who has the right to use the resource (e.g. water)? Will the owner of the resource, such as the land and water, be entitled to compensation? What is stated in the health legislation? What is stated in the infectious disease protection legislation? Rules regulating effluent qualities - are there environmental quality standards? Legislation according relevant to the production/handling/use of food - are the obstacles to the anything hindering the commercialisation of products cultivated with human excreta? Is authorisation or notification needed for different aspects of the recycling scheme? Is there legislation that, in practice, suppresses the development of recycling-oriented sanitation systems? Who enforces the rules? What is the legal status of excreta and greywater? Covered or excluded? How is the flow of different fractions regulated (keeping excreta and greywater separate throughout the collection/transport/use)? Does the existing legal framework direct the excreta and greywater flow towards use or towards deposition/ discharge? Right of access to excreta and greywater? Public health and legislation: quality standards for excreta and greywater, restrictions on crop use, application methods, occupational health, food hygiene, etc? Analysis of how different legal bodies relate to each other in these questions. Who has the responsibility to make legislation/regulation on different levels? Identification of appropriate standards for excreta and greywater use
…the relevant authorities	Responsibility analysis – is there coordination between the relevant authorities? Is there a clear and proper division of powers/finances/competence? What supportive policies are there? Is there a coordination of water and sanitation policies with environmental and agricultural policies? Are there action plans connected to the policies? What are the roles and relationships between national and local governments? Do authorities comply with legislation/regulations? Does the national or state-level government intervene when national policies are not implemented?
…the informal institutions	Assessment of attitudes, human and organizational behaviour, codes of conduct and behavioural patterns from an excreta and greywater use perspective[iii] Compliance with legislation/regulation[iv]?
…other issues	Corruption? Are there any other competing interests with the excreta and greywater?

10.4.3 Development of action plans

The analysis of the existing legal framework may find that new institutions, laws or regulations are warranted or that existing frameworks should be modified to accommodate the safe use of excreta and greywater[v]. New tasks within the changed framework may be included in action plans. Action plans should be output oriented with monitoring mechanisms. Developing an action plan may include consideration of the following elements:

- **Institutional reform action**
  - adding sanitation and resource recycling into Poverty Reduction Strategy Papers (PRSP's)
  - allocation of new or changed powers to existing bodies
  - the creation of new authorities, or new tasks for old authorities
  - development of new policies (see above for key features of sanitation policies)
  - coordination of policies
  - creation of economic incentives, removal of economic hindrances
  - new/changed legislation/regulation[vi],.
    - e.g. identification of environmental quality standards identification of time period to respect between excreta/greywater amendment event and harvest
    - One way to keep legislation modern for a longer time period is to make it less detailed and specific. For the sanitation case one way of achieving this is to avoid mentioning technologies in legislation/regulation, but rather focus on functions that the sanitation services should provide. A function, or performance or criteria, approach opens up for innovative technologies/systems as long as they comply with the criteria identified in the legislation/regulation.
  - action plans to enforce existing/new regulations
    - Better compliance to existing laws and rules and in many cases also reformed legislations is needed, as both these issues are important and intimately related. Better rules may foster different policies and help, amongst other things, to get better compliance. However, new laws and rules have to be coupled with concrete and specific application and enforcement of the law.
  - reallocation of financial resources
  - creation of monitoring mechanisms
  - creation of financial mechanisms allowing the safe use of excreta and greywater (e.g. microfinance, revolving funds, etc)
  - completed decentralization processes[vii]
- **Change in ways of working**
  - continuous stakeholder involvement in order for legislation/regulation and institutions to be viable and accepted by the public
  - enhanced cooperation between existing authorities
  - execution of integrated planning approaches[viii]
- **Piloting**
  - If the institutional framework does not embrace the safe use of excreta and greywater, identification of waiver possibilities in order to conduct use in pilot projects may be essential for decision-making. The programs should be

integrated, encompassing sanitation, health and hygiene, nutrient/resource recycling and food security.

- **Information, education, communication**
    - awareness-raising campaigns on different levels[ix]
    - development of local guidelines for the safe use of excreta and greywater in agriculture
    - capacity-building efforts (e.g. bringing together more resources, stronger institutions, better trained people and improving skills (WHO, 2004))
        - strengthening regulators so that they know how to support, regulate and control systems for the safe use
    - information sharing through conferences, workshops, and other forums
    - information and education programs (see e.g. the sanitation and hygiene promotion programming guide at http://www.who.int/water_sanitation_health/hygiene/sanitpromotionguide/en/).

10.4.4 Research

Research on minimizing health impacts associated with use in agriculture should be conducted at national institutions, universities or other research centres. It is important to conduct research at the national level, because data concerning local conditions are the most important for developing effective health protection measures and may well vary considerably between countries. Pilot schemes can be developed to investigate feasible health protection measures and answer production-related questions. In situations where excreta and greywater use is practised in small-scale diffuse facilities, often at the household level, national research may be used to validate health protection measures and then develop guidelines and standards to be used by small-scale farmers. Research results should be disseminated to various groups of stakeholders in a form that is useful to them.

A pilot project is particularly useful in countries with little or no experience of managing excreta and greywater use in agriculture or when the introduction of new techniques is envisaged. Health protection is an important consideration, but there are other questions that are difficult to answer without local experience of the kind a pilot project can give. These questions are likely to include important technical, social and economic aspects. A pilot scheme can help to identify potential health risks and develop ways to control them.

Pilot projects should be planned — that is, a variety of crops (both old and new) should be investigated, with different application rates. Information is required not only on yields but also on microbial contamination levels, toxic metals and organic chemicals and pathogens typically present in the region and in local waste and effects on the environment.

A pilot project should be carefully planned so that the work involved is not underestimated and can be carried out correctly; otherwise, repetition is required. After the experimental period, a successful pilot project may be translated into a demonstration project with training facilities for local operators and farmers.

11. PLANNING AND IMPLEMENTATION

The safe use of greywater and excreta requires adopting the appropriate planning approach at both the national level and the individual project level where health should be the first priority. Strategies for planning including communication with different groups of stakeholder have been dealt with in Chapter 10. This chapter describe further considerations, partly adapted to the local level.

11.1 Adopting the appropriate planning approach

The development and planning of sanitation programmes has been comprehensively addressed in a range of publications (see WSSCC publication 2005), which can be used as a base when new programmes are being drawn up. In the planning of sanitary systems aiming to use excreta and greywater, certain specific considerations should be taken into account to address the needs of a safe use oriented approaches.

- *Integrate aspects of safe use in the assessment of the current sanitary situation and in all the planning activities and conceptual work:*

A broader spectrum of issues has to be considered when planning systems to safely use excreta and greywater. Included in these are the assessment of the current agricultural situation, with the type of crops cultivated and agricultural practises. These relate to the water and fertiliser needs, agricultural equipment and irrigation practises. The quality of the irrigation water currently being used also relates to the relative risks of contamination as well as livestock production, practises concerning the treatment and use of manure and current and traditional practises of fertilisation and soil conservation. Productivity, costs and benefits, farmers and consumers perception of the use of artificial fertiliser, manure, treated wastewater, greywater and human excreta as well as other aspects should also be accounted for. The safety and benefit aspects also relates to where the use is directed. In addition to traditional agriculture excreta and greywater can and has been applied as fertilisers in areas such as forestry, aquaculture, market gardening or for energy production.

- *Integrate aspects related to water supply:*

As the separate collection of source-separated excreta and greywater can reduce the amount of treated fresh water used in homes (e.g. to transport excreta in water borne systems), water supply systems can often be reviewed and modified.

- *Integrate aspects of urban planning:*

As excreta and greywater should be used on the minimum practical level (i.e. close to the source) to minimise transport requirements, the consideration of aspects of urban planning may be required (e.g. in order to provide space for the integration of a constructed wetland in an urban park, to support urban agriculture, or to provide small scale service providers with an area for the treatment and storage of excreta in the neighbourhood).

- *Integrate aspects of solid waste management:*

The collection, transport, treatment and use of, for example, composted or dehydrated faeces, may be carried out by the solid waste management sector. In many countries this particular sector has long experience of how to organise the collection and use systems, as well as the marketing know-how.

- *Consider a much wider variety of sanitation systems:*

A wide array of technical and operational combinations for the use of excreta and greywater are available (see chapter 5 or examples of, on-site vs. off-site; decentralized vs. centralized; split-stream or mixed flow solutions). Planners can consider a range of different options for the prevailing specific circumstances. From the users perspective the ability to choose between varieties of effective technology options to fit their household and budgetary needs are vital. Planners should take into consideration the corresponding institutional and management arrangements needed for different excreta and greywater use options.

- *Apply new and wider- ranging decision-making and evaluation criteria for water supply and sanitation services:*

Excreta and greywater use systems highlight the widened boundaries of sanitation systems (integrating aspects of agriculture, energy production, nutrition and public health etc.). Traditionally used evaluation criteria (e.g. the limiting parameters for discharge into receiving water bodies) are insufficient to evaluate different sanitation options. Decision making criteria should be aimed towards choosing sustainable systems and based on considerations combining resources, the health impact, economic, environmental and social aspects and the technical functionality of the system.

- *Provide stakeholders with the relevant information, enabling them to make an "informed choice"*

The range of possibilities to recover and safely use excreta and greywater are often unknown to most stakeholders (including decision makers), which limit their possibilities to make informed choice of sanitary system and system components. Suitable information and awareness rising is therefore needed. In addition it is valuable to:

- *Integrate education, institution and capacity building aspects into planning instruments.*
- *Focus on the assessment of the needs of the user of the sanitary facilities and other relevant stakeholders, particularly the end users of the treated excreta and greywater and the service providers.*
- *Consider smaller planning units and a greater number of decentralised options*

To successfully integrate the additional considerations of safe use oriented sanitation systems an appropriate approach to the planning processes must be adopted. A sound basis for such an approach can be found in the Bellagio Principles (Box 11.1), drawn up by the Environmental Sanitation Working Group of the Water Supply and Sanitation Collaborative Council (WSSCC), and endorsed by the Council during its 5th Global Forum in November 2000 in Iguacu (Brazil). The principles call for a change of conventional sanitation policies and practices world-wide.

Box 11.1 The Bellagio Principles (2000)

(1) Human dignity, quality of life and environmental security at household level should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local and national 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 consumer 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 flow and waste management;
● Inputs should be reduced so as to promote efficiency and water and environmental security;
● 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 practical size (household, community, town, district, catchment, city) and wastes diluted as little as possible;
● Waste should be managed as close as possible to the source;
● Water should be minimally used to transport waste;
● Additional technologies for waste sanitisation and reuse should be developed.

The WSSCC has published an implementation guide for the Bellagio Principles, promoting a Household Centred Environmental Sanitation Approach (HCES) with two main components:
(1) The focal point of environmental sanitation planning should be the household, reversing the customary order of centralized top-down planning. The user of the services should have a deciding voice in their design, and sanitation issues should be dealt with as close as possible to the site where they occur. With the household as the key stakeholder women are provided with a strong voice in the planning process, and the government's role changes from that of provider to that of enabler;
(2) A Circular System of Resource Management should be used emphasizing the conservation, recycling and reuse of resources, in contrast to the current linear sanitation service system.

11.2 Local Project Planning Specific Considerations

Individual project planning also requires consideration of different issues including the involvement of stakeholders through the use of participatory approaches; treatment; crop restriction; waste application; human exposure control; costs; technical aspects; support services; and training.

11.2.1 Participatory approaches

Effective sanitation and hygiene programmes need to combine interventions to change behaviour with the selection of the right technology. Changing behaviour requires culturally sensitive and appropriate health education. People need to understand in terms meaningful to their lifestyles and existing belief systems why better health depends on the adoption of hygiene practices such as hand-washing; the use of sanitation systems for the safe management of excreta and greywater, safe storage and handling of drinking water and food. Raising awareness of why sanitation and hygiene are important may increase motivation to change harmful behaviours. Selecting the right sanitation technology is about having effective alternatives and making the right choice for the specific circumstances.

Making the right choice of technology requires an assessment of the costs (both for building the facility and for operations and maintenance) and its effectiveness in a specific setting. Participatory approaches such as SARAR and its focused application PHAST have been effective in increasing sanitation coverage and good hygiene behaviours (WHO 2004).

SARAR (Self-esteem, Associative strengths, Resourcefulness, Action-planning, and Responsibility) has been used successfully as a core tool to start sanitation programmes in places as diverse as Mongolia, Kyrgyzstan, Mozambique, South Africa, and El Salvador. Box 11.2 gives some examples of how SARAR tools have been used within the context of the TepozEco Municipal Ecological Sanitation Project in Tepoztlán, Mexico.

BOX 11.2 SARAR Programme Achievements in Mexico

Since its beginning in 2003, the TepozEco Project has used SARAR participatory tools to involve community groups in deepening their understanding of their environment and to develop strategies for improving water and sanitation services. TepozEco has worked closely with a local youth group in the periurban community of San Juan Tlacotenco, who has been trained as sanitation promoters as well as facilitators of the community decision making process. In San Juan, the SARAR tools have been particularly valuable as a way to explore community perceptions of their problems and needs and to maintain the focus of decision-making within the community itself. For example

- An adaptation of the extremely versatile ***3-pile sorting*** activity was used to involve the community in analyzing and prioritizing various public services: not surprisingly water and sanitation were at the top of the list.
- In a subsequent session, the ***sanitation ladder*** permitted the community to identify and compare the range of basic sanitation technologies available to them --and to decide which options would be most appropriate given the particular local context (severe seasonal water shortages; absence of a central sewage system now and for the longer term; moderate to low income; need for inexpensive fertilizer for local crops; and a concern to avoid contamination of local streams at the top of the watershed.
- A ***community mapping*** exercise, the ***story-with–a–gap*** and a set of hygiene behaviour ***sorting cards*** helped the community to identify critical interventions including greywater and solid waste management.

Finally, Sarar Transformación SC, responsible for coordinating the TepozEco, together with El Taller, a partner NGO, have produced an Ecological Sanitation Educational Tool Kit, to facilitate the replication of the process in other programs. The package includes a set of participatory materials as well as illustrated ***technical guides*** to provide information to the community in a timely and easily assimilated format with the aim to achieve better hygiene and sanitation behaviour as well as make use of accessible fertilizers in a safe way.

Source: Sarar Transformación SC, Mexico, 2005

11.2.2 Treatment

The differing characteristics and specific treatments available (see Chapter 5) allow choices to be made regarding the use of nutrients and soil conditioners from excreta, or of the water, using greywater.

When excreta from many small sources are used, the verification monitoring and assessment of the treatment efficiency of all the sources are impossible. Secondary off-site treatment is than an informed choice, especially in cities. The collection, treatment and reuse can then give economic incentives for small entrepreneurs. In rural areas, however, farmers who have used raw excreta for years may not be easily persuaded to treat it. This should be dealt with by health educators and extension officers.

Whatever method is used for health protection when using excreta or greywater its implementation is likely to demand a change in behaviour by a large number of individual users, which needs to be part of a sensitisation. One motivating factor might be the greater convenience and privacy of an in-house toilet, the waste from which can be treated, compared with open defecation.

11.2.3 Crop restriction

Crop restriction is relatively simple to implement where the treated excreta and greywater are used by a small number of large organisations, whether they are private firms, co-operatives, state farms, or the municipal authority itself. However, the enforcement of crop restrictions on a large number of smaller farmers can be much more difficult. The products most likely to be excluded, such as vegetables for direct human consumption, are among those, which would give higher cash yields than waste-use to produce animal feed. Crop restriction is not impossible in such circumstances; they are most likely to succeed where local dietary habits limit the demand for uncooked vegetables, and where there are profitable alternative crops for which a market exists.

In some countries, the existing planning machinery allows a firm control of all produce grown, with regular inspection of farms and sanctions against those who depart from the plan. These arrangements can be used at little extra cost to ensure that produce restrictions are followed.

If there is no local experience of the application of crop restrictions, their feasibility should be tested in a trial area before they are implemented on a wide scale. The trial will also give an initial estimate of the resources required for enforcement, as well as clarifying the most suitable institutional arrangements for implementation of restrictions.

Enforcement may not always be as easy as might at first appear. Though a crop may take months to grow and can be inspected throughout this time, the excreta and greywater may need to be applied for only a few days each month, and this can be concealed even from vigilant inspectors.

11.2.4 Application

The Agriculture Extension Service may be in the best position to promote hygienic practices relating to the application of excreta and greywater in agriculture / horticulture. Where a municipal body controls the source of treated excreta or faecal sludge, it may be able to encourage application before harvest periods by making it available only at certain times of the year. As stated in Chapter 4 a withholding time always apply in addition to on-site/off-site treatment. Alternatively, the agency controlling distribution of the excreta or greywater may itself assume responsibility for the application of the treated products and charge for this service. The workers handling the excreta would then be the employees of a single body, which would facilitate exposure control measures among them.

Source separation of urine and faeces may facilitate the application of excreta to a large degree, although if large amounts of nutrients are needed the urine volume to be transported may prove inconvenient.

11.2.5 Human exposure control

Measures to reduce exposure to pathogens causing diarrhoeal diseases and to promote good case management are well known components of primary health care. They include health education, particularly regarding domestic hygiene
An obvious measure is to provide an adequate water supply and sanitation. Controlling the exposure of users of excreta may have little effect if they continue to be exposed to infection from their drinking water and in their home environment through lack of these basic facilities. Particular care is required to ensure that the use of excreta or greywater does not cause contamination of nearby wells or other sources of drinking water.

Where salaried workers are involved, their employers have a responsibility to protect them from exposure to diseases, which in many countries is set down in existing legislation on occupational health. This may need to be brought to the employers' attention, together with guidance on the measures they should take such as the issuing of protective clothing, particularly footwear and gloves although these may not be comfortable in a tropical climate. Any effort to promote the issuing of protective clothing by employers must be accompanied by still greater efforts to convince their employees that they must wear it.

Measures to control the exposure of those who handle the produce can be implemented in much the same way as for farm workers. When they all work for a small number of employers, exposure control fits into a general programme of occupational health. On the other hand, when a large number of petty traders are involved, selling or making products from the produce, it will be difficult to implement exposure control measures unless they are all gathered together in a market. Most markets are in any case subject to public health inspection, and basic exposure control measures may be a good thing whether or not crops produced using wastes is being handled. As well as protecting produce-handlers from contamination, they may also help to protect other produce from contamination by the handlers.

Markets may also be the best places to advise consumers about the hygienic precautions they should take with the food they purchase. It is certainly good for consumers to be told of anything they can do to protect themselves from exposure to infection. However, they cannot be relied upon to do it, especially where it would mean a change from long-standing habits.

Residents who are not involved in the use of excreta or greywater are best placed to ensure that their health is not put at risk by those who are, once it has been explained to them what precautions are required and what risks they and their families may run if the precautions are not taken. Of course, a government inspector can ensure that fences are built and warning signs put up, but vigilant neighbours will be the first to notice when they need repair or replacement. The establishment of a resident's health committee can be a focus for a health education campaign, as well as providing a locally controlled institution to monitor the practice of wastes use. The treatment and operational guidelines will in most instances safeguard the use.

Treatment (chemotherapy) of farm workers, their families and other exposed groups for helminth infections is relatively easy to administer in a formal programme, although additional health personnel may be required to treat a large population. It can be quite popular, and provides an excellent opportunity for follow-up with hygiene education activities to publicize simple measures for personal protection. The employers may pay the cost of chemotherapy where salaried workers or sharecroppers work the fields.

If untreated excreta and greywater is used on many small and scattered fields, there are greater logistic problems. An additional problem arises where the excreta or greywater is used informally or illegally.
Those living close to fields are likely to include workers and their families, who will be exposed to infection in several ways. Adhering to the guidelines is the best assurance to minimise the risks.

11.2.6 Costs

The choice of which sanitation and safe use system to implement should also consider the overall costs - both of the initial expense of the technology but also the on-going costs of operation and maintenance. If the cost of those chosen for implementation is likely to exceed the economic benefit of using the wastes, it is important to consider whether less expensive measures might suffice, or whether it is worth while to use the wastes at all. In most cases, the benefits are likely to justify the costs, but some financial arrangement is needed to ensure that the costs are met from a suitable source. These aspects are considered in Chapter 8.

11.2.7 Technical aspects

Detailed planning for excreta and greywater use schemes should follow the usual national procedures for project planning, supplemented as necessary by the requirements of external funding agencies. The following discussion is centred on the particular planning needs resulting from the fact that the project is for excreta and/or greywater use and from the need for health protection measures. In other regards, planning requirements for excreta and greywater use schemes are similar to those for projects that are not based on the use of human wastes.

A great deal of information needs to be collected, and many decisions must be taken to prepare a detailed plan for a new scheme. The main technical aspects that should be covered by the plan are listed in Box 11.3. Several of these aspects interact.

BOX 11.3 Technical information to be included in a project plan

- Current and projected generation rates of the wastes (excreta, sludge or greywater); proportion of industrial effluents; dilution by surface water;
- Existing and required waste treatment facilities; pathogen removal efficiencies; physicochemical quality;
- Existing and required land areas: size, location, and soil types;
- Energy requirements and energy potential of excreta / greywater (and possibility to combine with other organic waste);
- Evaporation (need for make-up water);

● Conveyance of treated wastes (collection of treated excreta and sludge by farmers or delivery by treatment authority);
● Storage requirements for the wastes;
● Waste application rates and methods;
● Types of crops to be cultured, and their requirements for wastes quality and supplementary nutrients;
● Estimated yields of crops per hectare per year;
● Strategy for health protection.

For each scheme, the planner should seek to maximize the net annual benefit in a manner consistent with labour constraints and the need to protect health and minimize costs. For this cost estimates is valuable for the various activities, including major construction works for storage, treatment or transport of wastes, land preparation and necessary infrastructure, and also for staffing, treatment, pumping and maintenance as well as other inputs.

An assessment of the benefits requires a forecast not only of the probable yields of the produce to be grown but also of their anticipated prices. This in turn demands a survey to establish that an adequate market exists for the produce. This is particularly important where produce restriction is to be employed as a health protection measure, and where the produce to be grown requires industrial processing; in the latter case, sufficient processing capacity must be available.

Projects for the use of treated excreta and faecal sludge are not static; they take time to be implemented and thereafter to evolve and grow. The plan should allow reasonable time-scales for all its aspects: to obtain funding, to execute any necessary construction works and to prepare the ground for the scheme to begin. From then on it should envisage the configuration of the project in each year of its future existence. For some projects a long-time planning horizon will be needed.

It will often be advisable to allow for a modest beginning, followed by a phased expansion of the project in subsequent years. This will allow time to train farmers and staff in new methods and for lessons learnt in the early stages to influence later developments. It will also help to ensure that the level of production does not over-reach the current availability of excreta as fertilisers or the demand for the produce grown.

11.2.8 Support services

Various support services to farmers are particularly relevant to the implementation of health protection measures, and detailed consideration should be given to them at the planning stage in larger schemes. They include the following:

- Machinery (sales and servicing, or hire)
- Supplementary fertilizers or feed, pumps, nets, protective clothing, etc.;
- Extension and training;
- Marketing services, especially where new crops are to be introduced or new land brought into productive use;
- Primary health care, possibly including regular health checks for workers and their families.

11.2.9 Training

Training requirements must be carefully evaluated at the planning stage, and it may often be necessary to start training programmes before the project begins.

The likely need for extension services must be estimated, and provision made for them to be available to producers after implementation of the project. Extension officers will themselves need training in the methods appropriate to health protection, as will the staff responsible for enforcing sanitary regulations regarding produce restriction, occupational health, food hygiene, etc.

Such training requirements are best met by local technical colleges and universities, but many countries may lack the specific expertise needed; overseas training may then be the only alternative in the short term until sufficient in-country experience is developed. This is an area in which cooperation between neighbouring countries can be especially fruitful.

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i http://web.mit.edu/urbanupgrading/waterandsanitation/policies/defining-leg-frame.html

[ii] Many existing standards (national or municipal) are based on those developed in industrialized countries, under conditions different from those applying in developing countries, and so they are often inappropriate. Part of launching a household-centered environmental sanitation (HCES) approach should therefore be to secure a moratorium on the application of existing standards to the programme area, and part of the overall exercise should be to try to identify standards which would be more appropriate – because they meet the basic purpose of standards, to ensure that everyone has a healthy life (WSSCC, 2004).

[iii] It is important to remember that informal institutions are more resilient towards change than formal ones (Hukkinen, 1999).

[iv] Many of the problems related to the legal field have to do with a strong dichotomy between legislation and reality. Some countries may have advanced legislation and comprehensive policy and planning instruments, but poor law enforcement and poor implementation of plans and policies. Any effort to build a different legal framework must tackle this issue in order to promote laws that are in accordance with the complexities that the different actors will have to deal with when applying or being affected by the legislation concerned (Johansson et al, 2005).

[v] Institutional change is a complex process and depends on (i) the stability characteristics of institutions, (ii) the sources of change, (iii) the agent of change, and (iv) the direction of change and path dependence (North, 1990). Institutions typically change incrementally rather than instantaneously, which means that short-term profitable opportunities cumulatively create the long-term path of change (Seppälä, 2002).

[vi] Legislation/regulations should create conditions that favor innovation (both in technology and financing mechanisms); define cooperation between relevant stakeholders, including the private sector; allocate financial resources to capacity-building and training, and to monitoring implementation and maintenance (WHO, 2004).

[vii] If you apply the HCES approach to planning of Urban Environmental Sanitation Services, it is important to decentralize powers and functions since it builds on both bottom-up and top-down approaches to service provision planning (WSSCC, 2004).

[viii] The Household-Centered Environmental Sanitation (HCES) is a multi-sector, multi-actor approach to delivering urban environmental sanitation services (UESS), where UESS comprise not only sanitation but also storm water, and solid waste as well as water provision. In this way, the stakeholders have opportunities to participate in the planning, implementation and operation of UESS, which is believed to increase its sustainability (WSSCC, 2004)

[ix] The main reason for awareness raising, on decision-maker level, with regard to the use of excreta and greywater is that the possibilities it entails are relatively unknown. However, extensive, unregulated use of wastewater occurs in many cities today (e.g. Dakar), even if the main reason for farmers to divert raw wastewater to agricultural or horticultural fields might be to capture water rather than nutrients. Awareness-raising campaigns geared towards farmers should thus address the health risks associated with the use of raw wastewater/excreta and highlight the nutrient value of treated excreta. Awareness-raising for safe excreta and greywater use applies also to engineers, planners, and even sanitation professionals. There is an overall need to broaden the nature of the debate concerning the role of sanitation and the aims of sanitation provision.