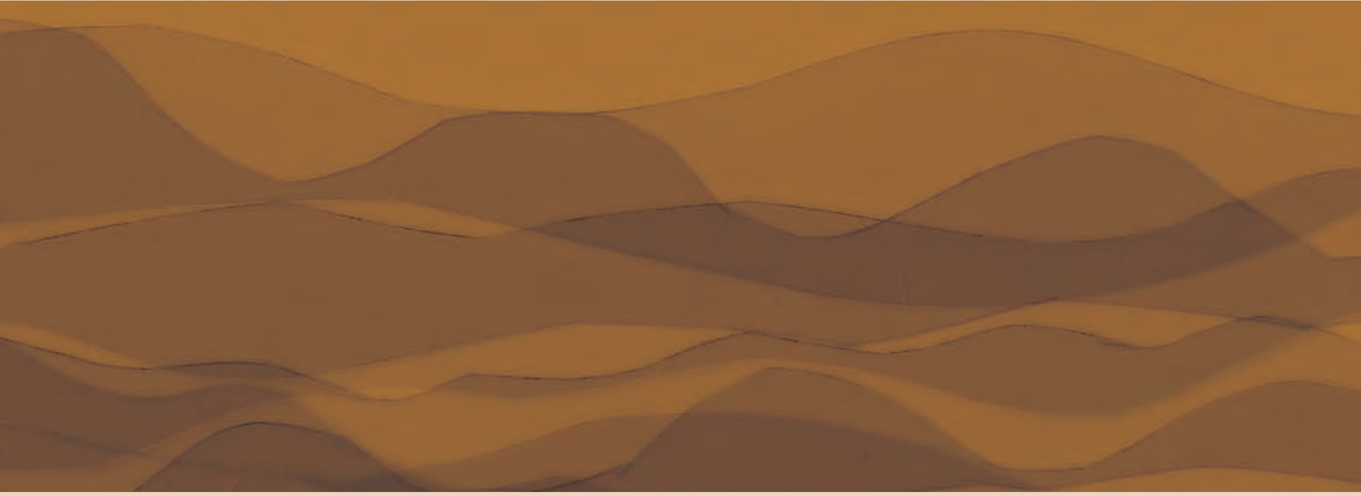

WHO GUIDELINES FOR THE

SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER

VOLUME IV

EXCRETA AND GREYWATER USE IN AGRICULTURE

World Health Organization

UNEP
United Nations Environment Programme

GUIDELINES FOR THE SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER

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CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

AIDS	acquired immunodeficiency syndrome
BKV	BK (polyoma)virus
BOD	biological oxygen demand
BOD_x	x-day biological oxygen demand
cfu	colony forming unit
COD	chemical oxygen demand
DALY	disability adjusted life year
EHEC	enterohaemorrhagic *E. coli*
EIEC	enteroinvasive *E. coli*
EPEC	enteropathogenic *E. coli*
ETEC	enterotoxigenic *E. coli*
FAO	Food and Agriculture Organization of the United Nations
FS	faecal sludge
HIV	human immunodeficiency virus
ID_{50}	median infectious dose
ISO	International Organization for Standardization
JCV	JC (polyoma)virus
MDG	Millennium Development Goal
PHAST	Participatory Hygiene and Sanitation Transformation
P_{inf}	probability of infection
QMRA	quantitative microbial risk assessment
SARAR	Self-esteem, Associative strengths, Resourcefulness, Action-planning, and Responsibility
T_{90}	number of days required for a decimal (90%) reduction (one log reduction)
VIP	ventilated improved pit latrine
VU	viral unit
WHO	World Health Organization
WSSCC	Water Supply and Sanitation Collaborative Council
WTO	World Trade Organization

PREFACE

The United Nations General Assembly (2000) adopted the Millennium Development Goals (MDGs) on 8 September 2000. The MDGs that are most directly related to the safe use of excreta and greywater in agriculture are "Goal 1: Eliminate extreme poverty and hunger" and "Goal 7: Ensure environmental sustainability." The use of excreta and greywater in agriculture 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* (WHO, 1973). 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* (WHO, 1989). These guidelines have been very influential, and many countries have adopted or adapted them for their wastewater and excreta use practices.

The use of excreta and greywater in agriculture is increasingly considered a method combining water and nutrient recycling, increased household food security and improved nutrition for poor households. Recent interest in excreta and greywater use in agriculture has been driven by water scarcity, lack of 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, chemicals 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 a particular 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 four separate volumes: *Volume 1: Policy and regulatory aspects*; *Volume 2: Wastewater use in agriculture*; *Volume 3: Wastewater and excreta use in aquaculture*; and *Volume 4: Excreta and greywater use in agriculture.*

WHO water-related guidelines are based on scientific consensus and best available evidence; they 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. 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 reduced 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* (Fewtrell & Bartram, 2001). 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 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 burden 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.

This edition of the Guidelines supersedes previous editions (1973 and 1989). The Guidelines are recognized as representing the position of the United Nations system on issues of wastewater, excreta and greywater use and health by "UN-Water," the coordinating body of the 24 United Nations 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 the 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;
- risk management strategies, 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, including environmental and public health scientists, educators, researchers, engineers, policy-makers and those responsible for developing standards and regulations.

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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 on 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 this volume 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. Thus, 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. Yet this is not a matter of simple trade-offs. Wherever excreta and greywater use contributes significantly to food security and nutritional status, the point is to identify associated hazards, define the risks they represent to vulnerable groups and design measures aimed at reducing these risks.

This volume of the Guidelines is intended to be used as the basis for the development of international and national approaches (including standards and regulations) to managing 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, but it should also be relevant to their 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 used 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 local social, cultural, environmental and economic conditions, 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, engineers, policy-makers and those responsible for developing standards and regulations.

Introduction

Traditional waterborne sewerage will continue to dominate sanitation for the foreseeable future. Since only a fraction of existing wastewater treatment plants in the world are optimally reducing levels of pathogenic microorganisms and since a majority of people living in both rural and urban areas will not be connected to centralized wastewater treatment systems, alternative sanitation approaches need to be developed in parallel.

The United Nations General Assembly adopted the Millennium Development Goals (MDGs) on 8 September 2000 (United Nations General Assembly, 2000). The MDGs most directly related to the use of excreta and greywater in agriculture are "Goal 1: Eliminate extreme poverty and hunger" and "Goal 7: Ensure environmental sustainability." The sanitation target in Goal 7 is to halve, by 2015, the proportion of people without access to adequate sanitation. Household- or community-centred source separation is one of the alternative approaches that is rapidly expanding in order to meet this target. It also helps to prevent environmental degradation and to promote sustainable recycling of the existing plant nutrients in human excreta for food production.

The principal forces driving the increase in use of excreta and greywater in agriculture are:

- increasing water scarcity and stress, and degradation of freshwater resources resulting from the improper disposal of wastewater, excreta and greywater;
- population increase and related increased demand for food and fibre;
- a growing recognition of the resource value of excreta and the nutrients it contains;
- the MDGs, especially the goals for ensuring environmental sustainability and eliminating poverty and hunger.

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-centred source separation and the safe use of excreta and greywater in agriculture will help to alleviate these pressures and help communities to grow more food and conserve precious water and nutrient resources. The additional advantages of nutrient use from excreta as fertilizers are that this "product" is less contaminated with industrial chemicals than when wastewater is used and that it saves water for other uses.

This volume focuses mainly on small-scale applications. It is applicable to both industrialized and developing countries.

The Stockholm Framework

The Stockholm Framework is an integrated approach that combines risk assessment and risk management to control water-related diseases. This provides a harmonized framework for the development of health-based guidelines and standards in terms of 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. The Stockholm Framework provides the conceptual framework for these Guidelines and other WHO water-related guidelines.

Assessment of health risk

Three types of evaluations are used to assess risk: microbial analysis, epidemiological studies and quantitative microbial risk assessment (QMRA). Human faeces contain a variety of different pathogens, reflecting the prevalence of infection in the population; in contrast, only a few pathogenic species may be excreted in urine. The risks associated with both reuse of urine as a fertilizer and the use of greywater for irrigation purposes are related to cross-contamination by faecal matter. Epidemiological data for the assessment of risk through treated faeces, faecal sludge, urine or greywater are scarce and unreliable, while ample evidence exists related to untreated faecal matter. In addition, microbial analyses are partly unreliable in the prediction of risk due to a more rapid die-off of indicator organisms such as *Escherichia coli* in urine, leading to an underestimation of the risk of pathogen transmission. The opposite may occur in greywater, where a growth of the indicator bacteria on easily degradable organic substances may lead to an overestimation of the risks. Based on the above limitations, QMRA is the main approach taken, due to the range of organisms with common transmission characteristics and their prevalence in the population. Factors accounted for include:

- epidemiological features (including infectious dose, latency, hosts and intermediate host);
- persistence in different environments outside the human body (and potential for growth);
- major transmission routes;
- relative efficiency of different treatment barriers;
- risk management 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 disability adjusted life year or DALY (i.e. 10^{-6} DALY), or it can be based on an appropriate health outcome, such as the prevention of exposure to pathogens in excreta and greywater anytime between their generation at the household level and their use in agriculture. To achieve a health-based target, health protection measures are developed. Usually a health-based target can be achieved by combining health protection measures targeted at different steps in the process.

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

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

For collected urine, storage criteria apply that are derived mainly from compiled risk assessment studies. The information obtained has been converted to operational guidelines to limit the risk to a level 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 heavy faecal cross-contamination, the suggested storage times may be lengthened. If urine is used as a fertilizer of crops for household consumption only, it can be used directly without storage. The likelihood of household disease transmission attributable to the lack of hygiene is much higher than that of transmission through urine applied as a fertilizer.

Table 1. Guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture

	Helminth eggs (number per gram total solids or per litre)	*E. co li* (number per 100 ml)
Treated faeces and faecal sludge	<1/g total solids	<1000 g/total solids
Greywater for use in:		
• Restricted irrigation	<1/litre	$<10^{5}$[a] Relaxed to $<10^{6}$ when exposure is limited or regrowth is likely
• Unrestricted irrigation of crops eaten raw	<1/litre	$<10^{3}$ Relaxed to $<10^{4}$ for high-growing leaf crops or drip irrigation

[a] These values are acceptable due to the regrowth potential of *E. coli* and other faecal coliforms in greywater.

Table 2. Recommendations for storage treatment of dry excreta and faecal sludge before use at the household and municipal levels[a]

Treatment	Criteria	Comment
Storage; ambient temperature 2–20 °C	1.5–2 years	Will eliminate bacterial pathogens; regrowth of *E. coli* and *Salmonella* may need to 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	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), whereas a more or less complete inactivation of *Ascaris* eggs will occur within 1 year.
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.

[a] No addition of new material.

For all types of treated excreta, additional safety measures apply. These include, for example, a recommended withholding time of one month between the moment of application of the treated excreta as a fertilizer and the time of crop harvest (Figure 1). Based on QMRA, this time period has been shown to result in a probability of infection well below 10^{-4}, which is within the range of a 10^{-6} DALY level.

Health protection measures

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

Hazards associated with the consumption of excreta-fertilized products include excreta-related pathogens. The risk from infectious diseases is significantly reduced if foods are eaten after proper handling and adequate 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 die-off of remaining pathogens;
- hygienic food handling and food preparation practices;
- health and hygiene promotion;
- produce washing, disinfection and cooking.

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

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

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

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

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

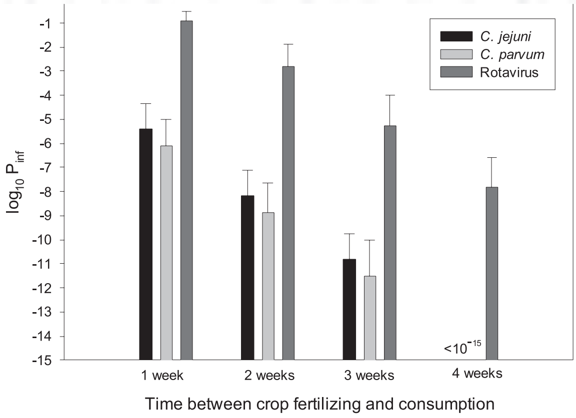

Figure 1

Mean probability of infection by pathogens following ingestion of crops fertilized with unstored urine with varying withholding periods (P_{inf} = probability of infection)

For all types of treated excreta, additional safety measures apply. These include, for example, a recommended withholding time of one month between the moment of application of the treated excreta as a fertilizer and the time of crop harvest (Figure 1). Based on QMRA, this time period has been shown to result in a probability of infection well below 10^{-4}, which is within the range of a 10^{-6} DALY level.

Workers and their families may be exposed to excreta-related and vector-borne pathogens (in certain locations) through excreta and greywater use activities. Excreta and greywater treatment is a measure to prevent diseases associated with excreta and greywater but will 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;
- limited contact during handling and controlled 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 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 agricultural 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 of excreta as fertilizers or use of greywater for irrigation purposes and product use or consumption. Three 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 and public perceptions of excreta and greywater use vary so widely in different parts of the world that one cannot assume that any of the local practices that have evolved in relation to such use can be readily transferred elsewhere. Even when projects are technically well planned and all of the relevant health protection measures have been included, they can fail if cultural beliefs and public perceptions have not been adequately accounted for.

Environmental aspects

Excreta are an important source of nutrients for many farmers. The direct use of excreta and greywater on arable land tends to minimize the environmental impact in both the local and global context. Reuse of excreta on arable land secures valuable fertilizers for crop production and limits the negative impact on water bodies. The environmental impact of different sanitation systems can be measured in terms of the conservation and use of natural resources, discharges to water bodies, air emissions and the impacts on soils. In this type of assessment, source separation and household-centred use systems frequently score more favourably than conventional systems.

Application of excreta and greywater to agricultural land will reduce the direct impacts on water bodies. As for any type of fertilizer, however, the nutrients may percolate into the groundwater if applied in excess or flushed into the surface water after excessive rainfall. This impact will always be less than that of the direct use of water bodies as the primary recipient of excreta and greywater. Surface water bodies are affected by agricultural drainage and runoff. Impacts depend on the type of water body (rivers, agricultural channels, lakes or dams) and their use, as well as the hydraulic retention time and the function it performs within the ecosystem.

Phosphorus is an essential element for plant growth, and external phosphorus 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 phosphorus ends up in aquatic environments or is buried in landfills or other sinks. This discharge into aquatic environments is damaging, as it causes eutrophication of water bodies. Urine alone contains more than 50% of the phosphorus excreted by 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 phosphorus from the treated effluents.

Economic and financial considerations

Economic factors are especially important when the viability of a new project is 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 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 considers 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 fertilized 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 safe excreta and greywater management practices. In many countries where such practices take place, these frameworks and regulations 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 the safe use of excreta as fertilizer, 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 on the WHO Guidelines will protect public health optimally 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 periode

Planning and implementation of programmes for the agricultural use of excreta and greywater require a comprehensive, progressive and incremental approach that responds to the greatest health priorities first. This integrated approach should be based on an assessment of the current sanitary situation and should take into account the local aspects related to water supply and solid waste management. A sound basis for such an approach can be found in the Bellagio Principles, which prescribe that stakeholders be provided with the relevant information, enabling them to make "informed choices." Thus, a wider range of decision-making and evaluation criteria for sanitation services can be applied.

In addition, project planning requires consideration of several different issues, identified through the involvement of stakeholders applying participatory methods and considering treatment, crop restriction, waste application, human exposure control, costs, technical aspects, support services and training both for risk reduction and for maximizing the benefits from an individual as well as a community point of view.

1

INTRODUCTION

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* presents information on the health risks associated with pathogens that occur in human excreta and greywater when used in agriculture. It also presents health protection measures, including technical barriers and best practices to minimize these risks. The Guidelines are based on the development and use of health-based targets. Health-based targets establish a goal of attaining a certain level of health protection in an exposed population. This volume furthermore includes evidence on the fertilizing value of treated excreta, relates their use to sustainability criteria, outlines planning, prevention and implementation strategies and puts their safe handling in a legal, institutional and economic framework. Any possible adverse impacts will be weighed 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 food security, especially for the poor, need to be considered in this context.

The poor bear the heaviest burden of diseases transmitted through faecal–oral pathways, which include 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 human 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.

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* is structured as outlined in Figure 1.1.

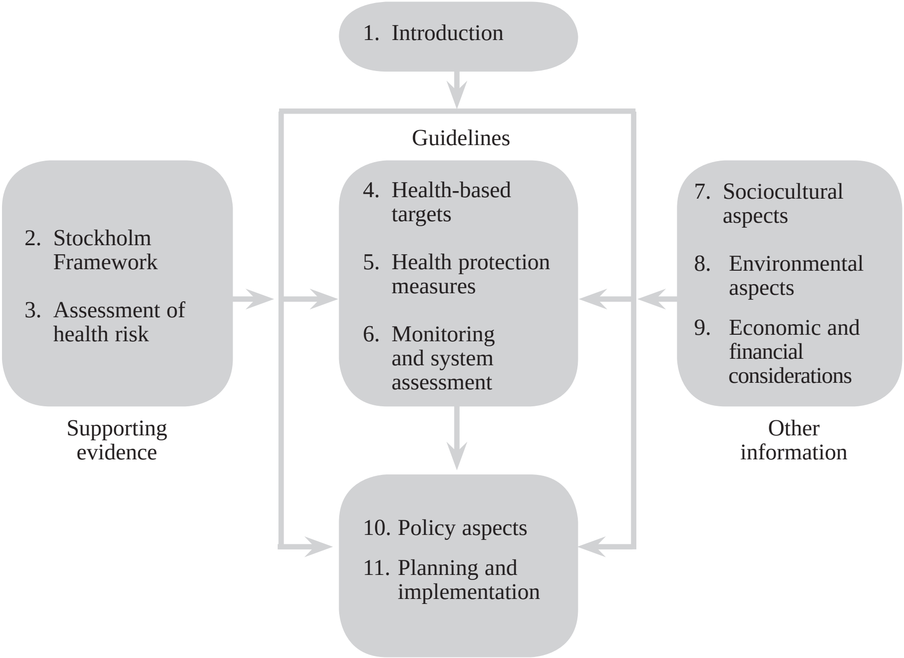

Figure 1.1
Structure of Volume 4 of the *Guidelines for the safe use of wastewater, excreta and greywater*

Chapter 1 presents the objectives and introduces some conceptual issues; it also describes the target audience, the driving forces behind excreta and greywater use, the resource value and the Millennium Development Goals (MDGs). 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 and system assessment. Chapters 7, 8 and 9 provide background information on sociocultural, environmental and economic and financial aspects. The policy, institutional and legal frameworks are covered in chapter 10, and planning and implementation procedures are presented in chapter 11.

1.1 Objectives and general considerations

The primary 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 agricultural applications. The Guidelines consider the positive health outcomes of this use (such as its contribution to better nutrition and food security), without presenting these as trade-offs.

To this end, the Guidelines describe recommended reasonable minimum safe practice requirements and system performance to protect the health of the people using excreta and greywater, local communities and the consumers of products grown with them. The Guidelines support the development and implementation of risk management strategies. The required level of health protection 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, the guidance provided concerns both good handling practices and quality speculations 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 relate to an integrated risk management framework (see the Stockholm Framework in chapter 2) applied from the point of generation to consumption of products grown with 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, 2004a). 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 once. The Guidelines allow incremental implementation. The greatest threats to health should be given the highest priority 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 judgement 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 judgement 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, in the context of national public health, environmental and socioeconomic realities and international trade regulations. The final judgement on safety standards and procedures is a matter for broad public consultation and should result from a transparent and accountable political decision-making process.

1.2 Target audience and definitions

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

The health hazards linked to the agricultural use of excreta and greywater vary with the distribution of pathogens, 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 for minimizing 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. Nongovernmental organizations and special interest groups also have an important role to play in helping local communities to maximize the reuse of valuable resources while ensuring that 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 (for definitions of terms used in the Guidelines, see Annex 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 discussed only in broad terms.

“Greywater” is defined as wastewater from the kitchen, bath and laundry, excluding wastewater from toilets, and therefore generally contains lower concentrations of excreta, except in specific situations as a result of infant care or where anal cleansing water is combined with the greywater. Greywater is used mainly 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.

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 they should be adapted for implementation under specific environmental, sociocultural and economic conditions at the national level or below. In some cases, countries may choose to develop different standards for products consumed locally and for products destined for export. Wherever lower national standards are set, based on a locally adopted level of tolerable risk (see chapter 2 for a further discussion of tolerable risk), the incidence of diarrhoeal or other diseases needs to be accounted for.

1.3.2 Food exports

The Guidelines can be adapted based on local conditions, except in relation to the rules that govern international trade in food, which have been 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. 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). There are documented cases where the import of contaminated vegetables has led to disease outbreaks in recipient countries. Pathogens can be introduced into communities lacking immunity, resulting in important disease outbreaks (Frost et al., 1995; Kapperud et al., 1995). Guidelines for the international trade of excreta-fertilized and wastewater-irrigated food products therefore need to be based on sound scientific risk management principles.

WHO Guidelines for the safe use of excreta and greywater in agriculture are based on a risk analysis approach that 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 WHO Guidelines will help to ensure the international trade of safe food products in the case of export of excreta-fertilized or greywater-irrigated food products.

1.4 Factors that affect sustainability in sanitation

Sustainable development, as defined in the Report of the World Commission on Environment and Development (WCED, 1987), is development that “meets the needs of the present generation without compromising the ability of future generations to meet their own needs.” From both a sustainability and a public health perspective, increasing access to adequate sanitation and promoting the adoption by individuals and communities of key hygienic behaviours are first priorities.

Within the scope of the *Guidelines for the safe use of wastewater, excreta and greywater*, sustainability can be described as the ability to plan and manage the use of excreta and greywater in agriculture as important resources in such a way that human health is not compromised, nutrients are recycled 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, organizational structure and technology, with a range of important criteria: health and hygiene, environmental and resource use, economy, sociocultural aspects and use and technology function. These aspects should be addressed with appropriate policies and within a conducive legal and regulatory framework; they are covered in different parts of the Guidelines.

1.4.1 Health and hygiene

The process of reducing disease burdens through improved sanitation is associated with the determinants of sustainability and is closely related to hygiene, behavioural change and proper access to and use of water and sanitation facilities. Focusing on just the provision of sanitation hardware will not result in sustainable change and will therefore not have a lasting impact on the health status of communities. Health aspects of excreta and greywater use are further dealt with in chapters 3 and 5.

1.4.2 Environment and resource use

Minimizing the negative impacts of excreta and greywater on surface water and groundwater and making more efficient use of the nutrient resources that they contain for crop and energy production will directly contribute to environmental sustainability. The environment will most importantly benefit from the treatment and safe use of excreta and greywater in terms of:

- recycling of water and nutrient resources;
- reduction of pressure on freshwater resources;
- reduction of downstream pollution from the discharge of wastes;
- reduction of potential environmental impacts from various chemicals (among others, endocrine disruptors, pharmaceuticals and their residues, which partly adsorb to soil particles and/or biodegrade in the soil, reducing the environmental impact on waters).

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

1.4.3 Economy

Economic aspects of sanitation are important at both national and household levels. At the national level, planners want to ensure optimal cost-effectiveness of investments in hygiene and sanitation options. These investments should give substantial economic returns in health benefits and time savings (Hutton & Haller, 2004). The cost–benefit of reducing adverse health and other impacts downstream as a result of better wastewater treatment and/or reducing waste discharges into surface waters has not been estimated but is 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; Wright, 1997; Samanta & van Wijk, 1998; Kolsky & Diop 2004). Most costs associated with gaining access to sanitation are incurred at the household level. Consumers want products that are durable and 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 & Diop, 2004). Economic aspects are further discussed in chapter 9 and in relation to institutional and legal aspects in chapter 10.

1.4.4 Sociocultural aspects and use

Sociocultural factors are fundamental for sustainability. A sanitation facility without appeal will not be used. Use is linked to access and convenience factors, but is also governed by social, cultural and religious beliefs. For girls and women, safe access is a major concern. The perception of ownership or responsibility is crucial and will affect, for example, the cleanliness of the facilities and, ultimately, their long-term success. Sociocultural issues concerning the use of excreta and greywater are further discussed in chapter 7.

1.4.5 Technology function

Technology function and selection contribute importantly to aspects of sustainability. Technologies selected for the safe use of excreta and greywater should meet all of the following sustainability criteria, accounting for robustness and variabilities in load:

- Health – technologies should provide inherent individual and public health protection;
- Environment – technologies should prevent contaminants from reaching groundwater and 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 it should be possible to upgrade or improve them as more resources become available;
- Sociocultural – 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 worldwide include:

- increasing water scarcity and stress, and degradation of freshwater resources resulting from improper disposal of excreta and greywater;
- population increase and related increased demand for food and fibre;
- a growing recognition of the resource value of excreta and greywater and the nutrients they contain;
- the MDGs, especially the goals for ensuring environmental sustainability and for eliminating poverty and hunger.

1.5.1 Water scarcity, stress and degradation

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 United States of America (China is predicted to reach water scarcity by 2050 and India by 2025) (Hinrichsen, Robey & Upadhyay, 1998). 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 resource.

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 "polluter pays" principle 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. Acknowledgement of the concept of 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 become increasingly 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 become a more attractive option.

1.5.2 Population growth and food production

Over the next 50 years, most population growth is expected to occur in urban and periurban areas in developing countries (United Nations Population Division, 2002). For example, a majority 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 the developing world (United Nations Population Division, 2002).

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

- greater populations will generate more wastes, especially in and around cities;
- on-site waste disposal will be more difficult in many densely populated areas;
- urban agriculture will play a more important role in supplying food to city dwellers. Excreta and greywater will become increasingly important as inputs.

Excreta and greywater 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 already to a large extent in these applications. Treated excreta would potentially pose fewer health risks in these types of applications. Esrey (2001) has summarized the impact of excreta use in relation to nutrients in urban areas.

Eighty per cent of the world's natural food resources are converted into waste and disposed of (Smit, 2000). According to 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 6000 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 their rural counterparts. 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 costs. Urban agriculture and home gardening can produce more food per unit space, because food can be grown on roofs, on walls and in and around buildings. Urban agriculture has enjoyed a revival in the past few decades (Smit, Ratta & Nasr, 1996). In greater Bangkok, 60% of the land is under cultivation. The demand for food by consumers and for 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 complete nutrition for plants. Access to affordable and more nutritious food will increase and post-harvest food losses will be reduced if food is grown and consumed locally. This represents a saving in water as well as nutrients.

When food is grown farther away from population centres, not only does it cost more, but valuable micronutrients are less likely to reach consumers, particularly people with little income. Urban farming and home gardening, on the other hand, can result in better diets, improving macro- and micronutrient intakes as well as the nutritional status of vulnerable groups, such as women, children, the elderly and the disabled (Maxwell, Levin & Csete, 1998).

1.5.3 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 need for artificial fertilizers and is important for nutrient recycling. Some studies indicate that the world's supply of readily available phosphorus is limited and will run out in 150 years (Rosemarin, 2004). Excreta are an accessible source of important plant nutrients, such as phosphorus, nitrogen and potassium. Excreta use can help to reduce the mining of finite phosphorus reserves and energy expended to create artificial fertilizers. Greywater is mostly used for irrigation, as service water or sometimes for groundwater recharge at a local scale. Its use helps reduce the demand for freshwater supply and mitigates the stress on water resources.

Excreta quantities and composition

Annually, about 130 million tonnes of fertilizers are sold globally, 63% of which are sold in the developing world. Of this quantity, 78 million tonnes are nitrogen and 13.7 million tonnes phosphorus. The rest represents potassium, sulfur and micronutrients. The excreta from 6 billion persons contain 27 million tonnes of nitrogen and 3 million tonnes of phosphorus. This means that one third of the world's mineral nitrogen use could in theory be replaced by nitrogen from excreta. Similarly, 22% of the world's use of mined phosphorus could be replaced by phosphorus from excreta.

The major plant nutrients nitrogen, phosphorus and potassium are found in human excreta and thus also in domestic wastewater (Figure 1.2), but the contents will vary depending on the food intake. Greywater will mainly recycle water and supplies only minor amounts of nutrients.

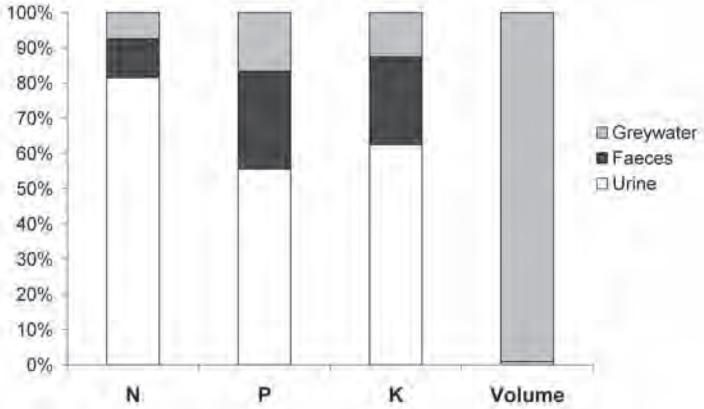

Figure 1.2
Content of major plant nutrients and volume in domestic wastewater in Sweden. The daily mean excretion per person and per day is 13 g nitrogen (N), 1.5 g phosphorus (P) and 4 g potassium (K) in a volume of 150–200 litres, including greywater (Vinnerås, 2002).

Mass balance and content of macronutrients in excreta

The nutrient content in urine and faeces depends directly on the amounts and quality of food consumed. Children need nutrients to grow; in adults, however, food consumption is mainly for energy, and only minor amounts of nutrients are retained and accumulated in the body. Almost all consumed plant nutrients will therefore leave the human body in 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 of 3 and 13.

Since most nutrients leave the human body in excreta, excreted plant nutrients can be calculated from food intake, on which information is readily available. Based on statistics from the Food and Agriculture Organization of the United Nations (FAO) (http://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 provides default values for these parameters in Sweden.

Table 1.1 Swedish default values for excreted mass and nutrients

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

Source: Vinnerås (2002).

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

$$N = 0.13 \times \text{total food protein} \qquad \textbf{Equation 1}$$

$$P = 0.011 \times (\text{total food protein} + \text{vegetal food protein}) \qquad \textbf{Equation 2}$$

These equations can be used to estimate the average excretion of nitrogen and phosphorus in different countries; see examples in Table 1.2. There tends to be greater variability in values for potassium.

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

The relative amounts of nutrients in urine and faeces depend on the diet: digested nutrients are mainly excreted with the urine, whereas undigested fractions are excreted in the faeces. Approximately 88% of the excreta nitrogen and 67% of the excreta phosphorus are found in the urine, and the rest are in the faeces. These figures are lower in China, where the urine contains approximately 70% of the excreta nitrogen and 25–60% of the phosphorus (Gao et al., 2002).

Digestibility also influences the amount of faeces excreted. In Sweden, the amount of faeces excreted is estimated at 51 kg wet mass/person per year (11 kg dry weight) (Vinnerås, 2002). In China, faecal excretion is estimated at 115 kg wet mass/person per year (22 kg dry weight) (Gao et al., 2002).

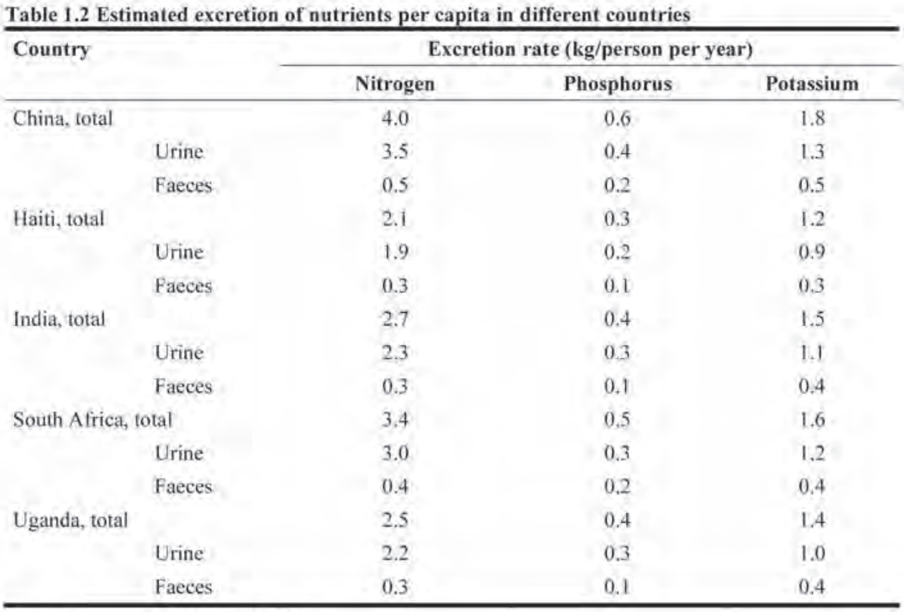

Table 1.2 Estimated excretion of nutrients per capita in different countries

Country		Excretion rate (kg/person per year)		
		Nitrogen	Phosphorus	Potassium
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

Source: Jönsson & Vinnerås (2004).

The concentration of nutrients in 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 per person per year) for adults and about half that amount for children in Europe (Lentner, Lentner & Wink, 1981), but it may be much higher due to climate or activity level. Similar amounts have been reported for China: 1.6 litres per person per day (580 litres per person per year) (Gao et al., 2002). Excessive perspiration results in concentrated urine, while consumption of large amounts of liquid dilutes the urine.

Use of urine as fertilizer

Urine is rich in nitrogen and can be used for fertilizing most non-nitrogen-fixing crops after proper treatment to reduce potential microbial contamination. Crops with a high nitrogen content that respond well to nitrogen fertilization include spinach, cauliflower and maize. Direct use of urine as a plant fertilizer will entail the most efficient use of nutrients, but addition of urine to improve composting of carbon-rich substrates is another possibility (although it may result in large ammonia losses). The nutrients in urine are in ionic form, and their plant availability and fertilizing effect compare well with those of chemical (ammonium- and urea-based) fertilizers (Kirchmann & Petterson, 1995; Johansson et al., 2001). When the nitrogen content of collected urine is unknown, a concentration of 3–7 g of nitrogen per litre at excretion can be used as a default value (Jönsson & Vinnerås, 2004). On a yearly basis, the amount of nitrogen produced per person equals 30–70 kg, 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 with chemical fertilizers, 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 be applied either 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). The test results of the use of urine as a fertilizer for barley in Sweden are shown in Box 1.1.

The best fertilizing effect is obtained when the urine is directly incorporated into the soil after application; shallow incorporation is sufficient (Rodhe, Richert Stintzing & Steineck, 2004). Direct incorporation also minimizes ammonia losses to the air. Surface application generally gives a nitrogen loss above 70% due to ammonia volatilization, and soil incorporation is therefore very important (Morken, 1998).

Trials with different application strategies using urine as a fertilizer for leeks gave a threefold 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 (Table 1.3). The strategy used in West Africa involves 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 fertilizer that can be used for most vegetables.

Table 1.3 Results of a field trial using human urine as a fertilizer for leeks

Treatment[a]		Nitrogen application rate (kg/ha)[b]	Yield (t/ha)[b]	Nitrogen yield (kg/ha)[b]
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	Unfertilized	0	17	24

[a] No statistically significant difference between treatments A, B and C.
[b] kg/ha = g/10 m^2; t/ha = kg/10 m^2.
Source: After Båth (2003).

Use of faeces as fertilizer

Faeces may contain high concentrations of pathogens, and appropriate treatment is therefore crucial to ensure its safe use. The total amount of nutrients excreted is lower in faeces than in urine, but the concentrations of (especially) phosphorus and potassium are higher in faeces than in urine. It is these two elements that may significantly increase the crop yield (Morgan, 2003). The content of organic matter in faeces also increases the water-holding and ion-buffering capacities of soils, which is of importance for improving soil structure and stimulates the microbial activity. The fertilizing effect of faeces is more variable than that of urine, since the proportion of nitrogen in mineral form and the content and properties of the organic matter vary depending on the treatment applied.

Faecal compost applied together with urine may have advantages, since the former conditions the soil and the latter provides rapidly accessible nitrogen. Incineration of faeces results in ash with high contents of phosphorus and potassium as well as micronutrients, but nitrogen and sulfur are lost to the atmosphere. Ash in general (which 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 fertilizing with, for example, urine, as shown on experimental plots in Zimbabwe (Morgan, 2005).

Box 1.1 Urine as fertilizer for barley in Sweden

Urine was tested as a fertilizer on barley in Sweden during 1997–1999 (Johansson et al., 2001; Rodhe, Richert Stintzing & Steineck, 2004). Results showed that the nitrogen effect of urine corresponded to about 90% of that of equal amounts of ammonium nitrate mineral fertilizers (Figure 1.3). The urine was spread before sowing with a conventional spreader for liquid manure (Figure 1.4).

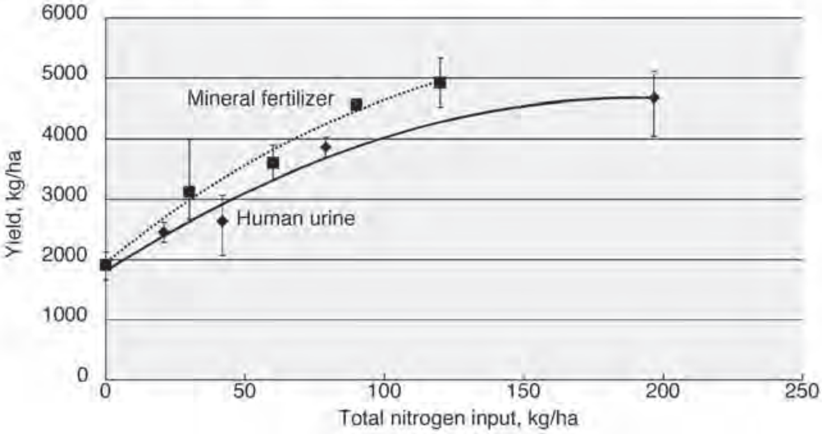

Figure 1.3
Results from field trials with urine as fertilizer for barley, 1999

Figure 1.4
Conventional slurry spreader used for application of urine

Faecal compost can be applied as a complete phosphorus–potassium fertilizer or as a soil improver. Approximately 40–70% of the organic matter and somewhat less of the nitrogen are lost through biological activity and volatilization. Most of the remaining nitrogen will become available to plants during degradation. This slow process improves the water-holding and buffering capacity of the soil. The phosphorus is also partly, but to a lesser extent, bound in organic forms, whereas the potassium is mainly in ionic form and readily available to plants. In anaerobic digests, approximately the same proportion of organic matter is degraded as in composting, but the mineralized nitrogen remains within the digested residue and 40–70% of the nitrogen is in the form of ammonium, which is readily available to plants. The digested residues make up a well balanced, quick-acting and complete fertilizer (Åkerhielm & Richert Stintzing, 2004). 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 dried rapidly and low moisture levels prevail, the loss of organic matter and nitrogen will be small. Compared with composting, dry storage recycles more organic matter and nitrogen to the soil, but the organic matter is less stable. Dried faecal matter is a complete phosphorus–potassium fertilizer, contributing considerable amounts of nitrogen as well.

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

The faecal matter from one person is enough to fertilize 200–300 m^2 of wheat at a yield of 3000 kg/ha based on the P content. Where the soil is devoid of phosphorus, 5–10 times the removal rate can be applied. At this application rate, most of the phosphorus will remain and will improve the soil, with significant yield increases and without negative effects from phosphorus or organic matter. Application rates for farmyard manure in agriculture are in the range of 20–40 t/ha. 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, materialize only 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 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 the composted faeces and urine mix to poor soil (Table 1.4).

Table 1.4 Average yields in plant trials comparing growth in topsoil only with growth in a mixture consisting of 50% topsoil and 50% Fossa alterna compost

Plant and soil type	Growth period	Yield (g fresh weight) in topsoil only	Yield (g fresh weight) in 50/50 topsoil/Fossa alterna soil	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

Source: Morgan (2003).

Greywater volume and composition

Greywater production and composition are dependent on sanitary standards, awareness of the need for water conservation, water availability and raw water composition (Lens, Zeeman & Lettinga, 2001; Eriksson et al., 2002). Greywater volume and composition also vary with lifestyle: family size, age of residents, eating habits and detergents used. The main sources of greywater are laundry, bathroom and kitchen. In the following summary, the results of some studies on greywater volume and composition are presented.

Greywater volumes produced may be as low as 20–30 litres per person per day in poor areas where water often is hand-carried from taps (Ridderstolpe, 2004; Winblad & Simpson-Hébert, 2004). When availability increases, the production of greywater increases, but it seldom exceeds 100 litres per person per day in developing countries. In industrialized countries, greywater production is normally in the range of 100–200 litres per person per day (the highest figures are reported from the USA and Canada) and sometimes exceeds 200 litres per person per day (Crites & Tchobanoglous, 1998; Bertaglial et al., 2005). In new housing developments in Europe, where awareness of the need for water conservation is promoted, the per capita daily greywater production is less than 100 litres (Table 1.5).

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

Table 1.5 Examples of greywater production

Location	Greywater production (litres per person per day)	Reference
China, ecological sanitation project	80	EcoSanRes (2005b)
Belgium	85	Bertaglial et al. (2005)
Germany	35–65	Panesar & Lange (2001)
Germany, Eco-village Flintenbreite	60	Ridderstolpe (2004)
Germany, Norway and Sweden, new built house area, water conservation	<100	Ridderstolpe (2004); Winblad & Simpson-Hébert (2004)
Norway, ecovillage	81	Kristiansen & Skaarer (1979)
Norway, student dormitories, water conservation	112	Jenssen (2001)
Sweden, range for ecovillages	66–110	Vinnerås et al. (2006)
Sweden, proposed norm	100	Vinnerås et al. (2006)
Sweden, existing norm	150	Vinnerås et al. (2006)
Europe, northern part	110	Lens, Zeeman & Lettinga (2001)
Australia, western part	112	Department of Health (2002)
USA	200	Crites & Tchobanoglous (1998); Bertaglial et al. (2005)
Developing regions	20–30	Ridderstolpe (2004); Winblad & Simpson-Hébert (2004)
Range	70–275	Otterpohl (2002)

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

Greywater contains 50% or more of the readily degradable organic matter in household sewage — measured as biological (BOD) or chemical (COD) oxygen demand — but the concentrations are highly variable, depending on household practices. In industrialized countries, excessive 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 biodiesel (Zhang et al., 2003), but they can also increase biogas yield in anaerobic digestion. Examples of concentrations of various water quality parameters found in untreated or primary treated greywater are presented in Table 1.6.

The concentrations of nutrients in greywater depend on the per capita mass discharge and the water use. The per capita discharges under Swedish conditions are presented in Table 1.7.

In the sites listed in Table 1.7, phosphorus-containing detergents were used. According to Norwegian studies, the per capita mass discharge of phosphorus is reduced to 0.2 mg/l with phosphorus-free detergents (Jenssen & Vråle, 2004). The major part of the heavy metal load in 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.

1.5.4 Millennium Development Goals

At the 2002 World Summit on Sustainable Development in Johannesburg, global leaders agreed to adopt a sanitation coverage target — namely, "to halve, by the year 2015, the proportion of people who do not have access to basic sanitation" (United Nations, 2002). Expanding access to and proper use of improved sanitation facilities would have far-ranging positive health consequences and would support meeting the relevant targets of the Millennium Development Goals.

To achieve the sanitation target under MDG7, WHO estimates that 1.9 billion people will need to gain access to improved sanitation by 2015 — 1 billion urban dwellers and 900 million rural dwellers. This figure takes into account the projected population growth. As of 2002, 77% of the unserved worldwide (i.e. 2 billion people) lived in rural areas. 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 periurban 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 1.6 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)	Suspended solids (mg/l)	Total N (mg/l)	NH_4 (mg/l)	Kjeldahl N (mg/l)	Total P (mg/l)	Faecal coliforms (log numbers/ 100 ml)
Canada / Brandes (1978)	149	366	162	11.5	1.7	11.3	1.4[a]	6.2
Norway / Kristiansen & Skaarer (1979)	130	341	35	19	11.5		1.3 (0.42[b])	5.1
USA[c] / Siegrist & Boyle (1981)	178	456	45			15.9	4.4	6.2
Sweden norm / Naturvårds-verket (1995)	187		107	6.7			4 (1.0[b])	
Norway[c] / Rasmussen, Jenssen & Westlie (1996)	116		39	42.2	36.1		3.97	
Australia / Department of Health (2002)	160		115		5.3	12	8	5.2
Norway[c] / Jenssen (2001)	88	277	–	8.8	3.8	4.9	1.0[b]	4–6
Sweden proposed norm / Vinnerås et al. (2006)	260[c]	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[d] / Jenssen et al. (2005)	128	212	75	37	12.6	22.2	2.4	5.8

BOD_5, five-day biological oxygen demand

[a] Excluding laundry.

[b] Phosphorus-free detergents.

[c] BOD_7, seven-day biological oxygen demand, for the Swedish proposed norm.

[d] Septic tank effluent.

In urban and periurban centres, much of the sanitation expansion may be in the form of sewerage (conventional sewerage in urban centres and simplified sewerage in periurban 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.

Table 1.7 Greywater volume and concentrations of various water quality parameters in greywater collected from Swedish eco-housing developments compared with Swedish norm values

Parameters	Ekoporten	Gebers	Vibyåsen	Swedish norm	Proposed norm
Volume (litres per person per day)	104	110	66	150	100.0
Dry mass (g/person per day)	59.2	15.1	29.2	20	59.8
BOD_7 (g/person per day)		21.1	27.7	28.0	26.0
COD (g/person per day)		47.9	39.0	72.0	52.1
Nitrogen (g/person per day)	1.7	1.4	0.6	1.0	1.4
Phosphorus (g/person per day)	0.4	0.6	0.5	0.3	0.5
Potassium (g/person per day)	4.0	1.0	0.5	0.5	1.0

BOD_7, seven-day biological oxygen demand

Source: Calculated from Vinnerås et al. (2006).

Therefore, if effective treatment were available at the household level, prior to discharge of waste 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, poor subsistence farmers do not 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 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.

However, increased poverty may also result 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 at the centre of the sanitation debate. Poor households spend a larger percentage (50–80%) of their income on food and water than do households that are better off (Lipton, 1983; World Food Programme, 1995). 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

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

2.1 A harmonized approach to risk assessment/management

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 & Bartram, 2001). This report 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.

The Framework encourages countries to adjust guidelines to local social, cultural, economic and environmental circumstances and compare the health risks associated with, for example, excreta and greywater use in agriculture with risks from microbial exposures through other routes, such as 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, not in isolation from other diseases or exposure pathways. Disease outcomes from different exposure routes can be compared by using a common metric, such as disability adjusted life years (DALYs), or normalized for a population over a time period (see Box 2.1).

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 to the years lived with a disability. Years of life lost are calculated from age-specific mortality rates and the standard life expectancies of a given population. Years lived with a disability 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 ranging from 0.09 to 0.12, depending on the age group) (Murray & Lopez, 1996; Prüss & Havelaar, 2001). DALYs are an important tool for comparing health outcomes, because they account not only for acute health effects but also for delayed and chronic effects — including morbidity and mortality (Bartram, Fewtrell & 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, 2004a) and the WHO *Guidelines for safe recreational water environments* (WHO, 2003a, 2005a) have both incorporated a harmonized approach to risk assessment and management as outlined in the Stockholm Framework.

2.2 Elements of the Stockholm Framework

The individual elements of the Stockholm Framework and how they specifically relate to the use of excreta and greywater are presented in Figure 2.1 and in Table 2.1. Some of the Framework elements are discussed in more detail in subsequent chapters of this document.

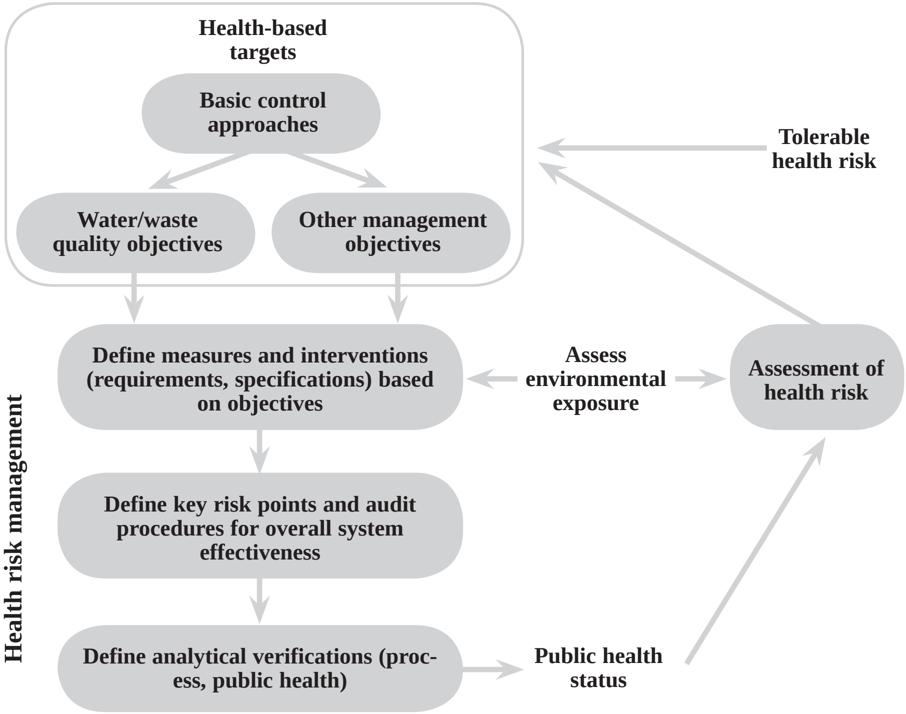

Figure 2.1
The Stockholm Framework for developing harmonized guidelines for the management of water-related infectious disease (adapted from Bartram, Fewtrell & Stenström 2001)

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 facilitate comparison of risks across different exposures and priority setting
	QMRA	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 supported by other data (e.g. outbreak investigations, epidemiological evidence and studies of environmental behaviour of microbes) Process dependent on quality of data Risk assessment needs to account for short-term underperformance

Table 2.1 (continued)

Framework component	Process	Considerations
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 Reference pathogens should be selected for relevance to contamination, control challenges and health significance (it may be necessary to select more than one reference pathogen) Health-based targets establish a desired health outcome
Health risk management	Define water/waste quality objectives Define other management objectives Define measures and interventions Define key risk points and audit procedures Define analytical verifications	Health-based targets 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 of the effectiveness of the health protection measures is needed to ensure that the system is capable of meeting the health-based targets; validation is needed when a new system is developed or additional barriers are added; 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 prioritization of risk management decisions

Source: Adapted from Carr & Bartram (2004).

2.3 Assessment of environmental exposure

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

The primary hazard is related to exposure to pathogens in untreated or insufficiently treated faecal excreta 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 food or water. Several helminths in excreta may also infect humans through the skin. Direct contact with contaminated material and subsequent accidental ingestion from contaminated fingers or utensils are 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 fertilized crop is to be cooked before consumption, surfaces may be contaminated and pathogens transferred to other foods or fluids.

2.4 Assessment of health risk

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

The assessment of risks is central in preventive public health. 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 (e.g. a population using excreta/greywater in agriculture or consuming products grown with them) with that in an unexposed or control population. 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 socioeconomic status and ethnicity. Potential confounding factors and bias, which could affect results, need to be addressed. There have been very few epidemiological studies concerned with the use of excreta or greywater in agriculture. Blumenthal & Peasey (2002) review some (see also chapter 3).

The indirect assessment of risk in QMRA is usually dealt with in a step-wise approach. *Risk analysis* embraces the three components of risk assessment (i.e. QMRA), risk management and risk communication (Haas, Rose & Gerba, 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 (i.e. microbial agents). *Risk management* is the process of controlling risks, weighing alternatives and selecting appropriate action, accounting for 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 associated with the use of excreta and greywater in agriculture are presented in chapter 3.

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

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. Hazard characterization	Dose–response assessment, to characterize the relationship between various doses administered and the incidence of the health effect, including underlying mechanisms and extrapolation from model systems to humans
3. Exposure assessment	To determine the size and nature of the population exposed and the route, amount and duration of the exposure
4. Risk characterization	To integrate the information from exposure assessment, hazard characterization 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 (2003a).

In *hazard characterization*, exposure and health effects are described with background information on, for example, the pathogens relevant in a special surrounding or environment. It also includes the range of human diseases associated with the identified microorganisms (Haas, Rose & Gerba, 1999). A conceptual model is developed that describes the interactions of pathogens with the defined population as well as assumptions made and attempts to address specific questions and identify information needs.

The dose–response relationship between microbial agents and the infection rate in a population is seldom directly estimated but is usually based on human volunteer studies presented in the literature. A mathematical relationship is obtained between the dose and the probability of infection (Teunis et al., 1996; Haas, Rose & Gerba, 1999), where either exponential (#1 in Box 2.2) or β-Poisson (#2 in Box 2.2) relationships are applied.

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

- pathogen characterization: determining the properties of the pathogen that affects its ability to be transmitted to and cause disease in the host;
- pathogen occurrence: characterizing the occurrence and distribution of the pathogen, including information on its 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 characterization of the source and temporal nature of the exposure. The dose of a pathogen is calculated from the density of the organism through the contact route multiplied by the volume ingested. Densities are either based on prevalence data for actual pathogens or indirectly estimated through index organisms (Ashbolt et al., 2006).

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 *risk characterization* integrates the information from the hazard identification, hazard characterization and exposure assessment to estimate the

Box 2.2 Example of mathematical determination of the dose–response relationship

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) due to either the organism or the exposed population, where α and β describe the relation: $P_{inf} \approx 1 - (1 + Dose/\beta)^{-\alpha}$

The β-Poisson model fits well with many dose–response data sets and is conservative when extrapolating to low doses (Teunis et al., 1996), whereas the exponential relationship is applicable when dealing with pathogens where no dose response studies have been made, where vulnerable populations are exposed or in worst case scenarios (Figure 2.2). Then r = 1 can be applied as a generic single hit model, where ingestion, inhalation or contact with one organism will lead to $P_{inf} = 0.63$.

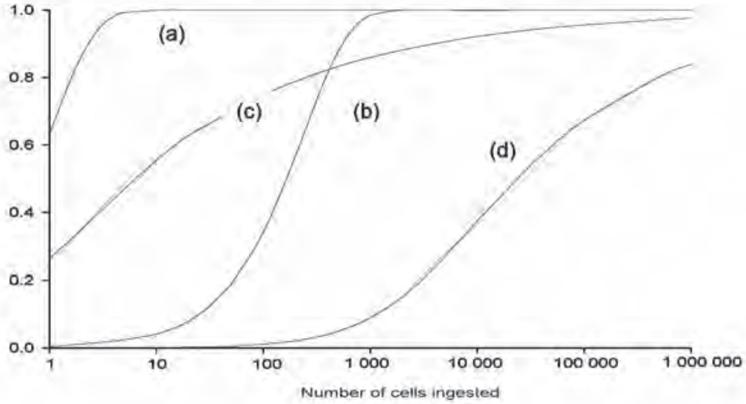

Figure 2.2
The probability of infection from the ingestion of pathogenic cells in different dose–response relationships: Exponential models for a) a worst-case scenario and b) *Cryptosporidium*; β-Poisson models for c) rotavirus and d) *Salmonella*

magnitude of the public health problem and to evaluate variability and uncertainty. Since information is usually incomplete and the density of pathogens fluctuates, probability density functions with Monte-Carlo simulations are better than point estimates or constant values in risk calculations. The microbial risk (probability of infection, P_{inf}) is presented either as the rate of infected people out of the number of exposed people or as the total number of infections per annum or system lifetime (Fane, Ashbolt & White, 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 needs to be made 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 in agriculture. 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.

For carcinogenic chemicals in drinking-water, guideline values have been set at a 10^{-5} upper-bound estimate of risk (WHO, 2004a). This means that there would be a maximum of one excess case of cancer per 100 000 of the population ingesting drinking-water that contained the chemical at the guideline concentration over a lifetime. 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, 2004a). This level of disease burden can be compared with a mild but more frequent illness, such as self-limiting diarrhoea caused by a microbial pathogen. The estimated disease burden associated with mild diarrhoea (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, 2004a).

2.5.2 Health-based targets

Health-based targets should be part of overall public health policy, taking into account status and trends and the contribution of the use of treated excreta or greywater in agriculture to the transmission of infectious disease both in individual settings and within overall health management. The purpose of setting targets is to 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 relate directly to the management strategies. This normally implies periodic review and updating of priorities and targets and, in turn, that norms and standards should be revised to take account of these factors and the changes in available information (WHO, 2004a).

A health-based target 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 exposure or concentration of pathogens.

Health-based targets 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 (DALYs or absence of a specific disease);
- *Excreta or greywater quality*: e.g. concentrations of viable intestinal nematode eggs and/or *E. coli*;
- *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 processes, either in general or with reference to specific circumstances of use.

2.6 Risk management

Health targets relate 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 address controllable factors, such as:

- behaviours (e.g. hand washing with soap; adding lime to faeces);
- treatment technologies;
- operational processes: application to fields; operation and maintenance of facilities;
- protective action: cooking food properly prior to consumption; wearing protective clothing when 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 be measured only if the baseline health status of the affected population is known or can be approximated. Similarly, tolerable risk and health-based targets can be set only with some knowledge of the incidence and prevalence of infection and disease in the community, the types of diseases that may result from the use of excreta and greywater and the vulnerability of different subsections of the population (e.g. people with reduced immune function or those 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, epidemiological studies or specific research conducted in a project area. Infectious disease outbreaks provide additional information. There may be seasonal fluctuations in disease incidence — 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 and greywater in a certain area, knowledge of disease trends (i.e. whether disease incidence is decreasing or increasing) is valuable. 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.

Risk management strategies for excreta and greywater aim at minimizing 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 pathogen reduction;
- crop restriction: growing crops that either are not eaten or are processed (cooked) prior to consumption;
- application techniques of excreta and greywater that reduce exposure of workers and contamination of crops (including withholding periods, buffer zones);

- exposure control methods: limiting public access; workers wearing protective clothing; washing, disinfecting and/or cooking food properly prior to consumption.

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

2.7 Public health status

In many countries, excreta and wastewater contain high concentrations of pathogens, and excreta-related infections are common. 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, types of viral 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 worldwide (WHO, 2004b). In addition to diarrhoea, WHO estimates that each year, 16 million people contract typhoid and over 1 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

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

Disease	Mortality (deaths/year)	Burden of disease (DALYs/year)	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 million 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
Schistosomiasis	15 000	1 702 000	Found in 74 countries, 200 million people worldwide are estimated to be infected, 20 million with severe consequences
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).

high-risk situations, where poor hygiene, lack of access to sanitation and poor water quality prevail — generally have a higher rate of gastrointestinal illness. Kosek, Bern & Guerrant (2003) found that children under the age of five in developing countries experienced a median of 3.2 episodes of diarrhoea per child per year.

Table 2.3 provides estimates of mortality and morbidity for some diseases of possible relevance to excreta and greywater use in agriculture.

3
ASSESSMENT OF HEALTH RISK

The use of excreta and greywater in agriculture 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, increase 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 described 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 presents an overview of organisms found in faeces and urine that are of public health importance. The microbial risks in relation to greywater relate 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 described. The risks to consumers are dealt with from an epidemiological perspective. The chapter also summarizes existing information on the survival/die-off of pathogens in faeces, urine and greywater systems, which forms an integrated concept in risk assessment. The assessment of health risk, following the procedure outlined in the Stockholm Framework (see chapter 2), is exemplified for faeces, urine and greywater.

3.1 Health benefits

The health benefits from excreta are linked mainly to their value as fertilizer to enhance crop productivity and thus the availability of agricultural products. Excreta use as fertilizer has so far been mainly applied in small-scale applications in rural areas and urban agriculture, as described in chapter 1. Greywater is used mainly for irrigation, similarly benefiting crop production. It is an important resource for the poor in water-scarce areas and elsewhere. Indirect health benefits also relate to its economic value (chapter 9) and reduced environmental impact (chapter 8). Although the benefits of excreta as a fertilizer are well established, the role of greywater is less well characterized in this respect.

Improving nutrition is critical for maintaining the overall health of individuals and communities, especially for children. Malnutrition is estimated to play 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 readily available sources of plant fertilizer, can help to alleviate malnutrition if managed well, yet they also can cause malnutrition (e.g. iron deficiency anaemia) through hookworm infection if proper risk management strategies are not employed (see chapter 5).

Combining poverty, malnutrition and lack of access to safe drinking-water and adequate sanitation into one picture shows a downward spiral, which, at the individual level, comes to expression in the following phenomena:

- Poor people may eat and absorb too little nutritious food and be more disease-prone.
- Inadequate or inappropriate food leads to stunted development (one in three children under the age of five 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 people are anaemic); malnutrition increases susceptibility to disease.

- The immune system is unable to adequately cope with often multiple infections.
- Disease decreases people's ability to cultivate or purchase nutritious foods.

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

3.2 Excreta-related infections

The first step of any risk assessment is hazard identification. For risk assessment of excreta-related infections, the pathogens relevant in a specific setting under specific conditions or associated with specific actions are identified. The associated infections are common in the human population in many countries with correspondingly high concentrations of excreted pathogens.

Several factors govern the likelihood of pathogen transmission:

- epidemiological features (including infectious dose, latency, hosts and intermediate host);
- persistence in different environments outside the human body (and potential for growth);
- major transmission routes;
- relative susceptibility to different treatment techniques;
- management control measures.

These factors are accounted for in the hazard identification step. The relevant microbial agents are identified, as well as the spectrum of human ill-health associated with each pathogen. Acquired immunity and multiple exposures (e.g. exposure at different times or through different routes) need to be considered. Since it is not feasible to assess the potential impact of all excreta-related pathogens, some are commonly chosen as indicator pathogens (when their reduction due to different barriers is assessed, the term "index pathogens" is often used).

The prevalence of excreta-related pathogens in a human population is a measure of their presence in the environment. Key factors to be considered at the stage of hazard identification are, therefore:

- disease prevalence and incidence (if possible, corrected for underreporting);
- percentage of infections leading to disease (morbidity, differs between organisms);
- excretion density (differs between organisms);
- excretion time and prevalence of asymptomatic carriers (differs between organisms);
- excretion route (faeces or urine).

The disease prevalence rate is the number of clinical cases caused by a specific pathogen at a specific moment in time, usually standardized to the number of cases per 100 000. The disease incidence rate is the number of new cases divided by the total population over a period of time, usually one year and usually standardized to the number of new cases per 100 000 people over that period. Incidence will vary in accordance with the prevailing epidemiological situation in a given 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 were reported) are presented in Table 3.1. Generally, pathogens causing less severe symptoms are less likely to be reported (Wheeler et al., 1999).

Table 3.1 Examples of different epidemiological data for selected pathogens

Pathogen	Incidence (per 100 000 people)	Under-reporting	Morbidity (%)	Excretion (per gram faeces)	Duration (days)	ID_{50}
Salmonella	42–58	3.2	6–80	10^{4-8}	26–51	23 600
Campylobacter	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 virus	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	–	1–14	1.7
Cryptosporidium	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

Source: Westrell (2004).

The infection prevalence and amount of faeces excreted will determine the pathogen concentration at the time of excretion. The subsequent risks will relate to (1) their persistence (or regrowth or environmental latency), which will vary in relation to the receiving environment and the organism in question, (2) dilution factors (e.g. the amount of human faeces that will end up in greywater), (3) exposure route (and frequency of exposure) and (4) dose (i.e. the amount of material, and thus the number of pathogens, to which a person is exposed). Risks will vary due to the infectious dose of the organism in question and the vulnerability of the exposed population. In order for a person to become infected when exposed to a pathogen, the pathogen must breach the host's defence mechanisms. The median infectious dose, ID_{50}, is the pathogen dose 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 who will show clinical symptoms when infected.

Values in Table 3.1 are taken from developed regions. The incidence data for norovirus 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 (Mead et al., 1999; Wheeler et al., 1999; Michel et al., 2000; Carrique-Mas et al., 2003) and morbidity (Feachem et al., 1983; Van et al, 1992; Graham et al., 1994; Gerba et al., 1996; Lemon, 1997; Haas, Rose & Gerba, 1999; Tessier & Davies, 1999; Havelaar, de Wit & van Koningsveld, 2000; Michel et al., 2000).

3.2.1 Pathogens in faeces

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

Enteric bacterial pathogens continue to be of major concern, especially in developing countries, where outbreaks of cholera, typhoid and shigellosis appear to be more frequent in urban and periurban areas. In areas where access to adequate sanitation is non-existent or insufficient, typhoid fever (*Salmonella typhi*) and cholera (*Vibrio cholerae*) constitute major risks through the resulting contamination of drinking-water. *Shigella* is a common cause of diarrhoea in developing countries, especially in settings where hygiene and sanitation are poor. Among the bacteria, at least *Salmonella*, *Campylobacter* and enterohaemorrhagic *E. coli* (EHEC) are of general importance, both in industrialized and in developing countries, from the perspective of microbial risks posed by the use of various fertilizer products (including faeces, sewage sludge and animal manure). These bacteria are also important as zoonotic agents (transmission between humans and animals, with contamination from faeces/manure).

Enteric viruses are also of general importance and are now considered to be the cause of the majority of gastrointestinal infections in industrialized regions (Svensson, 2000). Of the different types of viruses that may be excreted in faeces, the most common are members included in the enterovirus, rotavirus, enteric adenovirus and human calicivirus (norovirus) groups (Tauxe & Cohen, 1995). Hepatitis A virus has long been recognized as being of major concern when applying wastes to land and is considered a risk for both water- and foodborne outbreaks, especially when the sanitary standards are low. Recognition of the importance of hepatitis E virus is emerging.

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

In developing countries, geohelminth infections are of major concern. The eggs (ova) of, especially, *Ascaris* and *Taenia* are persistent in the environment and are therefore regarded as an indicator and index of hygienic quality (WHO, 1989). Hookworm disease is widespread in most tropical and subtropical areas and affects nearly one billion people worldwide. In some developing countries, these infections exacerbate malnutrition and indirectly cause the death of many children by increasing their susceptibility to other infections.

Of the parasitic trematode worms causing schistosomiasis, the eggs of one species, *Schistosoma haematobium*, are excreted predominantly in urine (see below), whereas the eggs of the other species (*S. japonicum*, *S. mansoni* and *S. mekongi*) are excreted in faeces. They also differ in their geographical distribution. *S. japonicum* occurs in the Western Pacific Region (mainly China and the Philippines), *S. mekongi* in foci in the Mekong River basin, *S. haematobium* in Africa and the Eastern Mediterranean Region and *S. mansoni* in Africa and in parts of Central and South America, notably Brazil (WHO, 2003a). More than 200 million people are currently infected with schistosomiasis. The use of treated excreta should not pose a risk, but the use of fresh or untreated faecal material does, if it happens close to freshwater sources where the intermediate host snail species are present.

The pathogens whose transmission can be attributed to the use of faecal excreta mainly cause gastrointestinal symptoms such as diarrhoea, vomiting and stomach

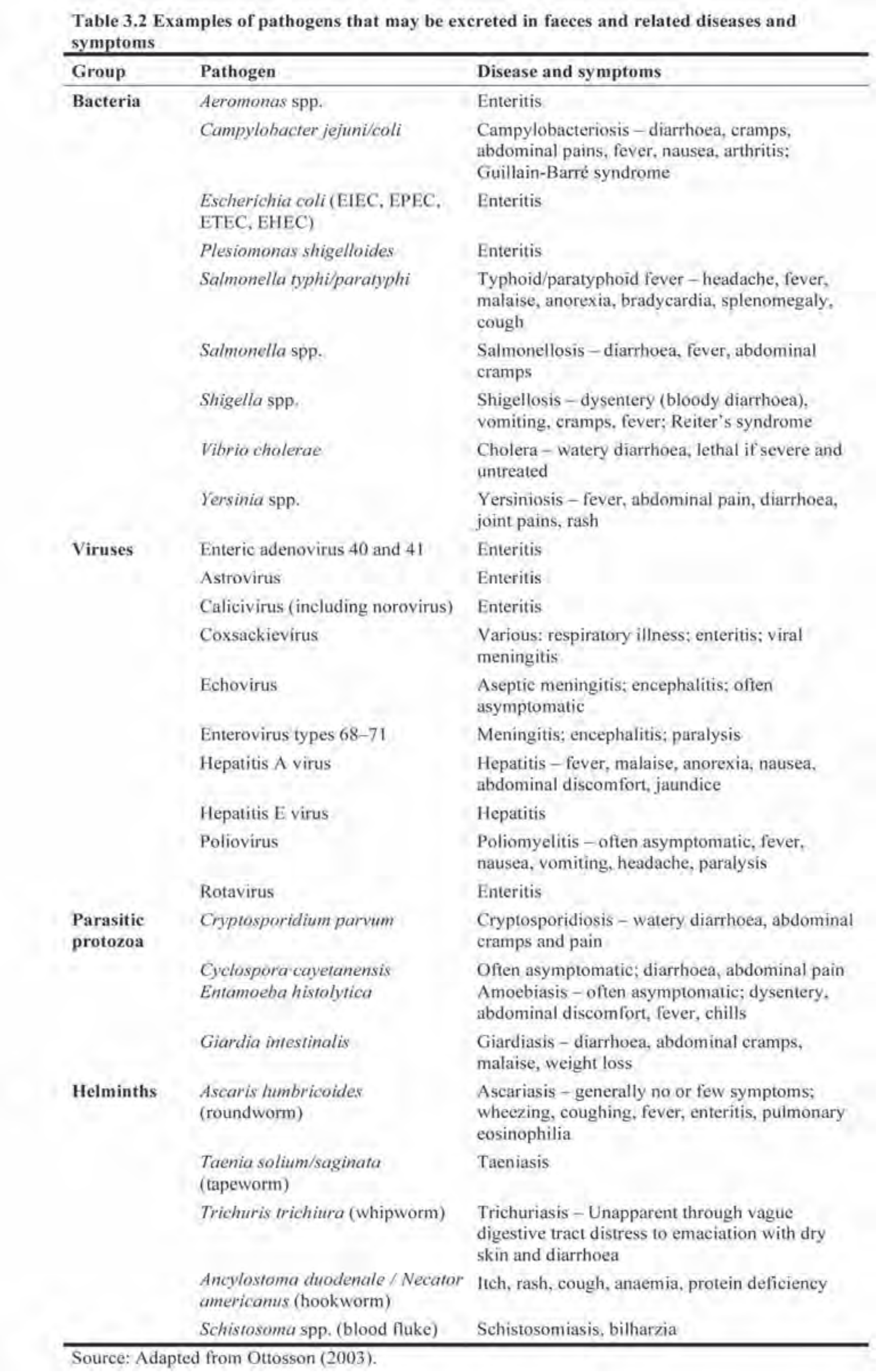

Table 3.2 Examples of pathogens that may be excreted in faeces and related diseases and symptoms

Group	Pathogen	Disease and symptoms
Bacteria	*Aeromonas* spp.	Enteritis
	Campylobacter jejuni/coli	Campylobacteriosis – diarrhoea, cramps, abdominal pains, 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
Viruses	Enteric adenovirus 40 and 41	Enteritis
	Astrovirus	Enteritis
	Calicivirus (including norovirus)	Enteritis
	Coxsackievirus	Various: respiratory illness; enteritis; viral meningitis
	Echovirus	Aseptic meningitis; encephalitis; often asymptomatic
	Enterovirus types 68–71	Meningitis; encephalitis; paralysis
	Hepatitis A virus	Hepatitis – fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
	Hepatitis E virus	Hepatitis
	Poliovirus	Poliomyelitis – often asymptomatic, fever, nausea, vomiting, headache, paralysis
	Rotavirus	Enteritis
Parasitic protozoa	*Cryptosporidium parvum*	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* (roundworm)	Ascariasis – generally no or few symptoms; wheezing, coughing, fever, enteritis, pulmonary eosinophilia
	Taenia solium/saginata (tapeworm)	Taeniasis
	Trichuris trichiura (whipworm)	Trichuriasis – Unapparent through vague digestive tract distress to emaciation with dry skin and diarrhoea
	Ancylostoma duodenale / Necator americanus (hookworm)	Itch, rash, cough, anaemia, protein deficiency
	Schistosoma spp. (blood fluke)	Schistosomiasis, bilharzia

Source: Adapted from Ottosson (2003).

cramps. Several may also cause symptoms involving other organs and severe sequelae. Table 3.2 lists the main pathogens of concern and the symptoms they cause.

3.2.2 Pathogens in urine

Environmental transmission of urinary excreted pathogens is of limited concern in temperate climates, but any faecal cross-contamination that may occur will end up diluted in the urine and may subsequently pose a health risk. In tropical climates, faecal contamination of collected urine is considered the main risk, but 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 for monitoring faecal contamination of urine due to their short survival time in urine. Faecal streptococci may be used as a "storage indicator" but are able to regrow in the pipes of larger urine diversion systems. Studies conducted with chemical indicators of faecal contamination (faecal sterols) indicate that faecal amounts are normally low, but contamination does 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, Leeming & Stenström, 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, urine in the bladder is sterile. However, different types of bacteria are picked up in the urinary tract. 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. Sexually transmitted pathogens may occasionally be excreted in urine, but there is no evidence that their potential survival outside the body would be of public health importance.

Some pathogens, such as *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi*, *Schistosoma haematobium* and some viruses, are excreted in urine. A range of other pathogens have been detected in urine, but further risk of environmental transmission may be considered insignificant.

Leptospirosis is a bacterial infection causing influenza-like symptoms and is in general transmitted by urine from infected animals (Feachem et al., 1983; CDC, 2003). It is considered an occupational hazard, for example, for sewage workers and for farm workers in developing countries (CDC, 2003). In tropical and subtropical climates, this disease is important in domestic animals, both for the risk to humans and due to economic losses. It is a severe disease with a 5–10% mortality rate (Olsson Engvall & Gustavsson, 2001). The bacteria survive for several months in freshwater and moist environments at neutral pH and at temperatures around 25 °C. Leptospiral bacteria in urine-contaminated environments enter a host through the mucous membranes and through small abrasions in the skin. Human urine is not considered to provide an important transmission pathway for 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 with faecal–oral transmission. 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 those for *E. coli* in collected urine.

Persons infected with *Schistosoma haematobium* excrete the eggs in urine, sometimes for extended periods of time. The eggs hatch in the freshwater environment, and the larvae (miracidia) infect the intermediate hosts, specific aquatic snails of the genus *Bulinus*. The parasites transform and multiply inside the snail, which then sheds the next stage of aquatic larvae (cercariae). These may infect humans in contact with water by penetrating the skin. If the eggs do not reach freshwater bodies where the snail intermediate host is present 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 & Yates, 1992). *M. tuberculosis* has occasionally been isolated in excreta and greywater 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 cowsheds (Huitema, 1969; Collins & 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 & 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 consequences for possible environmental transmission (Haas, Rose & Gerba, 1999). Microsporidia have been found in sewage and water. Water- or foodborne outbreaks have been suspected but are not well documented (Cotte et al., 1999; Haas, Rose & Gerba, 1999).

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

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

It can be concluded that pathogens that may be transmitted through urine (Table 3.3) 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, however, with a low risk of transmission due to its life cycle.

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 with other transmission routes
Schistosoma haematobium (eggs excreted)	Not directly but indirectly, larvae infect humans in fresh water	Needs to be considered in endemic areas where snail intermediate hosts are present
Mycobacteria	Unusual, usually airborne	Low
Viruses: cytomegalovirus, polyomaviruses JCV, BKV, adenovirus, hepatitis virus and others	Not normally recognized other than single cases of hepatitis A and suggested for hepatitis B; more information needed	Probably low
Microsporidia	Incriminated, but not confirmed	Low
Sexually transmitted pathogens	No, do not survive for significant periods outside the body	Insignificant
Urinary tract infections	No, no direct environmental transmission	Low to insignificant

The main risks in the use of excreta are related to the faecal and not the urinary fraction. Reducing faecal cross-contamination of the urine fraction is therefore an important control measure. Even though some pathogens may be excreted in urine, the faecal cross-contamination that may occur by misplacement of faeces in a urine-diverting toilet is associated with the most significant health risks (Höglund, Ashbolt & Stenström, 2002).

3.2.3 Pathogens in greywater

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 & Levine, 1996; Jeppesen, 1996; Trujillo et al., 1998; Dixon, Butler & Fewkes, 1999; Shrestha, Haberl & Laber, 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, such as *Legionella*, mycobacteria and *Pseudomonas aeruginosa*, may grow. The risk is probably not greater than from exposure to hot tap water.

The main hazards of greywater originate from faecal cross-contamination (section 3.2.2). 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 is measured traditionally by the use of common indicator organisms, such as coliforms and enterococci. This method has also been applied for assessing faecal contamination of greywater (Table 3.4).

Table 3.4 Reported numbers of indicator bacteria in greywater

Excreta and greywater origin	Numbers of indicator bacteria (log numbers/100 ml)				Reference
	Total coliforms	Thermotolerant coliforms	*E. coli*	Enterococci	
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, Eden & McFarlane (1996)
Shower, hand basin	2.7–7.4	2.2–3.5		1.9–3.4	Christova-Boal, Eden & McFarlane (1996)
Greywater	7.9	5.8		2.4	Casanova, Gerba & Karpiscak (2001)
Shower, bath	1.8–3.9	0–3.7		0–4.8	Feachem et al. (1983)
Laundry, wash	1.9–5.9	1.0–4.2		1.5–3.9	Feachem et al. (1983)
Laundry, rinse	2.3–5.2	0–5.4		0–6.1	Feachem et al. (1983)
Greywater	7.2–8.8				Gerba et al. (1995)
Hand basin, kitchen sink		5.0		4.6	Gunther (2000)
Greywater, 79% shower	7.4	4.3–6.9			Rose et al. (1991)
Kitchen sink		7.6	7.4	7.7	Naturvårdsverket (1995)
Greywater		5.8	5.4	4.6	Naturvårdsverket (1995)

Source: Ottosson (2003).

However, greywater may contain a high load of easily degradable organic compounds, which favours the growth of faecal indicators, as reported by Manville et al. (2001), in greywater systems. Hence, bacterial indicator numbers may lead to an overestimation of faecal loads and the associated risk. Occasionally, enteric pathogenic bacteria, such as *Salmonella* and *Campylobacter*, can be introduced by inadequate food handling in the kitchen (Cogan, Bloomfield & Humphrey, 1999), in addition to faecal matter derived 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 larger number of people may be exposed with reused greywater as the source. 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

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 did not consider the initial concentrations and die-off rate, but rather total inactivation. An additional compilation (Schönning et al., 2006) estimated the decimal reduction times for selected pathogens, but recent data on pathogen inactivation in human faeces are limited. If the initial concentrations are high and first-order die-off kinetics are applied, the time for total die-off is longer than in Feachem et al. (1983). However, this is not necessarily applicable during extended storage. 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 3.5) and expressed as time 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 (days, mean ± standard deviation)	T_{90} soil (days, mean ± standard deviation)
Salmonella	30 ± 8	35 ± 6
EHEC	20 ± 4	25 ± 6
Rotavirus	60 ± 16	30 ± 8
Hepatitis A virus	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 govern the time-dependent reduction or elimination. Ambient temperature, pH, moisture and biological competition will all affect inactivation. Variations in storage conditions will reflect in 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 resulted in a high reduction in pathogen numbers and faecal indicators and low moisture (Austin, 2001). Aeration increases inactivation, since a partial composting may have taken place (temperature not reported).

In a Danish study, the risks related to the use of faeces that had been stored for up to 12 months without additional treatment were calculated (Schönning et al., in press). *Ascaris* posed the highest risk, with a high likelihood of infecting vulnerable persons after accidental ingestion of the material. The protozoa (*Giardia* and *Cryptosporidium*) and 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 1:1000. The risk for hepatitis A or bacterial infections was generally lower. The storage was assumed to occur at about 10 °C.

In a study in Mexico (Franzén & Skott, 1999) with faecal material (moisture 10%, pH around 8, temperature 20–24 °C), a conservative viral indicator was added in controlled amounts and was reduced 1.5 log units after six weeks of storage. Low moisture content had a beneficiary reduction effect on added bacteriophages in latrines in Viet Nam (Carlander & Westrell, 1999). These latrines also had a pH of around 9, but higher temperatures (30–40 °C). A total inactivation of *Ascaris* was recorded within six 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. Strauss & Blumenthal (1990) suggested that one year was sufficient for inactivation under tropical conditions (28–30 °C), whereas 18 months would be needed at lower temperatures (17–20 °C). This has also been supported by additional studies in Viet Nam (Phi et al., 2004).

In El Salvador, an extensive study of faecal material collected in urine-diverting toilets has been conducted. Material to increase the pH is added to the faecal material by the users, but the recording of some pH values around 6 implies that, in some toilets, only treatment by storage occurs (Moe & Izurieta, 2004). Survival analysis suggested that faecal coliforms would survive more than 1000 days and *Ascaris* around 600 days in latrines with a pH of less than 9!

Storage is especially beneficial in dry, hot climates, with desiccation of the material and low moisture contents aiding pathogen inactivation. If the faecal material is completely dry, the decrease in pathogen numbers 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 odour 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; when moisture is added, the easily metabolized organic compounds will facilitate bacterial growth, including, for example, *E. coli* and *Salmonella*, if small amounts of these are occurring in or introduced into the material. Protozoan cysts are sensitive to desiccation, also affecting their survival on plant surfaces (Snowdon, Cliver & Converse, 1989; Yates & Gerba, 1998). Normal moisture levels do not inactivate *Ascaris* eggs. Moisture levels below 5% are needed to inactivate *Ascaris* eggs (Feachem et al., 1983), but the time required for inactivation is not known.

3.3.2 Survival in urine

For the hygienic risks related to the handling and reuse of urine, temperature, dilution, pH, ammonia and time are the main determinants 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 pathogen persistence.

The short survival of *E. coli* in urine makes it unsuitable as a general indicator for faecal contamination by, for example, viruses and protozoa. It is, however, representative for the die-off of Gram-negative bacteria. The T_{90} values were generally from <1 to 5 days, depending on the prevailing conditions; the longer times represent a pH value of 6. Longer persistence was also recorded if the urine was diluted 10-fold. Gram-negative bacteria such as *Campylobacter*, *Salmonella*, *Aeromonas hydrophila* and *Pseudomonas aeruginosa* were inactivated as rapidly 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 °C, but up to 30 days at 4 °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. Extreme pH values were 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 sentinel phage occurred at 5 °C during six months of storage, while the mean T_{90} values at 20 °C were estimated at 35 and 71 days for rotavirus and the phage, respectively (Figure 3.1). Rotavirus inactivation appeared to be largely temperature dependent, whereas there was an additional viricidal effect on the phage in urine at 20 °C (pH 9).

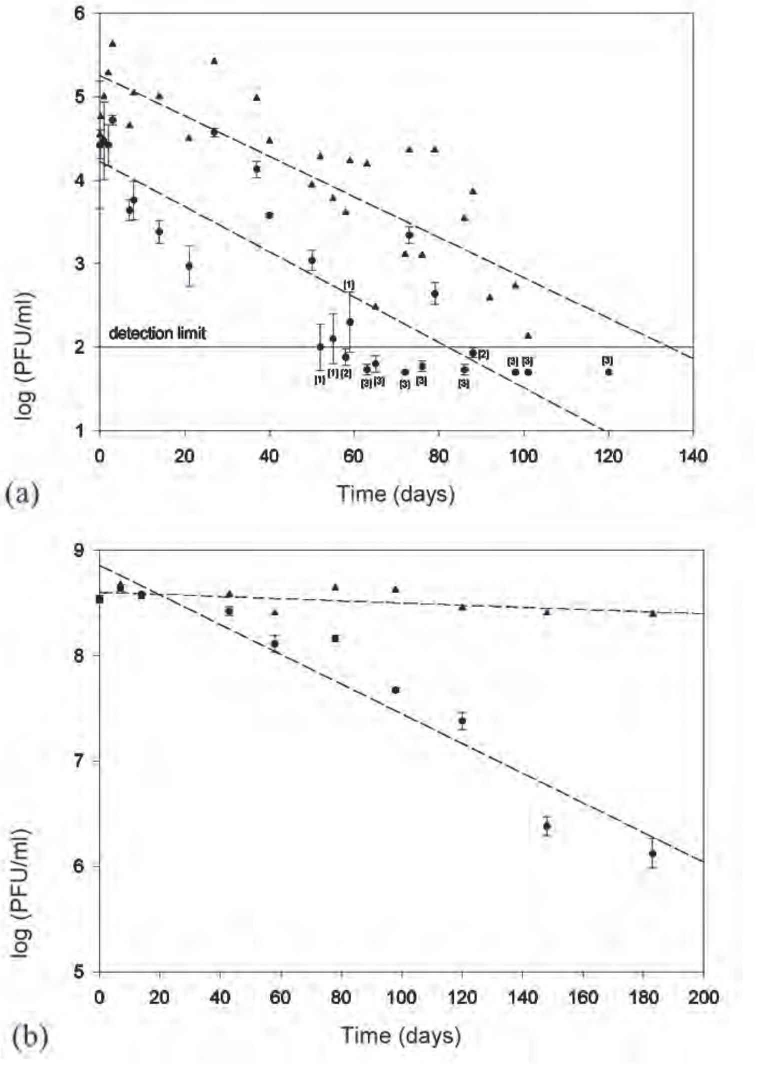

Figure 3.1
Inactivation of (a) rotavirus and (b) *Salmonella typhimurium* phage 28B in diverted human urine (•) and control medium (▲) at 20 °C (PFU = plaque-forming units)

Cryptosporidium parvum is known to be persistent in waste products as well as in water and to be resistant to disinfectants (Meinhardt, Casemore & Miller, 1996) and is a conservative index of protozoa in urine (Höglund & Stenström, 1999). In a urine mixture at pH 9 and 4 °C, the oocysts were inactivated to below the detection limit within about two months. The T_{90} value for *Cryptosporidium* was about one month at 4 °C and five days at 20 °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, Bowman & Ghiorse, 1998). The concentration of free ammonia (NH_3) in urine (pH 9, 4 °C) was about 0.03 mol/l (Höglund & Stenström, 1999).

In summary, Gram-negative bacteria are rapidly inactivated, while oocysts of *Cryptosporidium parvum* are reduced by approximately 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 3.6). For bacteria, further dilution of the urine prolonged their survival. The effects of pH and ammonia are combined. However, rotavirus was not affected by pH or by ammonia. The information on helminths, including *Ascaris*, is limited and partly contradictory. According to Hamdy (1970), urine is ovicidal and *Ascaris* eggs are killed within hours; preliminary results from ongoing studies indicate 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).

Table 3.6 Summarized results from survival experiments

	T_{90} values (days required for a 90% reduction)				
	Gram-negative bacteria	**Gram-positive bacteria**	***C. parvum***	**Rotavirus**	***S. typhimurium* phage 28B**
4 °C	1	30	29	172[a]	1466[a]
20 °C	1	5	5	35	71

[a] Survival experiments performed at 5 °C.

3.3.3 Faecal load and survival of faecal pathogens in greywater

The pathogen-related risks of greywater depend on the faecal load or faecal misplacement. The presence of degradable organic matter in greywater will support bacterial growth. Therefore, their numbers may lead to an overestimation of the risks. A number of faecal indicator organisms and biomarkers have been compared for a quantification of the faecal load in greywater (Ottosson, 2003) (Table 3.7), calculated as follows:

$$\frac{(\text{Microorganism density [numbers/ml]} \times \text{Flow [ml/person per day]})}{\text{Excretion density [numbers/g faeces]}}$$

The indicator organisms give a gross overestimation of the faecal input if the amounts of faecal sterols are used as a "true value." The use of *E. coli* would lead to an overestimation of the faecal load by more than three orders of magnitude and the use of enterococci by more than two orders of magnitude. In an example of QMRA for greywater (see section 3.6.1), coprostanol was used as a conservative biomarker.

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

$$\frac{(0.04\ \text{[g per person per day]} \times \text{excretion density [numbers/g faeces]} \times \text{excretion time [days]} \times \text{yearly incidence})}{(64\,900\ \text{[ml/day]} \times 365\ \text{[days]})}$$

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

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 unavailability (Ottosson & Stenström, 2003b). *Campylobacter* isolates of clinical importance are not likely to grow at temperatures below 30 °C (Hazeleger et al., 1998) and will not regrow under conditions common in greywater treatment systems. *Salmonella* can grow at 20 °C and below but is likely to be suppressed by the indigenous microorganisms, as shown by Sidhu et al. (2001). The growth rate of *Salmonella* at 20 °C, 0.022 ± 0.02 log/day, 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 used in QMRA are listed in Table 3.8. 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 sulfite-reducing anaerobic bacteria for *Giardia* and *Cryptosporidium* (oo)cysts.

Table 3.7 Faecal indicators in a greywater system and the corresponding faecal load with an average flow of 64.9 litres per person per day

Organism/biomarker	Mean	Min	Max	Excretion density (log numbers/100 ml or mg/g faeces)	Mean faecal load (min–max) (g/person per day)
Coliform bacteria	8.1	5.5	8.7		
E. coli	6.0	4.3	6.8	10^{7}[a]	65 (1.3–410)
Enterococci	4.4	3.0	5.1	$10^{6.5}$[a]	5.2 (0.2–26)
Sulfite-reducing anaerobes	3.3	2.3	4.8		
Somatic coliphages	3.3	1.4	4.0		
Coprostanol (µg/l)	8.6	3.1	14.9	12.74[b]	0.04 (0.016–0.076)
Cholesterol (µg/l)	17.3	7.4	31.6	5.08[b]	0.22 (0.094–0.40)

Min = minimum; max = maximum

[a] Geldreich (1978).

[b] Leeming, Nichols & Ashbolt (1998).

3.4 Survival in soils and on crops

Treatment of excreta should aim to fully or substantially eliminate pathogens before their application as a fertilizer. Nevertheless, in practice, inactivation of pathogens in the soil may contribute importantly to overall risk reduction. Inactivation is often more rapid in the soil and on crop surfaces than in stored excreta and greywater and more rapid on crops than in soils. Some pathogens can persist, however, for extended periods of time in soil or on crop surfaces and can be transmitted to humans or animals. The most environmentally resistant pathogens are helminth eggs, which in extreme cases can survive for several years in the soil. In Volume 2 of the Guidelines, the background evidence for pathogen survival in soils and crops, which also applies to excreta and greywater, has been reviewed. A summary of this 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 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. radish, onion) or crops grown close to the soil (e.g. squash). Certain crops may be more susceptible to contamination than others — for example, onions (Blumenthal et al., 2003), squash (Armon et al., 2002) and lettuce (Solomon, Yaron & Matthews, 2002). The surface properties of certain crops (e.g. hairy, sticky, with

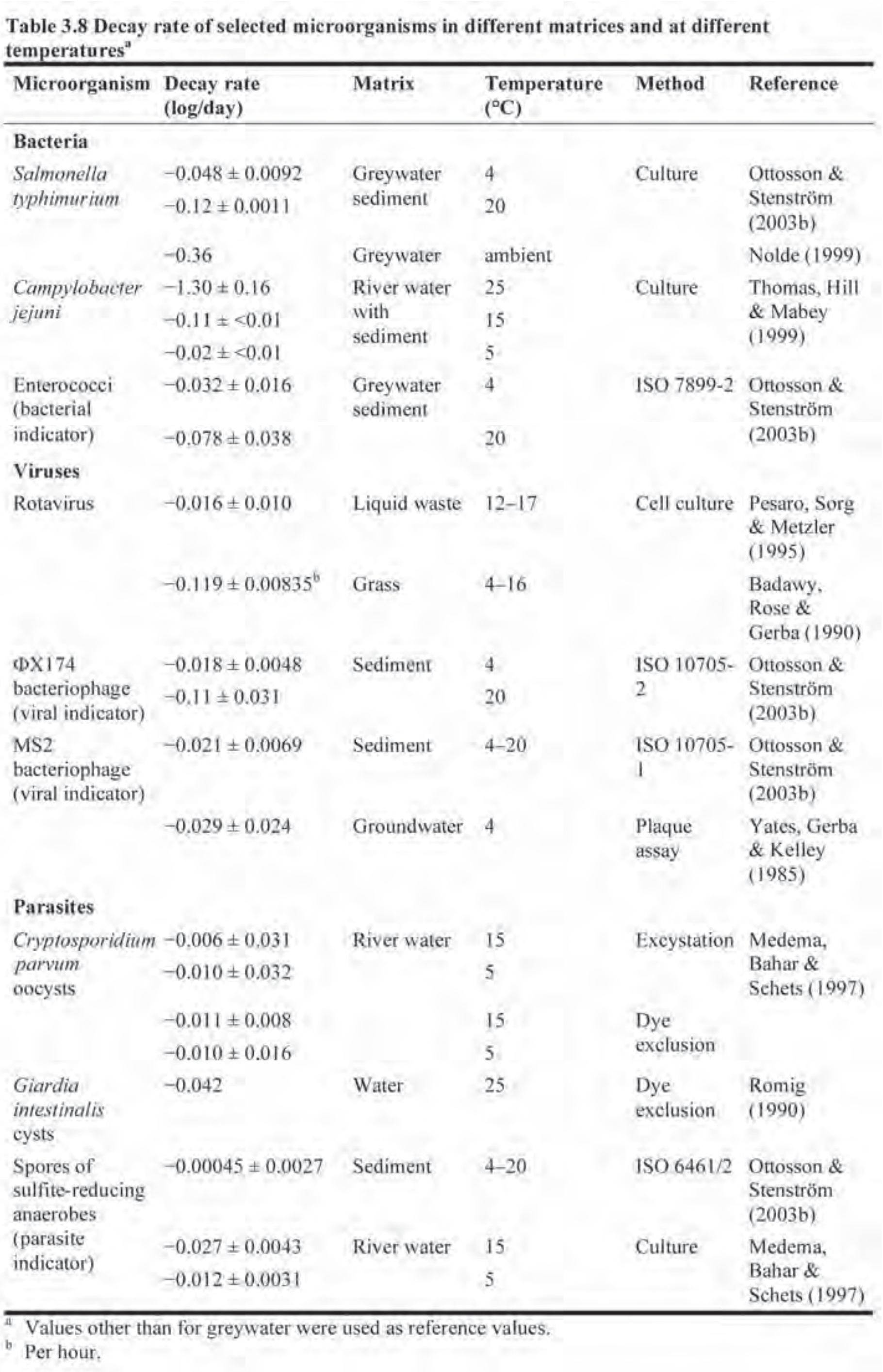

Table 3.8 Decay rate of selected microorganisms in different matrices and at different temperatures[a]

Microorganism	Decay rate (log/day)	Matrix	Temperature (°C)	Method	Reference
Bacteria					
Salmonella typhimurium	−0.048 ± 0.0092	Greywater sediment	4	Culture	Ottosson & Stenström (2003b)
	−0.12 ± 0.0011		20		
	−0.36	Greywater	ambient		Nolde (1999)
Campylobacter jejuni	−1.30 ± 0.16	River water with sediment	25	Culture	Thomas, Hill & Mabey (1999)
	−0.11 ± <0.01		15		
	−0.02 ± <0.01		5		
Enterococci (bacterial indicator)	−0.032 ± 0.016	Greywater sediment	4	ISO 7899-2	Ottosson & Stenström (2003b)
	−0.078 ± 0.038		20		
Viruses					
Rotavirus	−0.016 ± 0.010	Liquid waste	12–17	Cell culture	Pesaro, Sorg & Metzler (1995)
	−0.119 ± 0.00835^{b}	Grass	4–16		Badawy, Rose & Gerba (1990)
ΦX174 bacteriophage (viral indicator)	−0.018 ± 0.0048	Sediment	4	ISO 10705-2	Ottosson & Stenström (2003b)
	−0.11 ± 0.031		20		
MS2 bacteriophage (viral indicator)	−0.021 ± 0.0069	Sediment	4–20	ISO 10705-1	Ottosson & Stenström (2003b)
	−0.029 ± 0.024	Groundwater	4	Plaque assay	Yates, Gerba & Kelley (1985)
Parasites					
Cryptosporidium parvum oocysts	−0.006 ± 0.031	River water	15	Excystation	Medema, Bahar & Schets (1997)
	−0.010 ± 0.032		5		
	−0.011 ± 0.008		15	Dye exclusion	
	−0.010 ± 0.016		5		
Giardia intestinalis cysts	−0.042	Water	25	Dye exclusion	Romig (1990)
Spores of sulfite-reducing anaerobes (parasite indicator)	−0.00045 ± 0.0027	Sediment	4–20	ISO 6461/2	Ottosson & Stenström (2003b)
	−0.027 ± 0.0043	River water	15	Culture	Medema, Bahar & Schets (1997)
	−0.012 ± 0.0031		5		

[a] Values other than for greywater were used as reference values.
[b] Per hour.

crevices, rough, etc.) protect pathogens from exposure to radiation and make them more difficult to wash off. Crops that retain water (e.g. from rain, which, moreover, splashes up contaminated soil) are important in determining human exposure to pathogens. Lettuce retains a measured 10.8 ml of irrigation water, while a cucumber holds only 0.36 ml (Shuval, Lampert & 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 is often based on *E. coli* as an index organism or includes information about the frequency of detection of pathogens such as *Salmonella* spp. on the crops. These values may be used in extrapolation of the risks and generally provide validation that high amounts of these bacterial groups will be reduced below a background level within 1–2 weeks or what is found on market products if irrigated with treated wastewater (Armon et al., 1994; Bastos & Mara, 1995; Vaz da Costa Vargas, Bastos & Mara, 1996). A withholding time of at least one month between application of treated excreta and harvest is recommended in these Guidelines (which partly lowers the risk related to wastewater irrigation). Recommended levels of $<10^3$ *E. coli* per gram total solids or $<10^5$ *E. coli* in greywater would be appropriate (see chapter 4).

Petterson, Teunis & Ashbolt (2001) modelled the inactivation of enteric viruses on lettuce and carrots using data collected on crops grown under greenhouse conditions with a model virus *Bacteroides fragilis* B40-8. Initial die-off was rapid, but a more persistent subpopulation of viruses survived throughout the experiment. Ward & Irving (1987) observed survival times of 1–13 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 & Ashbolt (2003) summarized viral die-off data on different crops. These data are expressed as T_{99} values (number of days required for a two-logarithm reduction), not exceeding four days for leaf crops and 20 days for root crops. A withholding time of one month would normally ensure a safety margin against viral and bacterial contamination alike. On lettuce spiked with *Cryptosporidium* oocysts, no viable oocysts were detected after three days at 20 °C, while 10% remained at 4 °C (Warnes & Keevil, 2003). The inactivation rate is often considered to be more rapid on crops than in soils, with T_{90} values in the range of a few days (Asano et al., 1992; Petterson, Ashbolt & Sharma, 2001). Studies carried out in greenhouses in the United Kingdom (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 latter 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 in relation to both wastewater (see Volume 2 of the Guidelines) and excreta use. Data on pathogen survival in soil and on different crops are presented in Tables 3.9 and 3.10.

3.5 Epidemiological and risk-based evidence

Epidemiological evidence in relation to the reuse of treated excreta and greywater in agriculture is generally lacking. In areas where untreated human excreta are used as a fertilizer for crops, an elevated prevalence of *Ascaris* infection has occasionally been reported (Iran: Arfaa & Ghadirian, 1977; China: Xu et al., 1995). Hookworm infection

Table 3.9 Estimated survival times and decimal reduction values of pathogens during storage of faeces and in soil

Microorganism	Survival at 20–30 °C (days)[a]		Time needed for 90% inactivation of pathogen (T_{90}) at ~20 °C (days)[a]		Absolute max[d]/ normal max survival in soil[e]
	Faeces and sludge[b]	Soil[b]	Faeces[c]	Soil[c]	
Bacteria					1 year / 2 months
Thermotolerant coliforms	<90, usually <50	<70, usually <20	*E. coli*: 15–35	*E. coli*: 15–70	
Salmonella	<60, usually <30	<70, usually <20	10–50	15–35	
Viruses	<100, usually <20	<100, usually <20	rotavirus: 20–100 hepatitis A: 20–50	rotavirus: 5–30 hepatitis A: 10–50	1 year / 3 months
Protozoa (*Entamoeba*)	<30, usually <15[f]	<20, usually <10[e]	*Giardia*: 5–50 *Cryptosporidium*: 20–120	*Giardia*: 5–20 *Cryptosporidium*: 30–400	? / 2 months
Helminths (eggs)	Several months	Several months	*Ascaris*: 50–200	*Ascaris*: 15–100	7 years / 2 years

?, unknown; max, maximum

[a] Estimated survival times and decimal reduction values of pathogens during storage of faeces and in soil; presented in days if not stated otherwise.

[b] Feachem et al. (1983).

[c] Schönning et al. (in press).

[d] Absolute maximum for survival is possible under unusual circumstances, such as at constantly low temperatures or under well protected conditions (Feachem et al., 1983).

[e] Kowal (1985).

[f] Data are missing for *Giardia* and *Cryptosporidium*; their cysts and oocysts might survive longer than presented here for protozoa (Feachem et al., 1983).

is also prevalent in wet climates when excreta are used (Viet Nam: Needham et al., 1998; China: Xu et al., 1995). Blum & Feachem (1985) include descriptive studies of the prevalence of helminth infections in areas where untreated excreta are used as fertilizer. The risks to consumers and farm workers exposed to untreated or treated excreta used as fertilizer for crops, mainly from older studies, are shown in Table 3.11. The examples indicate that exposure to treated nightsoil was significantly associated with a reduction in *Ascaris* and hookworm infection compared with 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

Table 3.10 Survival of various organisms on crops at 20–30 °C

Organism	Survival on crops (days)
Viruses	
Enteroviruses[a]	<60 but usually <15
Bacteria	
Thermotolerant coliforms	<30 but usually <15
Salmonella spp.	<30 but usually <15
Shigella spp.	<10 but usually <5
Vibrio cholerae	<5 but usually <2
Protozoan cysts	
Entamoeba histolytica cysts	<10 but usually <2
Cryptosporidium oocysts	<3 but usually <2
Helminths	
Ascaris eggs	<60 but usually <30
Tapeworm eggs	<60 but usually <30

[a] Poliovirus, echovirus and coxsackievirus.

Sources: Feachem et al. (1983); Strauss (1985); Robertson, Campbell & Smith (1992); Jenkins et al. (2002); Warnes & Keevil (2003).

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 four months (Hanoi Medical School, unpublished observations, 1994). 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 results were 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 data presented, 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 with the use of treated faeces or no use of excreta as fertilizer. Comparisons are lacking between those who used treated faeces and those who did not use excreta. Excreta treatment before use or other management procedures to reduce risk should always be advocated. Treatment with ovicide could be considered (as occurs in parts of China), along with consideration of technologies for dry excreta storage and composting or thermophilic digestion.

Comparisons can be made with epidemiological studies on the use of raw wastewater. These have revealed an increased risk of parasitic and other enteric infections associated with raw wastewater use in agricultural irrigation (Katzenelson, Buium & Shuval, 1976; Fattal et al., 1986; Cifuentes, 1998; Srikanth & Naik, 2004; see also Volume 2 of the Guidelines). 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 for wastewater (e.g. in storage lagoons) seem to be efficient in reducing the transmission of pathogens and are also relevant for 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 exposed versus non-exposed populations[a]

Health outcome	Excreta quality	Population group	Prevalence of infection or reinfection after treatment (%)	Relative risk	Study group and comparison	Reference
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	(i) 4.9[b] (ii) 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	Anders (1952)
Ascaris	Untreated	Farming population	52 vs 0	52.0[b]	Families using excreta as garden fertilizer vs families using animal manure as garden fertilizer	Harmsen (1953)
Ascaris (positive conversion after chemotherapy)	Ovicide treated	Farming population	(i) 27.4 vs 41.5 (ii) 35.9 vs 41.5	(i) 0.66 (0.51–0.86)[c]** (ii) 0.86 (0.69–1.07)	(i) Ovicide-treated nightsoil vs untreated nightsoil (ii) Ovicide-treated nightsoil (commercial preparation) vs untreated nightsoil	Kozai (1962)
(i) *Ascaris* (prevalence)	Ovicide treated	Farming population	(i) A: 11.0 vs 17.5 B: 21.0 vs 33.1 C: 14.6 vs 11.6	(i) A: 0.63 (0.40–0.98)[c]* B: 0.63 (0.44–0.92)* C: 0.79 (0.53–1.18)	(i) A: After nightsoil treatment with ovicide plus chemotherapy vs before treatment B: After nightsoil treatment with ovicide vs before treatment C: Chemotherapy alone	Kutsumi (1969)
(ii) *Trichuris* (prevalence)			(ii) 47.1 vs 65.0	(ii) 0.73 (0.64–0.82)	(ii) After nightsoil treatment plus ovicide vs before treatment	