Table 3.11 (continued)

Health outcome	**Excreta quality**	**Population group**	**Prevalence of infection or reinfection after treatment (%)**	**Relative risk**	**Study group and comparison**	**Reference**
Hookworm (positive conversion after chemotherapy)	Ovicide treated	Farming population	(i) 17.7 vs 32.2	(i) 0.55 (0.36–0.81)[c]**	(i) Ovicide-treated nightsoil vs untreated nightsoil	Kozai (1962)
			(ii) 17.4 vs 32.2	(ii) 0.54 (0.36–0.81)**	(ii) Ovicide-treated nightsoil (commercial preparation) vs untreated nightsoil	
Hookworm (positive conversion after chemotherapy)	Ovicide treated	Adults	7.1 vs 12.5	0.56 (0.27–1.16)	Families using ovicide-treated nightsoil vs untreated nightsoil	Kutsumi (1969)
Hookworm	Treatment with ash and storage	Adult women		$P < 0.05$	Egg counts in women using fresh faeces vs women using treated faeces or not using faeces as fertilizer	Humphries et al (1997)

[a] Comparison is exposed vs unexposed for untreated excreta use; comparison is treated vs untreated excreta or after vs before treatment for treated excreta.

[b] Crude relative risk calculated from prevalence or incidence data reported.

[c] Relative risk and 95% confidence interval calculated from prevalence or incidence rates and population data reported. Statistical significance at levels P < 0.05 (*) and P < 0.01 (**).

3.6 Quantitative microbial risk analysis

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

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

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

3.6.1 Example of risk calculation for a greywater scenario

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

Exposure to potential pathogens in greywater may occur through direct contact, contaminated drinking-water sources and groundwater recharge where the exposure depends on drinking-water treatment. Greywater used for irrigation may, depending on distribution practices, expose people via inhalation of aerosols as well as through consumption of irrigated contaminated crops, in a similar pathway as for wastewater (see Volume 2 of these Guidelines).

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

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

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

Exposure	Health-related modelling units involved	Volume ingested
1) Drinking recharged groundwater (yearly risk from 365 exposures)	Dilution,[a] unsaturated zone[a] and saturated zone	$e^{(6.87 \pm 0.53)}$ ml/day[b]
2) Accidental ingestion of treated greywater (one-time exposure)	Pond	1 ml/exposure
3) Ingestion from a field irrigated with treated greywater (yearly risk from 26 exposures)	Survival on grass	1 ml/exposure
4) Ingestion/inhalation of aerosols	Tank	$e^{(-4.2 \pm 2.2)}$ ml[c,d]
5) Swimming in recreational water receiving treated greywater	Dilution	$e^{(3.9 \pm 0.3)}$ ml
6) Untreated greywater, *Salmonella* regrowth	Sink trap (growth)[e]	0.1 g

[a] Asano et al. (1992).
[b] Roseberry & Burmaster (1992).
[c] Dowd et al. (2000).
[d] Kincaid, Solomon & Oliphant (1996).
[e] Ottoson & Stenström (2003b).

Table 3.13 Indicator occurrence, measured as excreted organisms per person per day, and the corresponding faecal load in greywater (flow 64.9 litres per person per day)

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

Source: Ottosson & Stenström (2003a).

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

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

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

1) accidental ingestion of 1 ml treated greywater, pond outlet (P_{out});
2) accidental ingestion of 1 ml treated greywater, pond inlet (P_{in});
3) yearly risk from direct exposure after irrigation with greywater, assuming 1 ml intake per day, 26 days a year;
4) yearly risk from drinking groundwater recharged from the pond as described in Asano et al. (1992), with modifications on the environmental die-off data and the water intake.

The different approaches used were as follows:

1) measuring faecal contamination in greywater with coprostanol concentrations and using epidemiological data to assess risks, as in Höglund, Ashbolt & Stenström (2002);
2) using a dose–response model derived from occurrence of faecal enterococci in marine waters (Kay et al., 1994), assuming an exponential probability of infection;
3) using faecal enterococci as indicator organisms for the presence of *Salmonella* in greywater based on sediment experiments.

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

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

The scenario considered for the urine diversion included the following transmission pathways (from Höglund, Ashbolt & Stenström, 2002):

1) ingestion of urine that has not been stored: workers may be accidentally exposed while cleaning blocked toilet drains, through ingestion in the case of splashing while emptying the collection tank or by contaminated hand-to-mouth contact;
2) ingestion of stored urine: farmers or other workers may accidentally ingest urine during handling of stored urine;
3) inhalation of aerosols while fertilizing crops with urine;
4) consumption of crops fertilized with urine.

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

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

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

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

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

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

Table 3.14 Probability density functions used to calculate microbial health risks from various exposures to source-separated human urine

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

Range of 1.6–18.5 mg (mean 9.1 ± 5.6 mg) of faeces per litre cross-contaminated the separated urine. Triang = Triangular probability density functions; minimum, most likely and maximum given. T_{90} = time for 90% reduction in viable pathogen numbers.
Source: Höglund, Ashbolt & Stenström (2002).

Pathway 1: Risk from exposure to urine that has not been stored

The estimated risks of infection by the three indicator pathogens following accidental ingestion of 1 ml of unstored urine are illustrated in Figure 3.2. In the case of an epidemic, where no inactivation was assumed to occur in the collection tank, viruses may pose an unacceptably high risk, and bacteria pose a greater risk than protozoa. Similarly, for sporadic cases evenly spread out during the year, the risk of viral infection is the same as during an epidemic at 4 °C (probability of infection P_{inf} = 0.81), since very low inactivation of rotavirus occurs at this temperature, and slightly lower at 20 °C ($P_{inf} = 0.55$). In contrast, the risk for bacterial infection decreases significantly if sporadic rather than epidemic cases occur, since a large proportion of the added bacteria would die during collection at the two temperatures. For *Cryptosporidium*, the risk is approximately 1 log lower if there are sporadic instead of epidemic cases in the population connected to the tank, and the collection occurs at 4 °C ($P_{inf} = 3.1 \times 10^{-6}$). Collection at 20 °C decreases the risk another log ($P_{inf} = 4.5 \times 10^{-7}$).

Pathway 2: Risk from exposure to stored urine

Due to the inactivation of pathogens, risks associated with accidental contact decrease during storage. The exception was rotavirus during storage at 4 °C, which yields the same risk independent of storage time. The risk for *Campylobacter* infections was negligible after one month of storage at either 4 °C or 20 °C. If the urine is stored at 20 °C, the mean risk from *Cryptosporidium* is 4.7×10^{-11} after only one month, whereas if stored at 4 °C for one or six months, risks will be 1.1×10^{-5} and 2.8×10^{-9}, respectively. The risk for viral infection was much higher than the risk for protozoan infection, and inactivation was measured only in urine stored at 20 °C. After six months at 20 °C, the mean risk was estimated to be less than 10^{-4} (Figure 3.3).

Pathway 3: Risk from exposure to aerosols

The risk for infection through aerosols during the distribution of urine on arable land depended mainly on the urine storage time (Höglund, Ashbolt & Stenström, 2002). For people within an area of 100 m from the application of urine, the risks for bacterial and protozoan infections were low at any of the storage conditions. However, the risk for rotavirus infection was 0.72 for unstored urine or urine stored at 4 °C, if an epidemic was assumed. If the urine was stored for six months at 20 °C before fertilization, the mean estimated risk was reduced to 3.3×10^{-5}.

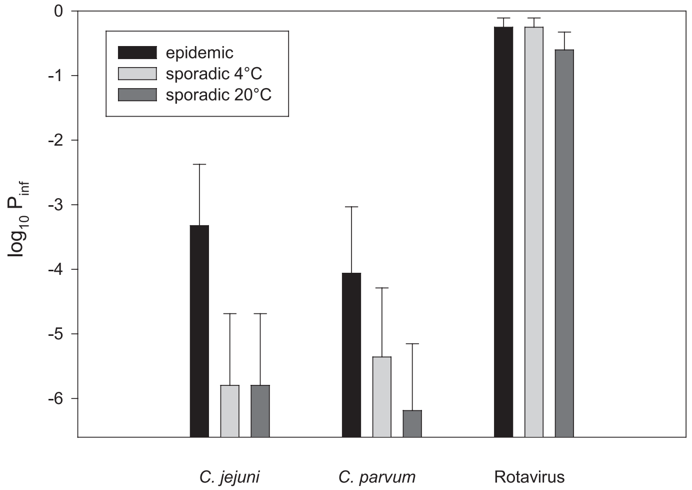

Figure 3.2

Mean probability of infection (5–95%) by *Campylobacter jejuni*, *Cryptosporidium parvum* and rotavirus following unintentional ingestion of 1 ml unstored urine for epidemic and sporadic scenarios and 4 °C or 20 °C during collection (Höglund, Ashbolt & Stenström, 2002)

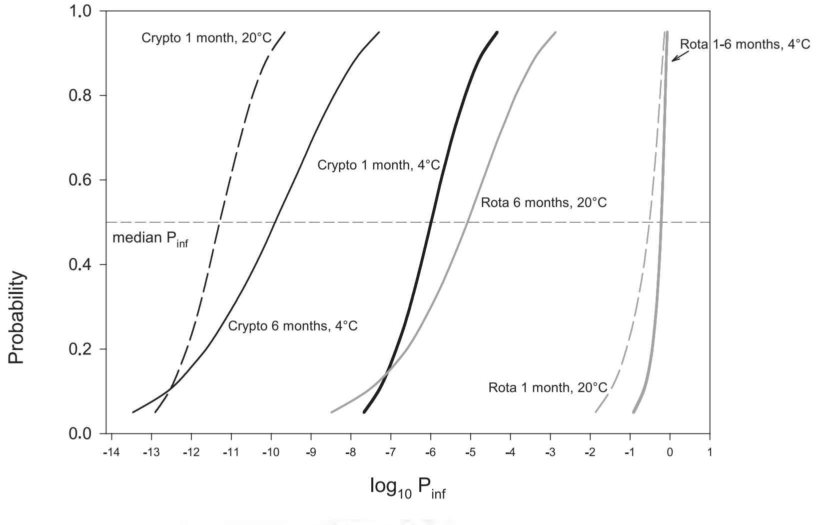

Figure 3.3

Probability of infection (5–95%) by *Cryptosporidium parvum* and rotavirus following ingestion of 1 ml stored urine (one or six months, 4 °C or 20 °C). *C. parvum* stored for six months at 20 °C yielded a risk that was $<10^{-15}$, as did *Campylobacter* after one month at both temperatures; this information has not been included in the figure (Höglund, Ashbolt & Stenström, 2000).

Pathway 4: Risk from exposure to fertilized crops

Possible risks following consumption of crops fertilized with fresh urine and urine stored for one or six months at 4 °C and 20 °C were examined. Crop withholding periods between one and four weeks were considered, to take into account the time between fertilization and crop consumption. The implications of different withholding periods following consumption of 100 g of raw crop fertilized with fresh urine are illustrated in Figure 3.4. With one week between fertilization and consumption, the risk for bacterial and protozoan infections was very low ($<10^{-5}$), whereas a three-week withholding period is needed for the risk of viral infection to reach the same level.

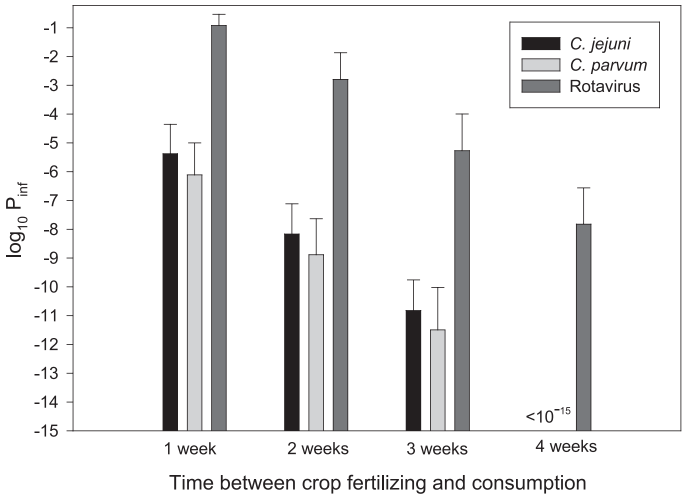

Figure 3.4

Mean probability of infection by pathogens following ingestion of crop fertilized with unstored urine with varying withholding periods. Error bars indicate one standard deviation (Höglund, Ashbolt & Stenström, 2002).

3.6.3 Example of risk calculation for stored but otherwise untreated excreta

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

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

Application means that the faeces were evenly distributed as topsoil, and incorporation means that the faeces were worked into the upper layer of the soil, resulting in a faeces to soil ratio of about 1:100.

Hazard identification

Organisms transmitted by the faecal–oral route were included, such as *Salmonella*, EHEC, rotavirus, hepatitis A virus, *Giardia*, *Cryptosporidium* and *Ascaris*.

Assessment of exposure

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

- emptying of the container and distribution of the material;
- recreational activities in the garden;
- gardening.

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

Dose–response relationships

There is no information available on susceptible population subgroups, such as children, the elderly or immunocompromised, and as such it is not accounted for in the models. Less susceptible groups in the population were not accounted for either. The uncertainty of the parameters in the dose–response relationships was included.

Microbial risk calculation

Calculations were made for two main scenarios:

1) applying the incidence in the population (unconditional);
2) assuming that one member of the family actually had an infection during the period of collection (conditional).

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

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

4

HEALTH-BASED TARGETS

This chapter deals with health-based targets and related recommendations for health protection. The potential to relate protective measures that respond to health risks to guideline values or good practice is determined by the compliance level that can be expected realistically. It is less practical to apply guideline values in small-scale settings, where procedural and best practice guidance may offer a better approach.

An attempt has been made to harmonize the health-based targets presented in this volume with those in Volume 2 of the Guidelines (*Safe use of wastewater in agriculture*). Furthermore, issues specific to the safe use of excreta, urine and greywater in agriculture are pointed out. Obviously, the risk of transmission of pathogens through environmental pathways when unsanitized excreta are used in agriculture may lead to increased disease prevalence. Treatment of human excreta and other barriers against human exposure are considered the most important precautions against such transmission (see chapter 5).

Health-based targets need to be an integral part of the overall health policy, accounting for the trends in and relative importance of different transmission pathways, on both individual and household levels as well as in the overall management of public health. To ensure effective health protection, the target needs to be realistic, relevant to local conditions and commensurate with resources available for required protection methods. Health-based targets aim to improve public health outcomes and should support the rational selection of health safeguards, interventions and control measures, mainly in relation to excreta and greywater treatment, exposure control and safe handling.

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

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

With increasing frequency, regulations and guidelines are based on the risk concept. By applying QMRAs, based partly on predictions and assumptions, sanitation systems can be evaluated and compared with established limits for acceptable risks. Treatment can also be adapted to reach a set of acceptable limits. Risk assessments can thus be made quite site specific, depending on information regarding, for example, the local health status of the population and behavioural patterns. An approach of setting acceptable local risk limits, applicable for sanitation systems where the use of the excreta products is practised, will relate to a subsequent change in the prevalence of infections. In developing countries with low sanitary standards, the goal will be to reduce the number of infections by implementing sanitation per se, including introducing new, more efficient treatment or exposure reduction alternatives, combined with other interventions related to safe treatment and storage, hygiene/health education as well as provision of access to safe drinking-water.

This volume of the Guidelines focuses on treatment, but also addresses other technical, practical and behavioural aspects intended to minimize the risk for disease transmission. Rules of thumb considered to obtain acceptable low risks are presented without a bias towards numeric limits in small-scale systems.

4.1 Type of targets applied

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

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

4.2 Tolerable burden of disease and health-based targets

The commonly accepted metric for expressing and comparing the burden of disease is the DALY (Murray & Acharya, 1997) (see also chapter 2). In the third edition of the *Guidelines for drinking-water quality* (WHO, 2004a), a tolerable burden of waterborne disease from drinking-water consumption of $\leq 10^{-6}$ DALY per person per year was adopted. This level can be compared with a microbial self-limiting diarrhoea and the corresponding case fatality rate of approximately 1×10^{-5} at an annual disease risk of 1 in 1000 (10^{-3}), which is also about 1×10^{-6} DALY (1 µDALY) per person per year (WHO, 2004a). Since food crops fertilized with treated excreta or irrigated with treated greywater, especially those eaten uncooked, are also expected to be as safe as drinking-water, the same high health protection level of $\leq 10^{-6}$ DALY per person per year is applicable in this context as well.

For operational purposes, treatment and other management options to reduce the level of pathogens and subsequently the degree of exposure should aim at this target.

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

Type of targets	Nature of targets	Application	Assessment
Health outcome; epidemiology based	Reduction in detected disease incidence or prevalence	Microbial with high measurable disease burden Through direct impact measurement, such as food-associated disease	Public health surveillance; analytical epidemiology Often difficult to assess actual impact Multiple factors
Risk-based assessment	Tolerable level of risk due to direct or indirect exposure Relationship to other alternative use, exposure or sanitation facilities in local context	Microbial hazards in situations where disease burden cannot be directly measured	QMRA Predictive tool Needs to be related to local exposure
Quality targets	Guideline values	Measurements of pathogens or indicator organisms, less applicable in: - small-scale application - for urine due to rapid die-off of indicators - for greywater due to growth resulting in overestimation of risk	Measurements mainly valid in assessment of technical performance of treatment of faeces Should mainly be applied within a similar framework as for the assessment of wastewater use Ensure validity of measurement parameters (system validation) Limitations in reflecting general pathogen risks
Performance targets	Generic performance targets for removal of groups of organisms Customized targets Guideline values less applicable	Microbial contaminants	Compliance through system assessment Review by public health authorities Checklists Recommended for small-scale applications. Limitations based on local conditions
Specified technology	Authorities specify specific processes or system approaches to address constituent handling practices or behaviours in relation to health effects	Health effects in small-scale settings	Compliance assessment Operation and handling

Campylobacter, *Cryptosporidium* and rotaviruses were chosen as index organisms (Havelaar & Melse, 2003; WHO, 2004a). An example of a calculation of the values for tolerable infection risk is given in Volume 2 of these Guidelines and is also applicable in the context of this volume. The cited values accounting for the infection ratios are:

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

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

Reliable epidemiological data relating to the safe use of excreta and greywater in agriculture are scarce. As an alternative, the range of tolerable disease risk can be deduced based on the QMRA, for which the risks resulting from exposure to faeces, urine and greywater were presented in chapter 3, for both its final use and handling. In this context, the current Guidelines are harmonized with the health aspects of the use of treated wastewater in agriculture, where the epidemiological appropriate level of tolerable risk for both crop consumers (unrestricted irrigation) and fieldworkers (restricted irrigation) has been identified (see Volume 2 of these Guidelines).

In chapter 5, the combination of different primary and secondary treatment barriers is described that can achieve a risk reduction to the health-based target level. Knowledge (or estimation) of the volume of treated excreta or greywater to which a person is exposed in the handling chain or that remains on the crop (ml or mg per 100 g crop) following fertilization, the withholding time and the die-off in the field will determine the degree of pathogen reduction required to achieve the tolerable additional disease burden of $\leq 10^{-6}$ DALY per person per year. This step requires the numbers of pathogens present in the untreated excreta or greywater to be known or estimated. In this context, the use of *E. coli* concentrations for verification monitoring is appropriate for treated excreta, but it is not for collected urine, due to a rapid die-off of the bacteria in this medium. In greywater, a regrowth of *E. coli* sometimes occurs, which may lead to an overestimation of the risks if verification monitoring is based on this parameter. It is suggested that *E. coli* guideline values, which are applicable for wastewater use, be applied cautiously for greywater. If applied, they will give a level of additional safety in this application, since the faecal load is usually 100–1000 times less than in wastewater. For helminth infections, the treatment verification monitoring level in terms of number of helminth eggs is presented in Table 4.2. The health-based protection to achieve the required pathogen reduction may consist of treatment alone or may be a combination of several measures. A guideline value of $<10^3$ *E. coli* per 100 ml is suggested for unrestricted irrigation with greywater. The target value of $<10^3$ *E. coli* per gram of treated faecal material applied as fertilizers would then ensure a comparative level of safety against bacterial pathogens and probably against viral pathogens as well. A clear value for parasitic protozoa does not exist.

The pathogen reduction that is needed in the on-site and off-site treatment of excreta is expressed as performance targets. This target for treated excreta is based on a storage time in the on-site treatment for 12–18 months of treatment (if only storage applies) and is combined with a stated withholding period that will further minimize

Table 4.2 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. coli* (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 high regrowth potential of *E. coli* and other faecal coliforms in greywater.

risks to the consumers. This period applies as the treated excreta are applied as a fertilizer and soil conditioner, which differs from the wastewater values, where the water is mainly used for irrigation purposes. The verification in relation to target values for *E. coli* and helminths is, however, applicable for faeces after storage/treatment.

Strauss & Blumenthal (1990) suggested that one year of storage was sufficient under tropical conditions (28–30 °C), whereas at lower average temperatures (17–20 °C) 18 months would be needed. Storage is especially beneficial in dry and hot climates where rapid desiccation of the material takes place and low moisture contents aid pathogen inactivation. Esrey et al. (1998) stated that there is rapid pathogen destruction at moisture levels below 25% and that this level should be aimed for in dry urine diversion toilets that are based on dehydration (i.e. storage). Low moisture content is also beneficial in order to reduce odour and fly breeding. Regrowth of bacterial indicators and some pathogens (EHEC and *Salmonella*) may, however, occur after application of moisture (water) or if the material is mixed with a moist soil, as indicated by results reported by Austin (2001).

The reduction of viruses in excreta is related to storage period and storage conditions. Figure 4.1 exemplifies this with a risk calculation for rotavirus in relation to storage.

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

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

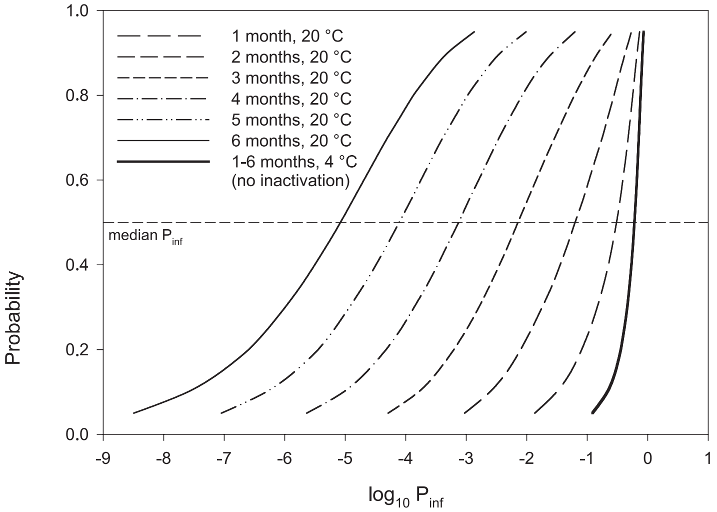

Figure 4.1
Effect of storage time on rotavirus risk (from Höglund, Ashbolt & Strenström, 2002)

4.3 Microbial reduction targets

The approach adopted in these Guidelines focuses on risks from the chain of excreta and greywater use from collection to the consumption of food crops eaten. Data on health effects were used to assess the infectious disease risk and harmonize with the approach taken in Volume 2 of the Guidelines. The analyses took account of consumption of crops eaten raw and of risks from direct contact with treated excreta (involving involuntary soil ingestion). Direct correlations between the relative risks of wastewater and treated excreta applications have not been established. However, the guideline values presented for both are in the same range as exemplified for *Ascaris* in Box 4.1.

Based on the exposure scenario for wastewater irrigation, it was shown that, in order to achieve $\leq 10^{-6}$ DALY per person per year for rotavirus, total pathogen reductions of 6 log units for the consumption of leaf crops (lettuce) and 7 log units for the consumption of root crops (onions) are required. Applying these values to excreta, this implies about an 8–9 log reduction for faeces (assuming a 100-fold dilution). The risk from source-separated urine and greywater relates to the faecal cross-contamination that occurs. Based on measurements, this cross-contamination is usually less than 10^{-4} of excreta, thus similar to a 100-fold dilution of wastewater with a need for a pathogen reduction of <4–5 log units as the performance target for unrestricted irrigation to achieve the tolerable additional disease burden of $\leq 10^{-6}$ DALY per person per year.

As an example, in source-separated urine, the faecal cross-contamination was estimated to be within a range of 1.6–18.5 mg of faeces per litre of urine, with a mean of 9.1 ± 5.6 mg/l, thus resulting in about a 5 log lower concentration of potential pathogens than in faeces. The faecal contamination of greywater was at a similar level, estimated to correspond to a faecal load of 0.04 g/person per day. Because the risks associated with exposure to rotavirus are estimated to be the highest, this level of

Box 4.1 Comparative performance targets for viable helminth eggs in wastewater, faecal matter and faecal sludge

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

The use of treated excreta or faecal sludge should not enrich the soil with a higher egg concentration than the quantity permitted by the application of irrigation water. The sludge application rate depends on the egg concentration in the total solids Eg (expressed as eggs/g total solids). The sludge quantity applied to the soil Rs thus amounts to: $Rs < Re/Eg = 10^7$ Rw/Eg (g total solids/ha·year).zYearly helminth load from irrigation (using an average of, e.g., 500 mm/year): ≤ 500 helminth eggs/m^2·year permissible. Application of treated faecal matter (same quantities as in good agricultural practice of manure): 10 t manure/ha·year at 25% total solids (1 kg/m^2· year) = 250 g total solids/m^2·year.

[helminths eggs]tolerable $\leq 500/250 = 2$ helminth eggs/g total solids
(with 1000 mm/year: 4 helminth eggs/g total solids)

Guideline value set to 1 helminth egg/g total solids (to account for variability).

pathogen reduction will provide sufficient protection against bacterial and protozoal infections.

These log unit pathogen reduction levels may be achieved by the application of appropriate health protection measures, each of which has its own associated log unit reduction or range of reductions (Table 4.3). A combination of these measures is used such that, for all combinations, the sum of the individual log unit reductions for each health protection measure adopted is equal to the required overall reduction. Several of the steps are similar to what has been presented in Volume 2 of the Guidelines, while the pathogen reduction due to treatment will differ. Treated excreta are always applied as a fertilizer in combination with planting or during the initial growth period. Thus, a withholding period of normally more than one month applies, except for application of greywater, which is normally done for irrigation purposes.

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

Microbial reduction targets for protection against helminth infections are based on the results of microbiological studies. Although investigations related to risk should be based on the number of viable eggs, in the microbiological investigations, the reduction refers to the percentage of viable eggs out of the total egg population and not the actual numbers.

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

Table 4.3 Pathogen reductions achievable by various health protection measures

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

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

Treatment processes to achieve, or partially achieve, the pathogen reductions exist. Different investigations show that in collected and stored dry faecal material, a time period of between 6 and 12 months may suffice with the application of an elevated pH and high ambient temperature (Table 4.4 and Table 4.5). If the number of helminth eggs is ≤1 per g total solids, then no additional health protection measures are required in relation to this group of organisms, as the target value is automatically achieved (this is the typical situation in most industrialized countries).

4.4 Verification monitoring

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

- Validation is the initial testing to prove that a system as a whole and its individual components are capable of meeting the performance targets and, thus, the health-based targets.

- Operational monitoring is the routine monitoring of parameters that can be measured rapidly (i.e. through tests that can be performed quickly, parameters measured online, or through visual inspection) to inform management decisions to prevent hazardous conditions from arising.
- Verification monitoring is done periodically to show that the system is working as intended. This type of monitoring usually requires more complicated or time-consuming tests that look at parameters such as bacterial indicators (*E. coli*) or helminth eggs.

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

4.4.1 Treatment of excreta and greywater

Pathogen numbers in raw or treated faecal sludge, excreta or greywater are not measured routinely (if at all). The performance of the on-site treatment used to partially or wholly ensure $\leq 10^{-6}$ DALY per person per year cannot, therefore, be determined on the basis of pathogen verification monitoring, but instead is based on validation of the general treatment efficiency. Verification monitoring is applicable mainly in larger collection systems or when a secondary off-site treatment after collection from a number of individual units is made. The microbiological performance of the larger system or the off-site treatment is evaluated by determining the content of a pathogen indicator bacterium, such as *E. coli*, in the treated material. The same applies for larger greywater collection and treatment systems, where the effluent may be monitored for verification purposes. For large-scale systems or when secondary off-site treatment is necessary, the values in Table 4.2 above apply.

When other exposure barriers are appropriate and can be enforced, the above guideline values can be relaxed based on national or local decisions — for example, when a public body has the legal authority to require that crop restrictions be followed regularly or when a strong project management exists. For fruits and vegetables, special restrictions may apply. For subsurface adsorption systems for greywater, no guideline values apply. However, the siting of such systems should not interfere with groundwater quality. For pond systems for greywater treatment, the risk of promoting mosquito breeding should be evaluated, and pond systems should not be opted for under circumstances where vector breeding may have a substantial impact on health without incorporating mosquito control measures into their design and operation.

4.4.2 Other health protection measures

Operational health protection measures include the agricultural use practices and the preceding treatment and transport. Even if a treatment is validated and verification monitoring has been done, process steps or handling practices may periodically malfunction, resulting in a fertilizer product that is not completely safe. Therefore, additional measures should be taken in order to further minimize the risk for disease transmission. These measures are applicable independent of the scale of the system (special considerations for small systems are provided in section 4.4.3). Thus:

- Excreta and faecal sludge should be treated before they are used as fertilizer, and the treatment methods should be validated.
- Equipment used for, for example, transportation of unsanitized faeces should not be used for the treated (sanitized) product.

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

Table 4.4 Additional treatments for excreta and faecal sludge off-site, at collection and treatment stations from large-scale systems (municipal level)[a]

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

[a] Run in batch mode without addition of new material.

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

4.4.3 Excreta in small systems

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

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

Table 4.5 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 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), while a more or less complete inactivation of *Ascaris* eggs will occur within 1 year (Strauss, 1985).
Alkaline treatment	pH >9 during >6 months	If temperature >35 °C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination.

[a] No addition of new material.

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

- Primary treatment (in the toilet) includes storage and alkaline treatment by addition of ash or lime.
- pH elevation to above 9 is preferred, which can be obtained by the addition of alkaline material (e.g. lime or ash; 200–500 ml; enough to cover the fresh faeces) after each defecation. (Total elimination may not occur, but a substantial reduction will be achieved.)
- Secondary off-site treatments as for larger systems (municipal level), including alkaline treatments, composting or incineration (Table 4.5), can be applied off-site and result in a further reduction when municipal collection is organized.
- In small-scale systems (household level), the faeces can be used after primary on-site treatment if the criteria in Table 4.3 are fulfilled.

As for larger collection and application systems, the following points need consideration:

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

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

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

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

Table 4.6 Recommended guideline storage times for urine mixture[a] based on estimated pathogen content[b] and recommended crop for larger systems[c]

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

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

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

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

[d] Not grasslands for production of fodder.

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

Sources: Adapted from Jönsson et al. (2000); Höglund (2001).

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

Specific recommendations include the following:

- For vegetables, fruits and root crops consumed raw, a one-month withholding period should always be applied.
- In areas where *Schistosoma haematobium* is endemic, urine should not be used near freshwater bodies.

- Urine should be applied close to the ground and preferably mixed with or watered into the soil.

General recommendations for the use of urine are as follows:

- Direct use after collection or a short storage time is acceptable at the single household level.
- For larger systems, urine should be stored for times and under conditions given in Table 4.6.
- An interval of at least one month should be observed between fertilization and harvest.
- Additional stricter recommendations may apply on a local level, in the case of frequent faecal cross-contamination. The recommendations for storage times are directly linked to agricultural use and choice of crop (Table 4.6).

Additional practices to minimize the risks include the following:

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

5

HEALTH PROTECTION MEASURES

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

To achieve this, a combination of health protection measures needs to be taken that will produce overall pathogen reductions and that differ by system component. Pathogen reduction required for fresh excreta will be in the order of 2 log units higher than for wastewater (i.e. in the range of 8–9 log units), while pathogen reduction for source-separated urine and greywater will be substantially lower (i.e. about 3–5 log units), based on the measured faecal cross-contamination in these system components. Most of the health protection measures are similar to those for the safe use of wastewater (see Volume 2 of these Guidelines), but some fundamental differences exist — for example, the potentially higher concentration of pathogens in excreta and lower concentrations in urine and the substantially higher die-off that may be achieved in the field, since fertilization occurs mainly during planting and does not continue up to harvest. Otherwise, the control measures are similar and include:

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

In planning for or assessing sanitation systems and health protection measures, it is of prime importance to take all components — e.g. sanitation facilities (toilets and latrines at private and public levels), treatment facilities, pit emptying, collection, transport — into consideration to the extent possible.

Health risks associated with excreta and greywater use are linked mainly to occupational exposure of those who handle the excreta and greywater and consumption of potentially contaminated products. Technology alone is unable to interrupt disease transmission and accompanying ill health, if hygiene awareness in a community is low. Poor domestic and personal hygiene diminish the positive impact of improved excreta and greywater management on community health. Treatment needs to fulfil a reliable reduction of different groups of pathogens so that the waste meets the quality guideline values and performance criteria. If this is achieved, disease transmission to those collecting and using the material as fertilizers as well as those consuming fertilized products will be reduced to acceptable levels.

Measures that prevent pathogens from reaching the agricultural produce and the selection of appropriate crops for fertilization (e.g. bioenergy crops or crops aimed for further processing) may prevent pathogens from affecting the consumer while taking advantage of the positive nutritional benefit of reliable fertilizers.

The feasibility and efficacy of any combination of health protection measures will depend on local factors, such as:

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

Especially for greywater use, secondary risks may arise from the creation of habitats conducive to the breeding of insect vectors of disease and a subsequent increase in the transmission of vector-borne diseases. Conducting an analysis of the storage, treatment and irrigation options will identify the key risk points as a basis for the selection and design of the most appropriate health protection measures.

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

Treatment of excreta (faeces) can be either on-site directly in the toilet (e.g. by prolonged storage without mixing with untreated material, drying the material or the addition of a pH-elevating compound) or off-site, where the material is collected from the toilet and treated in a controlled way with the purpose of reducing pathogens to acceptable limits. Systems designed for primary on-site treatment will produce an initial pathogen die-off that can be further corrected through off-site treatment should monitoring reveal that the initial pathogen reduction is insufficient. This combination is optimal for health protection.

If secondary off-site excreta treatment is needed to reduce the risks to an acceptable level but is logistically not feasible, some of the other health protection measures should be deployed; for example, suitable crop restriction can make any further measures redundant. If the effective implementation and enforcement of crop restrictions are somehow not possible, then recourse to other measures will be necessary. Decision-making on measures should ensure that their deployment is progressive, incremental and synergistic. Small-scale use schemes for excreta and greywater are often subsistence-level operations that are difficult to control in relation to treatment efficiency. Measures often need to be developed for minimization of risks to the individual, including health education and improved access to safe domestic water supplies. It is often desirable to combine several health protection measures. For example, crop restriction may be sufficient to protect consumers but will need to be supplemented by additional measures to protect collectors or workers. Sometimes, partial treatment to a less demanding standard may be sufficient if combined with other measures.

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

5.1.1 Exposure control: general principles

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

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

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

In the use of treated excreta, urine or greywater, certain key risk points and exposure pathways need to be considered. These are elaborated below in this chapter. Furthermore, the risks are related to the degree of faecal cross-contamination of untreated faeces as well as the efficiency of treatment. The factors in Table 5.1 apply for most systems, but are of major concern in larger systems where several units or users are involved. Handling is further discussed in section 5.2.2.

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

5.1.2 Exposure control at agricultural sites or site of use

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

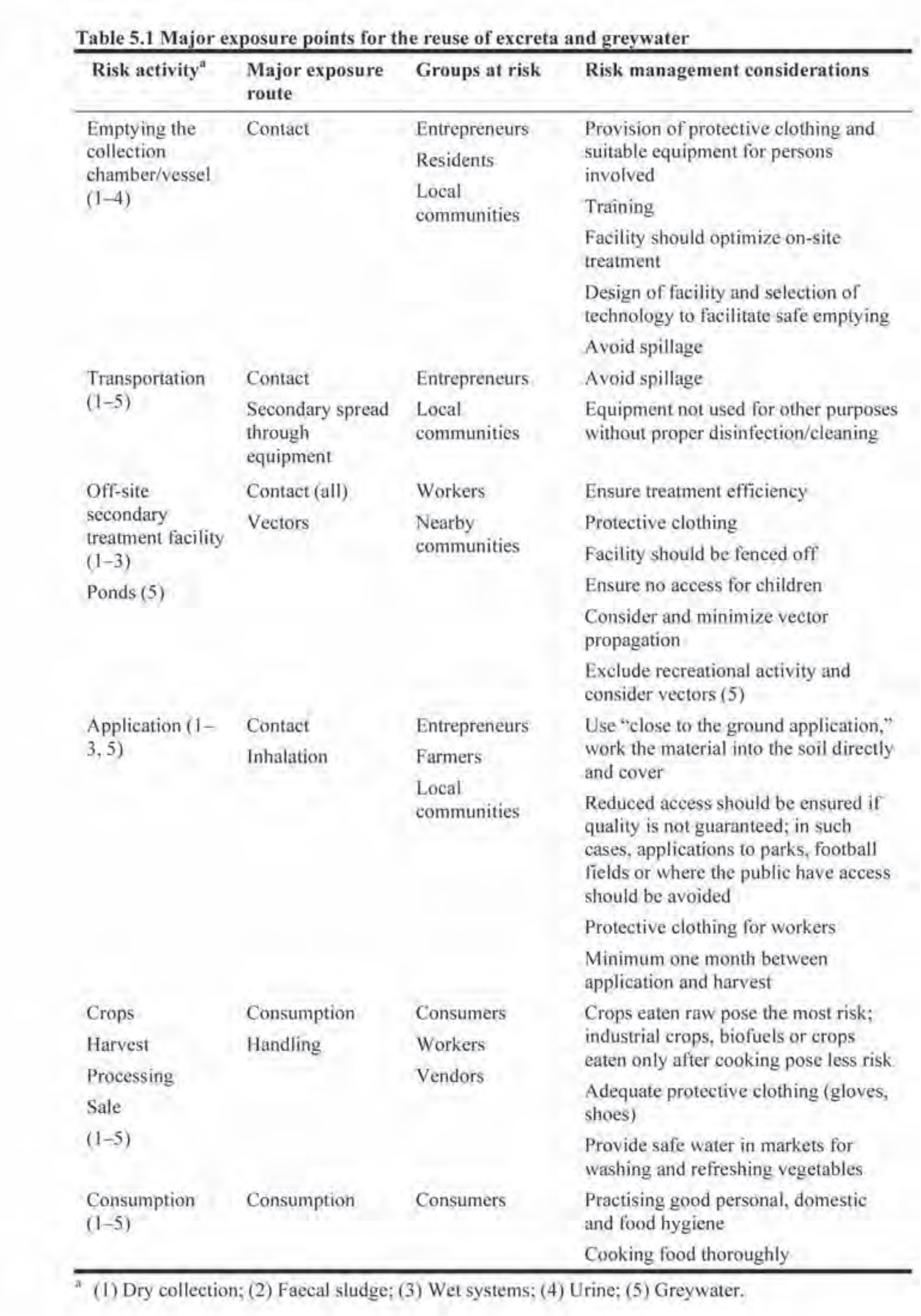

Table 5.1 Major exposure points for the reuse of excreta and greywater

Risk activity[a]	Major exposure route	Groups at risk	Risk management considerations
Emptying the collection chamber/vessel (1–4)	Contact	Entrepreneurs Residents Local communities	Provision of protective clothing and suitable equipment for persons involved Training Facility should optimize on-site treatment Design of facility and selection of technology to facilitate safe emptying Avoid spillage
Transportation (1–5)	Contact Secondary spread through equipment	Entrepreneurs Local communities	Avoid spillage Equipment not used for other purposes without proper disinfection/cleaning
Off-site secondary treatment facility (1–3) Ponds (5)	Contact (all) Vectors	Workers Nearby communities	Ensure treatment efficiency Protective clothing Facility should be fenced off Ensure no access for children Consider and minimize vector propagation Exclude recreational activity and consider vectors (5)
Application (1–3, 5)	Contact Inhalation	Entrepreneurs Farmers Local communities	Use "close to the ground application," work the material into the soil directly and cover Reduced access should be ensured if quality is not guaranteed; in such cases, applications to parks, football fields or where the public have access should be avoided Protective clothing for workers Minimum one month between application and harvest
Crops Harvest Processing Sale (1–5)	Consumption Handling	Consumers Workers Vendors	Crops eaten raw pose the most risk; industrial crops, biofuels or crops eaten only after cooking pose less risk Adequate protective clothing (gloves, shoes) Provide safe water in markets for washing and refreshing vegetables
Consumption (1–5)	Consumption	Consumers	Practising good personal, domestic and food hygiene Cooking food thoroughly

[a] (1) Dry collection; (2) Faecal sludge; (3) Wet systems; (4) Urine; (5) Greywater.

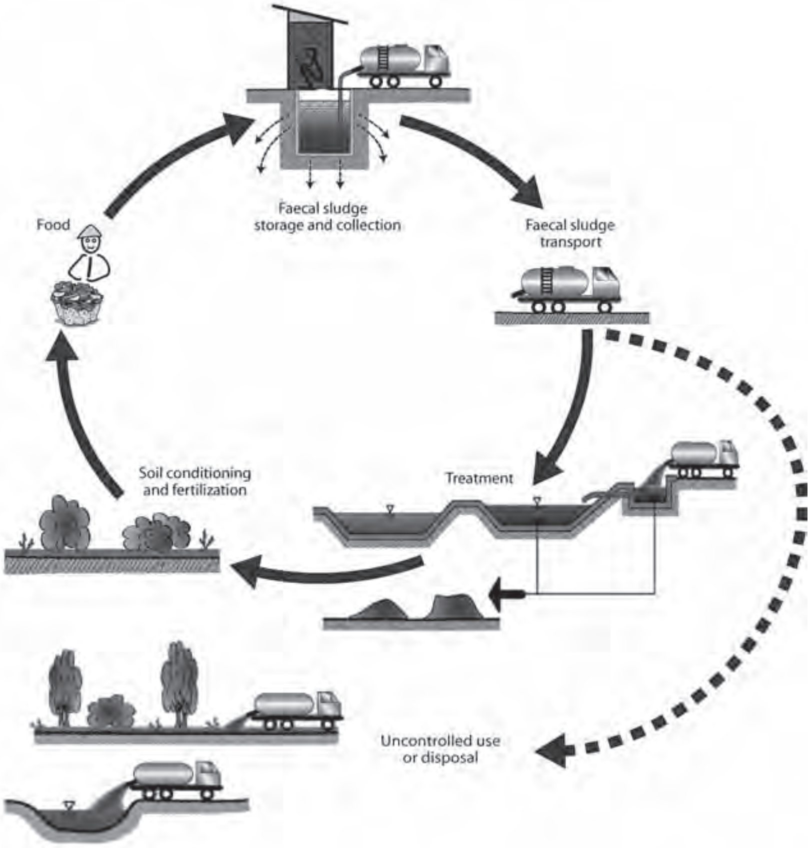

Figure 5.1
Critical control points in preventing enteric disease transmission in faecal sludge management

Crop restriction

Restricting crop selection does not normally need to be applied when treated urine and greywater are used, due to the low degree of faecal contamination. The use of treated excreta or faecal sludge may be restricted to non-food crops (e.g. cotton and bioenergy crops such as rapeseed or fast-growing woods, like *Salix* plantations used for biofuel). They may also be applied on crops processed before consumption (wheat) or crops that have to be cooked (potatoes). Crop restriction still requires that the excreta have been treated before use.

If greywater is heavily contaminated, vector breeding is likely to occur or pond treatment is not feasible, subsurface horizontal irrigation in the root zone of selected plants is a feasible option.

Application techniques

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

Fieldworkers

Agricultural fieldworkers are at high potential risk, especially for parasitic infections. Treated human excreta are often applied on a small scale, which should result in less risk than indiscriminate open-air defecation. In larger-scale applications, such as the use of treated faecal sludge, exposure to helminth eggs can be eliminated or reduced by appropriate treatment combined with the use of appropriate protective clothing (e.g. shoes or boots for fieldworkers). These health protection measures have not been quantified in terms of pathogen exposure reduction, but they are expected to have an important positive effect. In larger-scale applications, fieldworkers should have access to adequate sanitation facilities and water for drinking and hygienic purposes. It is beneficial that effective hygiene promotion programmes targeting fieldworkers be linked to agricultural extension activities or other health programmes.

Withholding period

It is always recommended that there be a period of at least one month between application of urine or treated excreta or faecal sludge and crop harvesting. Vaz da Costa Vargas, Bastos & Mara (1996) showed that cessation of irrigation with wastewater for 1–2 weeks prior to harvest can be effective in reducing crop contamination by providing time for pathogen die-off. A further reduction will occur during a 30-day period. Risk calculations have been done for urine application to the field, showing that a withholding period of one month will result in a risk level much below 10^{-6} DALY for pathogenic bacteria, viruses and parasitic protozoa. Enforcing a withholding period for treated excreta is normally no problem, since the fertilizer is usually used at planting or applied on seedlings.

Die-off of organisms before consumption

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

5.1.3 Post-harvest exposure control

Vigorous washing in tap water of rough-surfaced salad crops (e.g. lettuce, parsley) and vegetables eaten uncooked reduces bacteria by at least 1 log unit; for smooth-surfaced salad crops (e.g. cucumbers, tomatoes), the reduction is approximately 2 log units (Brackett, 1987; Beuchat, 1998; Lang, Harris & Beuchat, 2004). Washing in a disinfectant solution (commonly a hypochlorite solution) and rinsing in tap water can reduce pathogens by 1–2 log units. Washing in a detergent (e.g. washing-up liquid) solution and rinsing in tap water can reduce helminth egg numbers by 1–2 log units

(B. Jiménez-Cisneros, personal communication, 2005). Peeling fruits and root vegetables reduces pathogens by at least 2 log units. Cooking vegetables achieves an essentially complete reduction (5–6 log units) of pathogens.

These reductions are extremely reliable and should always be taken into account when selecting the combination of excreta/greywater treatment and other health-based control measures. Effective hygiene education and promotion programmes will be required to inform local food handlers (in markets, in the home and in restaurants and food kiosks) how and why they should wash produce fertilized with excreta and/or irrigated with greywater effectively with water or disinfectant and/or detergent solutions.

5.2 Technical measures

Excreta and greywater treatment and handling systems are often decentralized and involve no or limited sewerage. Currently available technology allows design of such systems in both urban and rural areas in rich and poor countries (Jenssen et al., 2004; Werner et al., 2004). In low-income countries, rural populations with access to sanitation facilities mostly use on-site installations such as traditional pit, ventilated improved pit (VIP) or pour-flush toilets and more recently, in selected areas, urine-diverting toilets. In contrast to the situation in industrialized countries, where the dominating urban sanitation system is centralized sewerage, the majority of urban dwellers in low- and middle-income countries are served by on-site sanitation systems. Small-diameter gravity sewers or other low-cost sewer systems might also prove feasible in selected, mainly densely populated urban areas served by reliable water supply. It is unlikely that sewerage will become a predominant sanitation option of choice in developing countries in the foreseeable future due to water scarcity and unreliability of water supply services and for financial, economic and resource reasons. Due to growing pressures on public health systems, environment and natural resources, a variety of reuse-oriented on- and off-site systems have been developed and implemented at an increasing rate (Werner et al., 2004). These comprise urine-diverting toilets, composting toilets, anaerobic (yielding biogas) and aerobic treatment of excreta and separate greywater treatment systems.

This section gives a brief overview of sanitation for low- as well as high-income countries where excreta and greywater are collected and treated for reuse in urban or periurban agriculture. This includes systems where excreta (urine and faeces diverted or combined) and greywater are handled separately and on site and cluster systems that handle combined wastewater through septic tanks and small-diameter sewers. Figure 5.2 summarizes some technical options for excreta and greywater management based on the collection, treatment and use options.

5.2.1 On-site sanitation systems

On-site sanitation systems serve a single home or small clusters of homes. They range from traditional septic tank or soil infiltration systems to the more recent source separating systems that are designed for recycling of resources from excreta and greywater (Figure 5.3). Systems where the excreta are treated and handled separately from the greywater are termed source separating systems, with either two fractions (the excreta — urine and faeces — and the greywater) or three fractions (urine, faeces and greywater).

Toilets that use no or very little water will limit collection to excreta only. The toilet options used in the source separating systems range from pit toilets to modern urine-diverting and vacuum toilet systems. The principal difference between the pit

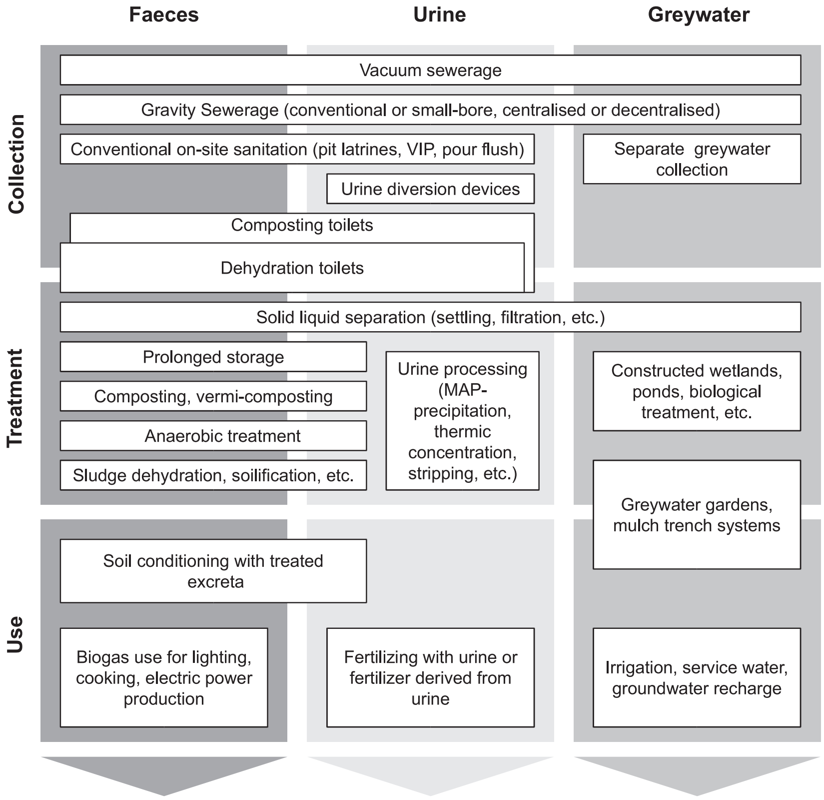

Figure 5.2
Overview of technologies for management of excreta and greywater

and pour flush toilets and the other options is that the former utilize pits or soak-aways in natural soils, which due to local soil and groundwater conditions may pose a threat to the groundwater quality and, therefore, to human health. The other options collect all excreta for on- or off-site treatment and potential use and thus provide better protection of the local groundwater. The pit toilets, constructed for disposal of excreta and not for use of the material, can also be excavated, providing possibilities of recycling of phosphorus and organic matter but losing nitrogen. The composting or dry sanitation toilets lose nitrogen to the air, while the urine-diverting or low-flush systems with holding tanks have very little loss of plant nutrients prior to agricultural application of excreta when they are handled properly. Greywater treatment options are described in section 5.2.4.

Pit toilets

Pit toilets include the simple pit latrine and VIP latrine, which do not require water for flushing, and pour flush toilets, where 1–3 litres of water are used to flush the excreta to a soak-away. Traditionally, pit latrines were dug quite deep, often discharging their percolate directly into groundwater. When pit latrines are used, shallow pits should be dug, since these may limit the groundwater impact as well as being easier to excavate for reuse after ample storage.

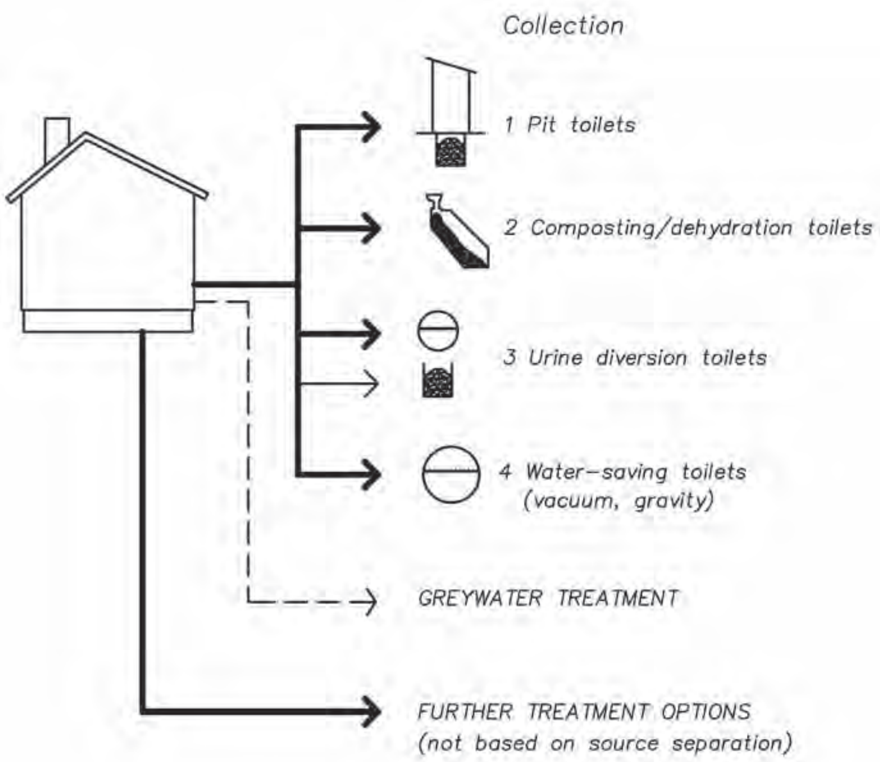

Figure 5.3
One-site sanitation options: 1-4, systems with source separation. For the systems with source separation, greywater is handled in a separate system (see section 5.2.4).

The separation distance between the latrine and the groundwater is an important hygienic barrier and should be maximized. It depends on several factors, such as the soil texture, structure, chemical composition and hydraulic loading. Normally, finer-grained soils (fine sand silt or finer) give better protection than coarser sands and gravel. Water use should be limited to anal cleansing and cleaning of the toilet. The toilet should be constructed so that no rain or surface water can flow into the pit, either when the toilet is in use or when the pit is full and covered for its contents to mature and sanitize.

The potential for fly breeding is reduced by a fly mesh at the ventilation pipe (VIP), the use of a toilet cover and frequent adding of bulking material or ash to reduce the possibility of flies coming into contact with fresh faecal material. Adding ash or lime will cause a rise the pH and enhance pathogen die-off.

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

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

Composting toilets

Composting toilets (Figure 5.4) have a collection chamber where all excreta are confined. Composting systems should preferably be operated in a batch mode, such as provided by the double vault system (B in Figure 5.4), where one vault is used while the other matures, or by collection containers (C in Figure 5.4), which are changed when full and set aside to mature and sanitize. This eliminates mixing of fresh and matured material and is safer for persons emptying the toilet. Secondary composting may be a way to ensure that material from composting toilets sanitizes properly. The toilets can be designed with or without urine diversion. Composting toilets rely mainly on aerobic degradation of organic matter, resulting in a volume reduction of the excreta of 70–90% if properly designed (Del Porto & Steinfeld, 1998). Adding dry bulking material is important; otherwise, it will not function as a composting toilet, but will be a collection chamber for wet excreta with potential odour and fly breeding problems. Proper ventilation will help improve odour control.

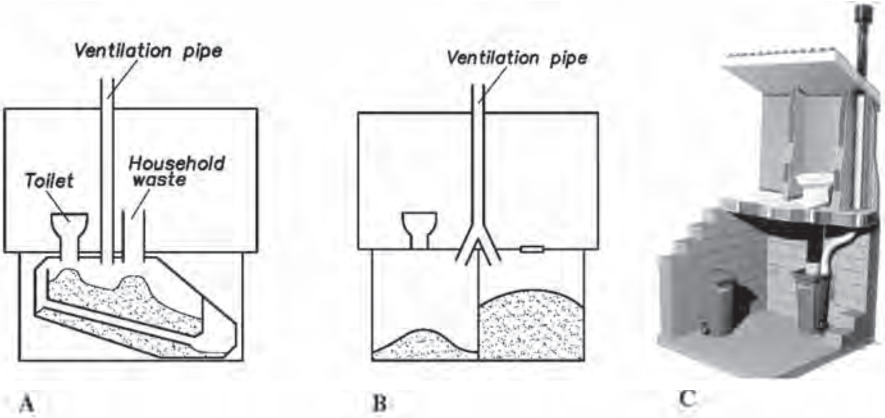

Figure 5.4
Examples of composting toilet systems: A, Continuous system; B, Batch system – dual compartment; and C, Batch system – removable compartments

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

Thermophilic composting of faecal material normally gives a fast and substantial reduction of pathogens if elevated temperatures are reached. Experimentally, T_{90} values (i.e. 1 log reduction) are 6 min at 65 °C and 1 h at 52 °C for *E. coli*. Enterococci and viruses have a slower die-off rate (Eller, Norin & Stenström, 1996). Composting will fulfil the criterion of an acceptable risk reduction to below 10^{-4} per year (Watanabe Fan & Omura, 2002). Due to its complexity, however, the composting process may prove difficult to manage within the chamber. Experience from temperate regions has shown that it is difficult to reach temperatures above 40 °C in the composting compartment. The normal operating temperature range is therefore often mesophilic or ambient. Pathogen reduction may require either long maturation times or a secondary composting (section 5.2.3) or storage period.

Emptying composting toilets constitutes a critical handling point. Proper protection measures, mainly personal protection, should be taken if the material is not fully sanitized, and the material should be further treated or stored out of reach from people until proper maturation times have been reached. In addition to protective clothing (e.g. gloves and boots), normal hygiene and washing after the emptying operation are important (see also section 5.2.2 below).

Dehydration toilets

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

Several studies report the pathogen die-off rate in dehydrating toilets (Table 5.2). Early studies indicated that *Ascaris* eggs were particularly resilient to dehydration (Strauss & Blumenthal, 1990) but dependent on the temperature, moisture content and pH; 6–12 months in warm climates are usually sufficient to allow for the die-off of helminth eggs (Peasey, 2000). Investigations in Viet Nam have shown that a six-month retention period gave an 8 log reduction in resistant indicator viruses and no viable *Ascaris* eggs (Carlander & Westrell, 1999). The mean temperature ranged from 31 to 37 °C (overall maximum was 40 °C), the pH in the faecal material from 8.5 to 10.3 and the moisture content from 24% to 55%. The inactivation was described as a combination of factors, but pH for the virus indicator inactivation was shown to be statistically significant as a single factor (Carlander & Westrell, 1999; Chien et al., 2001). Another study indicated that a period of 12 months was needed to achieve a complete destruction of *Ascaris* eggs (Phi et al., 2004). In a Chinese study by Wang

(1999), plant ash was mixed with faeces in a ratio of 1:3 and yielded a pH of 9–10. A >7 log reduction in bacteriophages and faecal coliforms and a 99% reduction in *Ascaris* eggs were recorded after six months, even though the temperature was low (–10 to 10 °C), resulting in partial freezing of the material. Coal ash and soil addition led to a lower or insufficient reduction, respectively. The coal ash gave an initial pH of 8. Use of these additives warrants an extension of the subsequent storage time to 12–18 months without new faecal additions, and alternating collection chambers are recommended. According to Lan et al. (2001), a pH above 8 resulted in inactivation of *Ascaris* within 120 days.

Addition of a pH-elevating agent like lime or ash has the potential to enhance inactivation of pathogens. After alkaline treatment, the resulting fertilizer will have an elevated pH (>8). This may be beneficial for many soils, but it may affect crop production in already alkaline soils adversely. The conditions to achieve complete removal of pathogens may vary due to local circumstances. On a large scale, secondary treatment of collected material may function as an additional treatment

Table 5.2 Investigated microbial reduction in dry collection of faeces

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

Table 5.2 (continued)

Area of investigation	Type of toilet	Additive	pH, temperature, moisture	Most important findings: Inactivation of pathogens and indicators	Reference
El Salvador	118 double-vault urine-diverting latrines; 38 single-vault solar latrines	Lime, ash or lime-mixed soil	pH: 6.2–13.0	**Organisms present in material:** Faecal coliforms inactivated after 500 days. pH most important factor. *Ascaris* inactivated after 450 days (pH >11), after 700 days (pH 9–11). Temperature strongest predictor for inactivation.	Moe & Izurieta (2004)
China	2 latrines	Plant ash mixed with faeces in ratio 1:3	pH: 9–10 temperature: −10 to 10 °C	**Controlled challenge test and organisms present in material:** After 3 months: >7 log reduction of *Salmonella typhimurium* phage 28B and faecal coliforms. 1% viability of *Ascaris*.	Wang (1999)[a]
China		No detailed information given	pH >8	**Controlled challenge test:** Inactivation of *Ascaris* within 120 days.	Lan et al. (2001)

[a] The other additives coal ash, sawdust and loess were also tested and resulted in lower pH and lower inactivation.

barrier, resulting in a higher safety level when the material is used as a fertilizer. High-temperature (thermophilic) composting of the dehydrated faeces may in some instances be considered as a secondary treatment, particularly if the contents of the toilet are to be used on food crops (Peasey, 2000).

Urine diversion systems

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

In urine diversion toilets, urine and faeces are collected separately. Low-, medium- and high-cost alternatives of this technology have been developed. The toilets come in both slab and sitting/pedestal toilet versions, and versions also exist for anal cleansing with water. Inserts for urine collection (Figure 5.5d) can be made from local material, but are also commercially available. In recent years, toilets made especially for urine diversion are available and used on all continents. In commercially produced urine-diverting toilets, the bowl/slab is divided into two compartments: a front one collecting urine and a rear one collecting faecal material (Figure 5.5a–c).

Figure 5.5
Examples of urine-diverting toilets: a) slab toilet, Guanxi province, China; b) double-flush urine diversion toilet; c) single-flush urine diversion toilet, Sweden; d) urine-diverting insert for a bucket toilet.

Urine diversion toilets with flushing apply either a single flush for urine with <0.5 litres or a double flush for either the urine or faecal matter with <4 litres. The single-flush system requires a straight chute down to the faecal collection chamber (Figure 5.6). The faecal matter is normally composted on site and the urine collected for use in agriculture (Winblad & Simpson-Hébert, 2004). Within pedestal toilets, a pan generally located towards the front of the defecating area collects the urine. Additional urinals can be used to collect urine from male users. If urinals are used, it is important to select models that use little water. In recent years, several new waterless urinals have appeared on the market. They have been tested in airports, hotels and universities and found to be without odour problems if properly maintained.

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

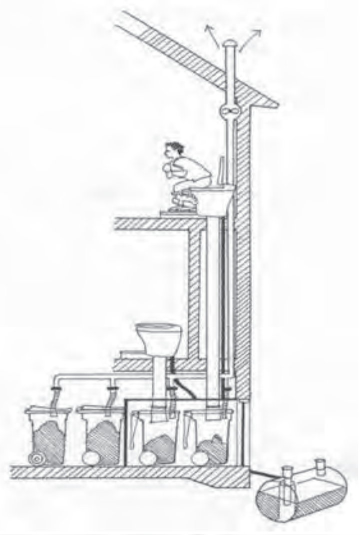

Figure 5.6
Technical layout of a single-flush urine diversion system in a two-storey apartment house (from Winblad & Simpson-Hébert, 2004)

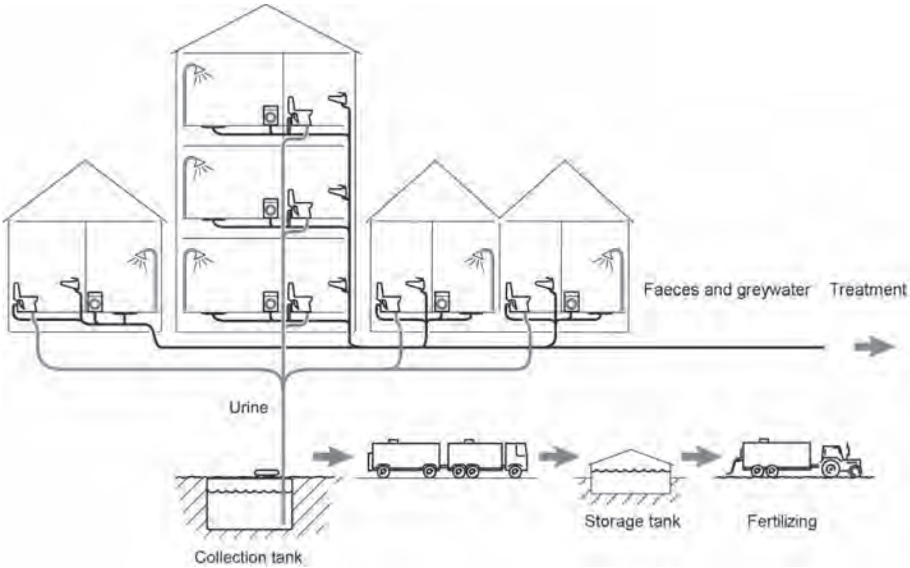

Figure 5.7
Layout for a dual-flush urine-diverting system. The urine is collected for use in agriculture, and the faecal matter is flushed away together with the greywater (Jönsson et al., 2000).

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

Vacuum and low-flush gravity toilets

Vacuum and low-flush gravity toilets are used to collect blackwater (urine and faeces together) as concentrated as possible for further treatment, processing and use in agriculture. Vacuum toilets use 0.5–1.5 litres per flush; gravity toilets using as little as 1 litre per flush also exist. Blackwater collected using 1 litre per flush toilets has a low dry matter content (Jenssen, 2001). To treat the blackwater aerobically or anaerobically (section 5.2.3), additional organic matter (e.g. ground organic household waste) must be added (Figure 5.8).

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

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

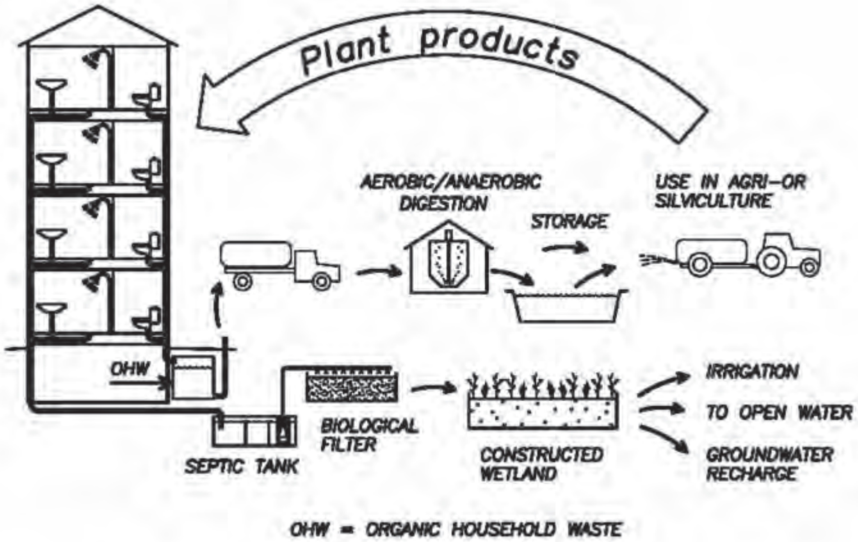

Figure 5.8
Example of a fully recycling system using vacuum or low-flush gravity toilets for separate collection of blackwater and separate treatment of greywater. Other greywater treatment options are given in section 5.2.4 (Jenssen, 2001).

Septic tank systems

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

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

5.2.2 Handling and transport of excreta and sludge

Faeces and sludge need to be handled at various steps of the sanitation, treatment and use system. Handling and transport of faeces and sludge constitute critical points in a sanitation system from a health perspective, as people handling these materials may be exposed directly to pathogens, and there is a risk for accidental spill or intentional dumping. The nature of materials that need to be handled varies, depending on their origin:

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

Different options are available for the handling and transport of faeces and sludge:

- manual handling through excavation or emptying using buckets, transport in buckets or simple carts;
- mechanical emptying and transport, by vacuum tankers or trucks;
- pumping and piped transport of liquid sludge.

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

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

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

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

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

5.2.3 Treatment of blackwater and septic tank/faecal sludge

Low-cost treatment options

The faecal material collected from latrine or toilet pits may contain high numbers of pathogens if it has been stored for short periods of time (no more than 1–2 weeks) prior to collection. Secondary treatment serves to inactivate these pathogen levels below the tolerable risk threshold and the related guideline values. The solids fraction constitutes a valuable soil conditioner and fertilizer when stabilized and treated to the required hygienic quality. In contrast, the undiluted liquid fraction will, in most cases, not be usable in agriculture due to excessive salinity.

The solids–liquid separation processes, applicable for pumpable sludges, comprise settling and filtration and lead to a concentration of the pathogens trapped in the solids fraction. The sanitization process for this fraction will therefore be crucial, as the pathogen concentrations will have increased several-fold compared with the raw faecal sludge. Figure 5.9 schematically depicts an array of faecal sludge treatment processes and options, which may be suitable for low- or middle-income countries (Ingallinella et al., 2002).

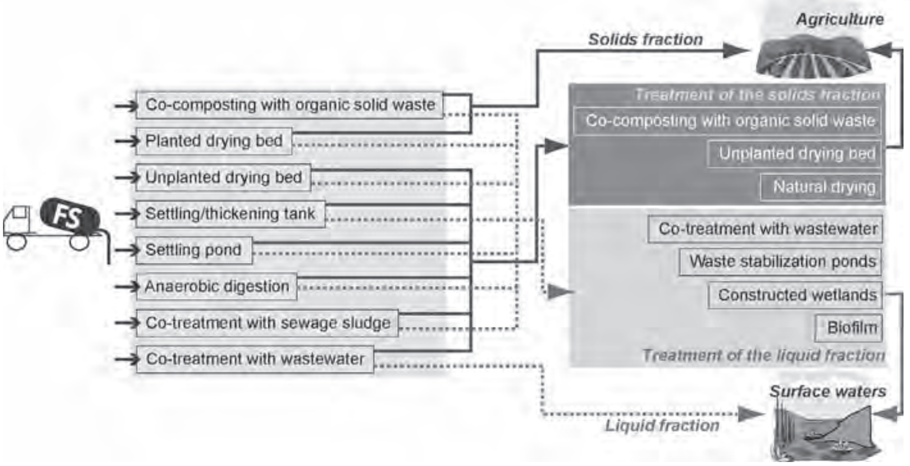

Figure 5.9

Low-cost options for treating faecal sludge (FS) and blackwater (Ingallinella et al., 2002)

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

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

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

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

Co-composting — i.e. the combined composting of faecal matter and organic solids waste — is practised all around the world, usually in small, informal and uncontrolled schemes or at a backyard scale. Most of this may proceed at ambient temperatures, with concomitant inefficient inactivation of pathogens. Thermophilic composting, however, can effectively sanitize and stabilize faecal sludge, faeces that have been pretreated in a urine diversion toilet or slurry from anaerobic treatment. If operating conditions required for thermophilic composting are adequate (moisture content 50–60%, carbon to nitrogen ratio 30–35 and mixing of bulking material to allow for sustained air passage), the temperature will rise to between 50 and 65 °C. Such temperatures will effectively inactivate pathogens. Fresh faecal sludge is normally too wet and exhibits too low a carbon to nitrogen ratio for optimal composting. Faecal sludge has to be dewatered prior to co-composting. Admixing of a relatively dry, carbon-rich bulking material such as organic municipal waste is required. The end-product of the aerobic composting process is an odourless, stabilized material with good properties as a soil conditioner and as a slow-release phosphorus fertilizer. Due to the complexity of the composting process, however, optimal thermophilic conditions throughout the composting mass can be guaranteed only if moisture content, bulking structure and carbon to nitrogen ratio are maintained and controlled throughout the thermophilic and maturation phases. Well operated thermophilic composting schemes can achieve close to 100% pathogen destruction, including very low helminth egg viabilities, if regular turnings are done during the 3- to 4-week thermophilic phase. Small-scale composting on a household level is less efficient and pathogen inactivation is incomplete, as the temperature increases only marginally above ambient. Prolonged storage would be the method of choice in that case. Composting is therefore best suited as a secondary off-site treatment.

Anaerobic digestion is a biological process that takes place in the absence of oxygen. The organic material is broken down, producing biogas (a mixture of methane, carbon dioxide and traces of other gases), water and remaining slurry. The slurry from the biogas reactor constitutes a valuable soil conditioner and fertilizer. This option is, in principle, suited to treat blackwater and higher-strength faecal sludge, which have not undergone substantial degradation. In India, in the order of 100 large-scale biogas plants are in operation, treating highly concentrated, fresh faecal sludge from public pour flush toilets. Small biogas digesters (Figure 5.10) serving one or a small number of households have become increasingly popular. The main goal of the household digesters is to produce biogas and provide the family with energy, mainly for cooking. The main input is animal manure from small household livestock, while human excreta and other organic wastes usually constitute the smaller fractions.

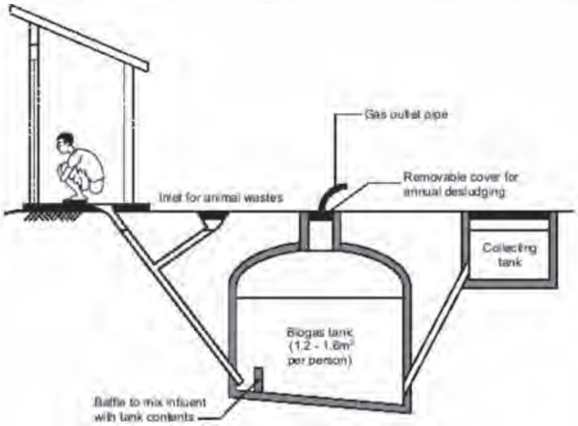

Figure 5.10

Household biogas digester for treatment of animal manure and human excreta

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

High-cost treatment of faecal sludge and blackwater

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

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

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

Pathogen removal performance of treatment options and processes

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

5.2.4 Greywater

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

Table 5.3 Helminth removal in different treatment processes for faecal sludge

Treatment option or process	Helminth egg log reduction	Duration	Reference
Low-cost			
Faecal sludge settling ponds	3	4 months	Fernandez et al. (2004)
Faecal sludge reed drying beds (constructed wetlands)	1.5	12 months	Koottatep et al. (2004)
Drying beds for dewatering (pretreatment)	0.5	0.3–0.6 months	Heinss, Larmie & Strauss (1998)
Composting (windrow thermophilic)	1.5–2.0	3 months	Koné et al. (2004)
pH elevation >9	3	6 months	Chien et al. (2001)
Anaerobic (mesophilic)	0.5	0.5–1.0 month	Feachem et al. (1983); Gantzer et al. (2001)
High-cost			
pH elevation >12	3		Gantzer et al. (2001)
Thermophilic, in-vessel (aerobic/anaerobic)	3	1–5 days	Haug (1993); Eller, Norin & Stenström (1996)

Source control and water conservation are part of the general management of greywater. This relates to the use of environmentally friendly household chemicals and reducing faecal input as well as reducing the amount of water to be treated. Progressive planning can calculate a mean amount of 80 litres of greywater per person per day (Ridderstolpe, 2004). In industrialized countries, excess amounts of detergents are responsible for substantial BOD input, and greywater will also contain excess amounts of grease and oil originating from food preparation. If greywater is to be used for irrigation, liquid soaps containing potassium are preferred, since hard soaps often contain sodium, which increases the risk of soil salinization. More information on greywater volume and composition has been given in chapter 1.

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

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

Pretreatment/solid–liquid separation

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

The most common pretreatment unit for greywater as well as for treatment of combined wastewater (greywater and excreta) on site is a septic tank (see Septic tank systems in section 5.2.1). The pathogen removal in septic tanks is poor (normally <0.5 log) and depends on the efficiency of particle removal. A regular (yearly) inspection is recommended to prevent problems with particle overflow.

For small systems, such as a single dwelling, an alternative to the septic tank may be filter bags from natural or synthetic material that produce the same effluent quality. A homeowner can remove such bags with proper personal protection against exposure to the material, which may contain pathogens. The bags can be composted together with their content if they are made of natural fibre or dried and reused if they are made of synthetic fabrics.

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

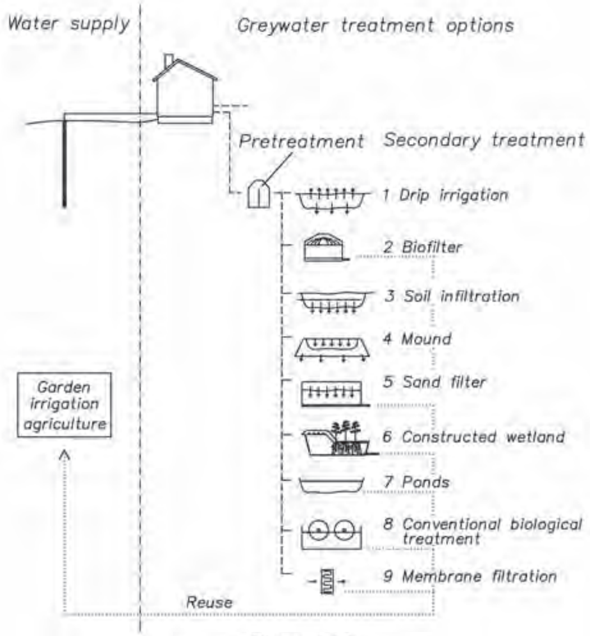

Figure 5.11
Greywater treatment options

Soil infiltration

Soil infiltration is a simple and suitable method for on-site greywater treatment, for which comprehensive experience exists regarding both separated greywater and combined wastewater. It is, for example, the primary system for on-site and decentralized wastewater treatment in the United States. The treatment efficiencies are high (normally >2 logs for both bacteria and viruses and >3 logs for parasitic protozoa), thus giving a similar reduction efficiency as a traditional wastewater treatment plant (Siegrist, Tyler & Jenssen, 2000).

After the pretreatment, the effluent is distributed to the soil through open ponds or shallow trenches or infiltration basins (Figure 5.12).

The water percolates down through an unsaturated zone to the groundwater (saturated zone). Most of the treatment occurs in the unsaturated zone. The size and

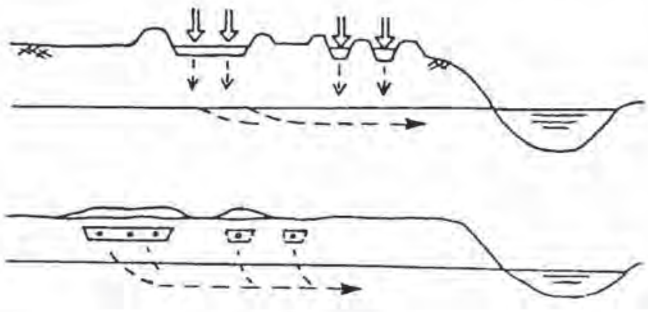

Figure 5.12
Infiltration in open basins/ponds (above) and in buried shallow trenches (below); the percolation down to the groundwater and subsequent flow towards a stream are indicated

load of the system need to account for the local soil conditions to keep the flow unsaturated, which assures optimum conditions for filtering of pathogens. Unsaturated flow also assures aerobic conditions that generally promote a more rapid die-off of pathogens.

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

Drip irrigation

Drip irrigation is a shallow soil infiltration system where the plant uptake of water and nutrients is optimized, thus minimizing vertical percolation to the groundwater. The system may be simple or advanced, with pressurized distribution of the liquid. Localized irrigation is estimated to provide an additional pathogen reduction of 2–4 log units, depending on whether the harvested part of the crop is in contact with the soil (see Volume 2 of the Guidelines) (NRMMC & EPHCA, 2005).

Ponds

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

Effluent storage reservoirs can also be used for greywater treatment in arid and semi-arid countries. Due to the organic load, a pretreatment step may be needed. Effluent storage and reservoirs may, if properly designed, operated and maintained, result in pathogen removals within the same range as waste stabilization ponds.

Constructed wetlands

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

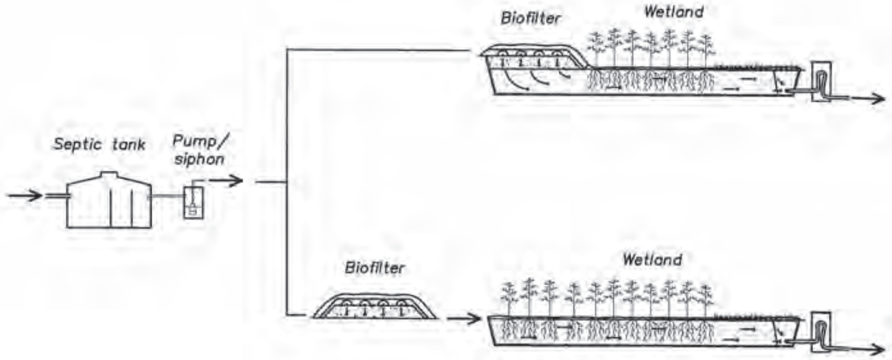

Figure 5.13

A subsurface flow wetland with and without integrated biofilter (Source: post-graduate training materials prepared by P. Jenssen & A. Heistad, Agricultural University of Norway, Aas, Norway, 2000)

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

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

In warm climates where plants do not have a long dormant period, a greywater treatment wetland can be constructed without a pretreatment biofilter, and the dosing system (pump/siphon) can also be omitted. However, with a biofilter, more compact systems can be made (Jenssen & Vråle, 2004) for urban applications.

Sand filters/vertical-flow constructed wetlands

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

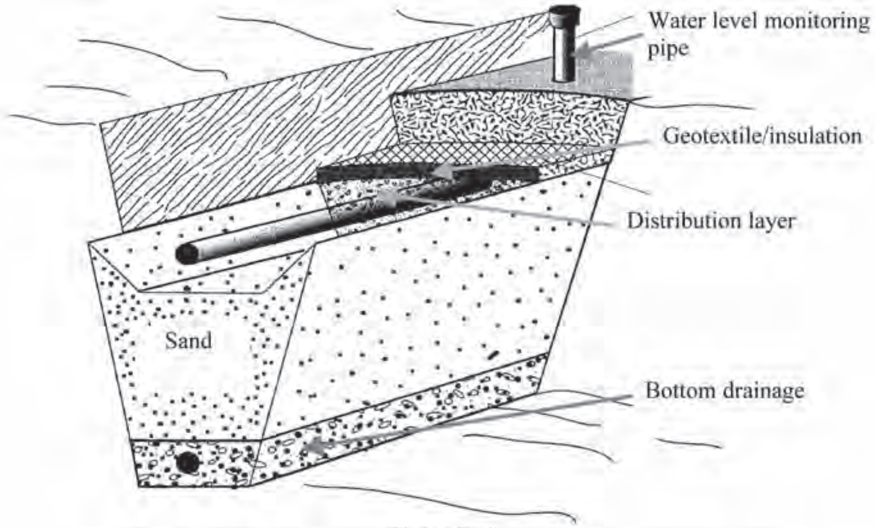

Figure 5.14
Sand filter design with sloping sand walls at the level of the distribution pipe

Biofilters

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

Mulch beds and greywater gardens

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

Greywater gardens are a similar technology, where greywater is treated in a planted constructed wetland. Contrary to mulch beds, which need to be replaced when the organic material is decomposed, greywater gardens are permanent installations. Pretreatment is recommended to avoid clogging, and subsurface application minimizes the exposure of workers in the gardens.

Activated sludge

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

Rotating biological contactors

In Germany, a successful system using rotating biological contactors has been developed. The system is compact and can be located, for example, in the basement of an apartment building. In order to achieve a reduction of faecal indicators above 3 logs, the system is equipped with ultraviolet disinfection.

Membrane filtration

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

6

MONITORING AND SYSTEM ASSESSMENT

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

The most effective means of consistently ensuring safety in source separating systems and the final use of the end-products in agriculture is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the process, from the generation and use of excreta and greywater to the consumption of the agricultural product. This approach is captured in the Stockholm Framework (see chapter 2). Three components are important: system assessment; identifying control measures and methods for monitoring them; and developing a management plan. System assessment and its components are discussed in section 6.2.

The combination of health protection measures adopted in a particular excreta and greywater use scheme requires regular monitoring to ensure that the system continues to function effectively. Monitoring, in the sense of observing, inspecting and verifying, is not sufficient on its own. Institutional arrangements must be established for the information collected in this way to provide feedback to those who implement the health protection measures. The structure of the monitoring system is site specific and may vary in size and function, but its planning and operation will be concentrated around simple questions, such as:

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

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

6.1 Monitoring functions

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

Table 6.1 Definitions of monitoring functions

Function	Definition
Validation	Testing the system and its individual components to obtain evidence that they are capable of meeting the specified targets (i.e. microbial reduction targets). Should take place when a new system is developed or the treatment is changed.
Operational monitoring	The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a control measure is operating within design specifications. Emphasis is given to parameters that can be measured quickly and easily and that can indicate if the system is functioning properly. Operational monitoring data should help managers to make corrections that can prevent hazard break-through.
Verification	The application of methods, procedures, tests and other evaluations, in addition to those used in operational monitoring, to determine compliance with the system design parameters and/or whether the system meets specified requirements (e.g. microbial testing for *E. coli* or helminth eggs).

Source: Adapted from NRMMC & EPHCA (2005).

6.2 System assessment

The first step in developing a risk management system is to form a multidisciplinary team of professionals with a thorough understanding of different aspects of the system for recirculation of excreta or greywater as resources. Typically, such a team would include agriculture experts, engineers, environmental health specialists and public health authorities. In most settings, the team would include members from several institutions, and there should be some independent members, such as from universities.

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

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

6.3 Validation

Validation is concerned with obtaining system evidence on the performance of control measures, both individually and collectively. It should ensure the system's capability

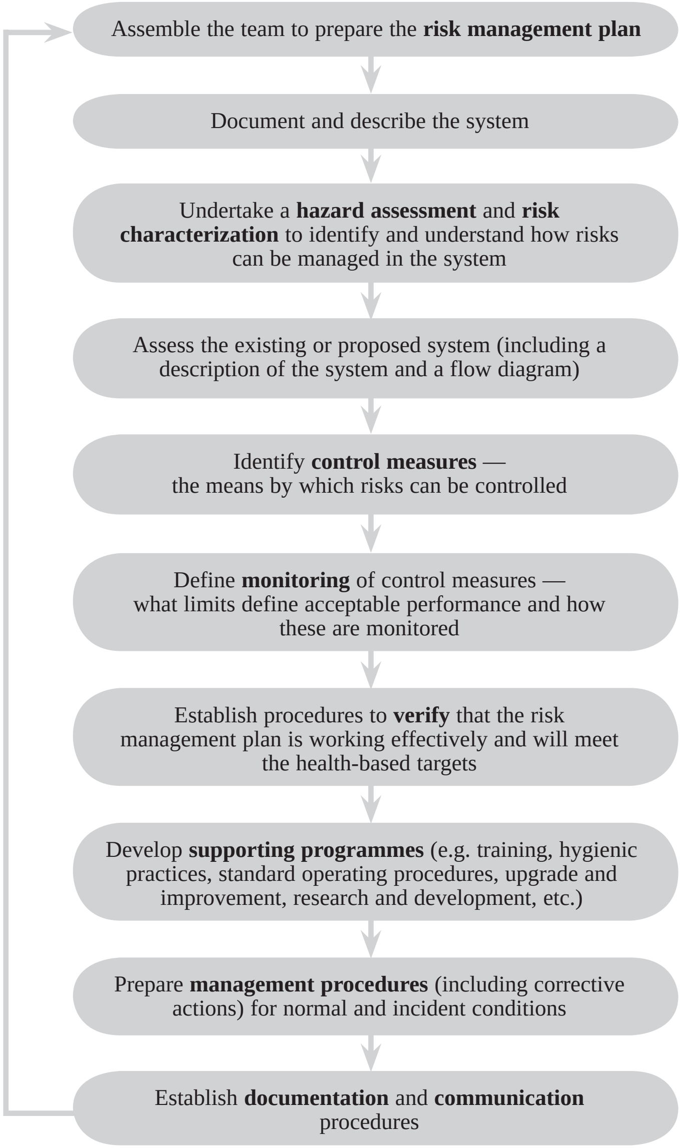

Figure 6.1
Development of a risk management plan (WHO, 2004a)

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

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

6.4 Operational monitoring

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

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

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

Control measures (numbers refer to control points in Figure 6.2)	Validation requirements	Operational monitoring parameters and technical measures	Verification monitoring
Excreta and greywater treatment	Effectiveness of treatment processes at inactivating/removing pathogens and indicator organisms (*E. coli*, trematode eggs, other helminths, e.g. *Ascaris*)	Parameters ensuring sufficient treatment, design, limiting vector transmission and secondary transmission and reducing personal contact	For faeces and greywater: *E. coli* Helminth eggs (*Ascaris*) For urine: Faecal cross-contamination
1. Toilet	Reduction efficiency against enteric bacteria, viruses and parasites	Design that facilitates cleaning, elevated and/or lined collection chamber (no seepage to groundwater or environment), fly control measures (tight-fitting lid, ventilation pipe with screen) Clean water and soap for hand washing available	Ensure appropriate construction and use

Table 6.2 (continued)

Control measures (numbers refer to control points in Figure 6.2)	Validation requirements	Operational monitoring parameters and technical measures	Verification monitoring
II. Primary handling – collection and transport	Reduced direct contact with insufficiently treated material	Adequate storage time in double-vault toilets Ash, lime or other means of reducing microorganisms at toilet Collecting and transporting mechanisms that reduce contact, e.g. removal containers Gloves, washing hands, personal protection	Ensure adequate handling and adequate treatment
III. Treatment	Reduced direct contact with insufficiently treated material and environmental contamination	Suitable choice of location; treatment in closed systems; information signs in place Wearing gloves and protective clothing; washing hands; avoiding contact in treatment areas	Ensure adequate handling and adequate treatment
Health and hygiene promotion	Testing of promotional materials with relevant stakeholder groups	Local programmes in operation Promotional materials available Promotion included in school curriculum	Increased awareness of health and hygiene issues in key stakeholder groups Improved practices
IV. Secondary handling – use, fertilizing	Reduced direct contact with insufficiently treated material and environmental contamination	Wearing gloves Washing hands Equipment used	Informed farmers using excreta Special equipment available
V. Fertilized field	The amount of time needed for pathogen die-off under different climatic conditions and for different pathogens/ indicators between waste application and crop harvest to ensure minimal contamination	Working excreta into the ground Information and signs Avoiding overfertilization	Analyse plant contamination
VI. Fertilized crop –produce restriction	Survey of product consumers to identify species always eaten after thorough cooking Analysis of marketability of different species/crops Economic viability of growing products not for human consumption Harvesting, transport and trade Consumption Contamination of hands, kitchen utensils, food	Harvesting and transport practices Withholding time between fertilization and harvest Types of crops grown in excreta use areas Crops cooked before eating	Testing of excreta/greywater to ensure that it meets WHO microbial reduction targets Proper preparation and cooking of food products Domestic and food hygiene Hand washing

Figure 6.2
Elements of an excreta monitoring system

The frequency of operational monitoring varies with the nature of the control measure. If monitoring shows that a limit does not meet specifications, then there is the potential for a hazard break-through. For the treatment of excreta, storage time and temperature can be monitored to indicate pathogen inactivation. The emptying process, either for on-site units or for faecal sludge, the transportation system as well as the withholding time on the fields are other examples of simple monitoring. For a greywater system, the faecal cross-contamination and following adequate treatment are central. Open greywater systems should be controlled for mosquito breeding. For faecal sludge, the indiscriminate dumping of chemicals may warrant control. In most cases, operational monitoring will be based on simple and rapid observations or tests rather than complex microbial or chemical tests. Instead, these may be a part of validation and verification activities rather than of operational monitoring. Monitoring needs to be conducted in such a way that it provides statistically meaningful information (e.g. sample duplicates), is directed at controlling the most important hazards and can inform changes to health protection measures. A monitoring programme should be designed in such a way that it can be performed within the technical and financial resources of any given situation. The objective is timely monitoring of control measures with a logically based sampling plan, to minimize negative public health impacts (WHO, 2004a).

6.5 Verification

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

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

6.6 Small systems

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

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

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

6.7 Other types of monitoring

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

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

7

SOCIOCULTURAL ASPECTS

Human behaviour is a key determinant of the transmission of excreta-related diseases. The feasibility of changing certain behavioural patterns in order to optimize safety in the introduction of excreta or wastewater use schemes or to reduce disease transmission in existing schemes can be assessed only with a prior understanding of the cultural values attached to the social preferences that determine behaviour and practices. Cultural beliefs vary so widely in different parts of the world that it is not possible to assume that any of the practices that have evolved in relation to excreta and wastewater use in one place can be readily transferred elsewhere; a thorough assessment of the local sociocultural context is always necessary. There appears to have been a positive correlation, however, between the phenomenon of traditional "waste" use in societies and their population density. This is referred to as the "nutritional imperative." Societies that use excreta or have used it in the recent past in agriculture or aquaculture are the most densely populated: Europe, India, China and South-east Asia (Edwards, 1992).

Culture varies, and social groups have their own norms and practices with respect to excretion, which will vary with age, gender, education, class, religion, marital status, employment and physical capacity (Tanner, 1995). Social change may put attitudes and norms under pressure, depending on what is considered modern or fashionable or what customs can be retained in new environments (Drangert, 2004b). They may also evolve as technology advances and governance structures and procedures are updated. Sociocultural aspects of excreta and greywater use in agriculture are outlined in the sections below.

7.1 Perceptions of excreta and greywater use

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

In Africa, the Americas and Europe, use of fresh excreta is generally regarded with disaffection. However, conditioning makes caretakers perceive faeces of children and elderly as inoffensive, and the same applies to one's own faeces. Products fertilized with raw excreta are regarded as tainted or defiled, but large agricultural areas in many countries are fertilized with raw sewage, and the products find consumers (see Volume 2 of the Guidelines). Negative views are less articulated in relation to excreta-derived compost or wastewater sludge commonly used in agriculture, horticulture and land reclamation schemes.

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

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

In many countries, sanitation facilities that produce fresh excreta, such as bucket latrines, are being replaced by those that do not, such as pour flush toilets. This trend is actively promoted by many governments putting into place pour flush toilets, VIP toilets and urine-diverting toilets. The rationale is not only improved health, but also "society's demand for doing away with the demeaning practice of human beings carrying nightsoil loads" (Venugopalan, 1984). From the viewpoint of excreta-related disease control, this should be welcomed, as the risks to health are substantially reduced. Perceptions about urine are rarely documented, but most people entertain a fairly relaxed attitude towards it. Urine has traditionally been used to smear wounds or as an insecticide to kill banana weevils in East Africa. In contrast to raw faeces, dried and composted faecal material has a distinctly different appearance, similar to ordinary soil, and is more acceptable. It is odourless and has a soil-brown colour that reminds people of soil conditioner. Cultural avoidance of handling well processed composted faecal material is little reported.

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

A common practice in areas with flush toilets where recurring interruptions in water supplies are frequent is the collection by residents of greywater from washing machines and showers to use it for flushing the toilet. In water-scarce areas, residents sometimes unplug greywater taps and use this for watering the garden in periods of restrictions. In parts of India, villagers may bring along the day's greywater to the person who has milk cows as partial payment for the milk (H.C. Sharatchandra, personal communication).

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

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

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

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

7.2 Food-related determinants

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

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

7.3 Behavioural change and cultural factors

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

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

Studies of alternative sanitation in housing areas show that residents may be willing to take on new responsibilities for environmental reasons. Among users, criteria such as privacy, convenience, cost and ease of construction or maintenance are, however, often considered more important in system selection than the protection of human health or the environment (Guzha & Musara, 2004; Holden, Terreblanche & Muller, 2004). The absence of flies and odour in correctly maintained urine diversion toilets and their permanent structures, allowing them to be built directly onto a house, have proven to be important factors in their widespread use in areas of South Africa, where they are seen as a modern sanitation alternative (Drangert, 2004a).

Behavioural change regarding toilet use has occurred rapidly when local conditions have created an imperative for the recovery and use of excreta and/or greywater (Wirbelauer, Breslin & Guzha, 2003), such as a need for improved sanitation or for the products, such as fertilizer, soil conditioner or biogas. Physical conditions, such as high water table, regular flooding as well as rocky areas with high cost for digging trenches in the area, may prevent conventional sanitation solutions; instead, dry urine-diverting toilets may represent an affordable alternative to improve sanitation. For coastal estuaries as well as waterlogged areas occupied by the urban poor, technically sound and socially acceptable solutions may be found. In dry areas with poor soils, use of greywater and treated excreta may become a driving force for improved sanitation, since application will make urban agriculture possible, as has been demonstrated in West Africa.

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

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

Educational efforts can be directed at school children — for example, informing them about helminth infections, their life cycles and preventive measures against transmission. Encouraging workers to use protective gear (e.g. rubber boots and gloves) while harvesting or handling crops/products will reduce exposure to infectious agents, and improving hygienic practices (handwashing!) during produce handling, transport and produce preparation for consumption is very important. Communities should educate people about the risks associated with contact with untreated excreta. Direct work with farmers to restrict the types of produce grown in excreta-fertilized fields is advocated.

In many cases, it will be possible to tie efforts to achieve hygienic behavioural changes through education to ongoing agricultural extension and health outreach activities (Blumenthal et al., 2000). However, health interventions should focus on a few key specific behaviours to be successful and may work better if social and cultural reasons for changing hygienic practices are emphasized rather than motivation building on health benefits (Curtis & Kanki, 1998; Blumenthal et al., 2000). The acceptance of a change in sanitary practices is facilitated when users have been given the opportunity to examine and identify their own problems and are offered a wider choice of sanitation systems. "Seeing is believing" has also proved important in overcoming reservations concerning the use of certain systems, particularly when people have had the opportunity to visit them in the homes of neighbours or peers. The equipment and treatment used, the necessary maintenance and the recycled resources available and their form have to be both economically affordable and socially and culturally acceptable. This can best be achieved with the active participation of all relevant stakeholders in planning processes, as is conceived by the PHAST method (see section 11.2.1; WHO, UNDP & WSP, 1997; WHO, 2004a).

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

7.4 Convenience factors and dignity issues

Convenient use and operation have proven to be of crucial importance for users of sanitation facilities, including the level of comfort, privacy and security. The cost to construct and maintain installations is another important consideration. Many users who have changed to urine-diverting systems from pit or VIP latrines appreciate the level of comfort that, by their perception, is comparable with that of water toilets. When permanently installed in the house, they are more convenient for use day and night and provide security for women and girls who would otherwise be exposed to the risk of sexual harassment when visiting external toilet facilities. Permanent in-house structures receive a great deal of attention and have therefore become status symbols in some areas. They can also be adapted to accommodate different anal cleansing practices (Drangert, 2004a).

One of the greatest perceived inconveniences of these systems is the need for handling of faeces. During this activity, the exposure should be minimized. It has implications for the esteem that the community at large attributes to those engaged in it. In some parts of southern Africa, the practice of collecting and using someone else's excreta is looked upon unfavourably. However, an example from South Africa shows that with the right economic incentives, it may be acceptable (Drangert, 2006). In this case, a contractor collects the dry faeces and is paid by the residents for this service. The residents view him as a service provider. He, in turn, runs a successful company, recovering the nutrients and selling the treated product back to the residents.

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

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

7.5 Gender aspects on use of excreta and greywater

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

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

Another indication of deviation from male responsibility in East Africa (Drangert, 2004b) relates to the choice of locating the urine-diverting toilet inside the house or in the backyard. Male heads of households often opt to have the toilet in the yard, while female heads prefer that the toilet be indoors. This reflects the perceived benefits of the indoor toilet for women's household chores, while men tend to undervalue female benefits and talk instead about the risk of a bad odour. Also, men generally have more options for excreting; they work outside the home more often and can use the facilities at the workplace or elsewhere. The gender perspectives on sanitation systems that intentionally recover and use excreta and greywater have not yet been specifically explored. Women are actively involved in food crop production and concerned about food security. They would be directly affected by increased access to soil nutrients provided by such systems. Access to a ready supply of fertilizer will help to increase food production and facilitate the development of small vegetable gardens and fruit trees close to homes.

Given women's overall prime responsibility for the health and well-being of families in many areas, it may also be assumed that they would support such systems on the basis of health gains. Women's support would also be critical for the success of different methods to treat faeces and ensure a sufficient reduction in pathogens. Since women have the responsibility for tending the cooking fires, their involvement could be used to ensure a supply of ashes to be used in the latrines. Men construct the latrine, and it may be assumed that they would appreciate not having to construct a new latrine and pit each time the old pit is filled. The possibility of simply emptying the toilet chamber and continuing to use it must be positive from a labour expenditure point of view. However, this task has to be done on a regular basis, which makes it different from typically male household tasks. Both women and men need access to cash incomes and would be assumed to welcome the potential economic benefits of excreta and greywater use, if the opportunities for small-scale entrepreneurship in construction of sanitation facilities and starting small market gardens are made available to both women and men. In India, the fertilizer value of a family's excreta can pay for the investment in a urine diversion toilet within four years (Jönsson et al., 2005).

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

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

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

Experience from Zimbabwe (Morgan, 2005) indicates that women in rural areas prefer the sanitation alternative offered by the arbour loos (an "arbour loo" is a simple form of latrine with a shallow pit, with a light, moveable slab. When the pit is three quarters full, a new pit is dug, and the slab and superstructure are moved to the new site. The old one is covered with topsoil, in which a fruit tree is planted) to the conventional pit latrines, as they can be built closer to the house. Women expressed appreciation of the gains in terms of privacy and safety, particularly for children, in night use. Women also consider the use of the filled pits for planting fruit trees beneficial. Having the fruit trees close to the house enhances the potential for tending them properly, particularly in terms of being able to use the greywater from bathing and dish washing for watering. Men expressed appreciation of the arbour loos because the pits are smaller than conventional pit latrines and building them requires less labour. These findings are, however, based not on well documented empirical data but on the observation of practitioners working in the communities.