3.4 Health targets

Which targets can be achieved in relation to exposure and treatment?

How are barriers used in guidelines to minimise health risks?

Learning objective: *To know and be familiar with faecal indicators and the risk concept and to understand their application in guidelines for reuse of excreta and greywater.*

A growing world population, unrelenting urbanization, increasing scarcity of good quality water resources and rising fertilizer prices are the driving forces behind the accelerating upward trend in the use of wastewater, excreta and greywater for agriculture and aquaculture (according to e.g. WHO).

The health risks associated with this practice have been long recognized, but regulatory measures were, until recently, based on rigid guideline values whose application often was incompatible with the socio-economic settings where most wastewater use takes place. In 2006, WHO published a third edition of its *Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture*. In four volumes, these guidelines propose a flexible approach of risk assessment and risk management linked to health-based targets that can be established at a level that is realistic under local conditions. The approach is to be backed-up by strict monitoring measures.

In this module the background and the purpose of these guidelines are described. How barriers in general can be used in regulations and guidelines to minimise exposure and health effects is further elaborated on. The potential of various types of monitoring in sanitation systems is also included. In order to cover these aspects two major issues need however firstly to be explained – the faecal indicator concept and the concept of microbial risk assessment.

A more direct view on the important barrier treatment is included in chapter 4.

What is a faecal indicator organism?

- Used to indicate faecal contamination – from human faeces, sewage, animals, etc.

Why do we need to use indicators?

- There are hundreds of pathogens
- Pathogens are often present in low concentrations – hard to detect
- Pathogens are difficult and expensive to analyse

A faecal indicator organism is analysed to see whether a sample (of e.g. water) is contaminated by human or animal faeces, by sewage or other waste that contains excreta from humans or other warm-blooded animals. The purpose is that the presence of the indicator will give us the knowledge if there is a risk to be infected by enteric pathogens when exposed to the material (e.g. the water). Indicators are needed, and used instead of pathogens, since there are hundreds of pathogens that theoretically could be analysed for. Since pathogens often are present in low concentrations, compared to indicators, they are hard to detect and it would often be like looking for a needle in a haystack. Furthermore, it is often difficult and expensive to analyse for indicators.

Ideal features of a faecal indicator

- A member of the intestinal microflora
- Present in greater numbers than the pathogen
- Do not multiply in the environment
- Non-pathogenic
- Present simultaneously as pathogens
- Equal resistence as pathogens
- Can be detected with easy, rapid and affordable methods

- There is no ideal indicator !

The ideal features of a faecal indicator are:

That it is a natural member of the intestinal microflora,

That it is present in greater numbers than the pathogen,

That it does not multiply in the environment,

It should be non-pathogenic and

Present simultaneously as pathogens.

It should have approximately equal resistance as pathogens and it should be able to detect with easy, rapid and affordable methods.

These criteria are hard to fulfill and consequently there is no ideal indicator but even so they can be useful both in research and in regulations as we will see.

Indicator	Key feature
Total coliforms	Abundant occurrence
E. coli	Faecal-specific indicator
Faecal streptococci	More persistent than *E. coli*
Sulphite-reducing clostridia	Most persistent indicator
Bacteriophages	Similar to human viruses
Coprostanol	Human faecal biomarker

Total coliforms is present in faecal material but can also be found in other material such as soil and is therefore not specific for faecal pollution.

E. coli is specific for faeces and is considered a faecal indicator. There are however, specific, much more unusual strains that can be pathogenic (disease-causing).

Faecal streptococci are often considered more persistent than *E. coli*, for example i sea water. Clostridia can be said to be the most persistent indicator since this bacteria is spore-forming, a dormant stage that can withstand most environmental pressures and requires sterilization for elimination. Bacteriophages are viruses that infect bacteria and can thus be useful in studies investigating viral behaviour, e.g. as in transport in soil (module 3.2). Coprostanol is a chemical indicator that will be further described later on in this module.

Faecal indicators – abundance in faeces

Indicator	% presence	Density in faeces [per g]
Total coliforms	87-100	10^7 - 10^9
Faecal or thermo-tolerant coliforms	96-100	10^6 - 10^9
E. coli (presumtive)	87-100	10^7 – 10^9
Faecal streptococci / Enterococci	100 (74-76)	10^5 – 10^6
Clostridia	13-35	10^6 – 10^7
Coliphages	?	$<10^3$

(Geldreich 1978, Havelaar et al. 1991)

Abundance in faeces varies according to this table. Faecal or thermotolerant coliforms is part of the total coliform group, that can grow at higher temperatures, and is more specific for faecal contamination. As can be seen faecal streptococci are similar to enterococci, the terminology has been changed over the years, and nowadays faecal enterococci is the group that is analysed, but approximate comparisons of results and conclusions from studies using any of the terms are still valid. One disadvantage with clostridia is that they are not present in all humans, and they can also be found in other materials such as soil. Coliphages are the bacteriophages that have *E. coli* as a host (varying strains).

Presence in different media

Concentrations of indicator bacteria in faeces, incoming and outgoing wastewater from wastewater treatment plants and in raw sludge

Indicator bacteria	Faeces [cfu/g ww]	Raw wastewater [cfu/ml]	Raw sludge [cfu/g ww]	Treated wastewater [cfu/ml]
Total coliforms	10^7-10^9	10^3-10^5	10^6-10^8	10^1-10^3
E. coli	10^7-10^9	10^3-10^5	10^5-10^7	10^0-10^3
Enterococci	10^5-10^7	10^3-10^4	10^4-10^6	10^1-10^2
Clostridia	10^5-10^6	10^2	10^3-10^5	10^0-10^1

(Geldreich 1978; Stenström 1996; Sundin 1999)

Another table, with slightly different numbers, present indicators in faeces, incoming and outgoing wastewater from wastewater treatment plants, and in raw sludge. The purpose is to give an indication of reduction of indicators in wastewater treatment. It can also be seen that a concentration of the bacteria occurs in sludge, i.e. the content is higher than in wastewater but still lower than in faeces. This gives an implication of the risk level associated with the different waste flows.

How can we use the indicators?

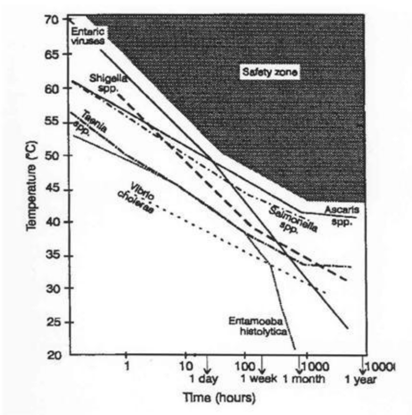
- An *indicator* indicates presence of other organisms, i.e. pathogens
- An *index organism* mimics the behaviour of another organism
  - e.g. the reduction of clostridia for *Cryptosporidium* in drinking water treatment
- A *model organism* - an organism representing a whole group of organisms
  - e.g. rotavirus representing enteric viruses in risk assessments

Besides being an actual indicator of presence of pathogens, organisms can be used as substitute for a specific pathogen for other reasons. The terminology may vary but an index organism can be said to mimic the behaviour of another organism. There are for example studies of water treatment processes where clostridia spores are used instead of Cryptosporidium oocysts. A model organism can be said to represent a whole group of organisms, e.g. it may not possible to analyse for several viruses, or include them all in risk assessments, and therefore rotavirus was chosen as a model organism in a risk assessment of urine (see module 3.5). It is however important that two different organisms never will have the exact same behaviour or constitute the exact same risk.

How can we use the indicators?

- If Ascaris has been killed during treatment of excreta, all other pathogens are probably inactivated as well – Ascaris functions as a process indicator
- Bacteriophages have been used as tracers, i.e. modelling the transport of viruses in soil

Temperature – safety zone



(Feachem 1983; EC 2001)

Ascaris eggs are considered to be hardy organisms, as illustrated by the graph where Ascaris is more persistent to temperatures around 40-45°C than the other organisms included. Even if this is not an exact truth (more research studies have been performed since 1983 when the graph was first published), it gives an indication of that Ascaris can function as a process indicator, i.e. if the eggs have been inactivated or killed it can be concluded that other pathogens that are a potential risk also have been killed and thus the material (e.g. the faecal matter) can be considered safe for reuse. However, as explained in module 3.3 and later on in 3.4, a multiple barrier approach is recommended, and verification monitoring is not a tool on its own in sanitation systems.

As described in module 3.2 bacteriophages can be used as tracers for e.g. transport in soil and they can then be called as model organisms as well. They can also function as a tracer, model or process indicator if looking at their removal in water treatment processes such as sand filtration. Thus, the terminology is in many respects a bit mixed.

Indicators for water and wastewater quality

Examples:

- Drinking water – heterotrophic bacteria, E. coli
- Recreational water – E. coli, total coliforms (previously), faecal streptococci (EU)
- Excreta and wastewater (for irrigation) – coliforms, intestinal nematodes (WHO 1989)
- Sewage sludge – coliforms, Salmonella, (Ascaris, viruses – validation, US EPA)
- Guidelines & regulations – now rely less on indicators

The indicators are also commonly used in quality standards (regulations) or guidelines. Especially in water it is valid to analyse for their presence to investigate potential risks, e.g. if the indicators are present, it is likely that a contamination has occurred and it is then possible that faecal pathogens are also present. In drinking water heterotrophic bacteria is a general measure of bad quality or failure in the treatment processes and E. coli indicates that a potentially hazardous contamination has occurred. For recreational water – E. coli, total coliforms (previously), faecal streptococci (EU) has been used as a quality measure. For excreta and wastewater (for irrigation) coliforms and intestinal nematodes was used in the former WHO guidelines (WHO 1989). The present requirements for verification monitoring are presented further on in this module. For sewage sludge the quality requirements vary between countries, some include coliforms and Salmonella. The US EPA uses Ascaris and viruses for validation purposes, e.g. to see that a process has the potential of sufficient pathogen reduction.

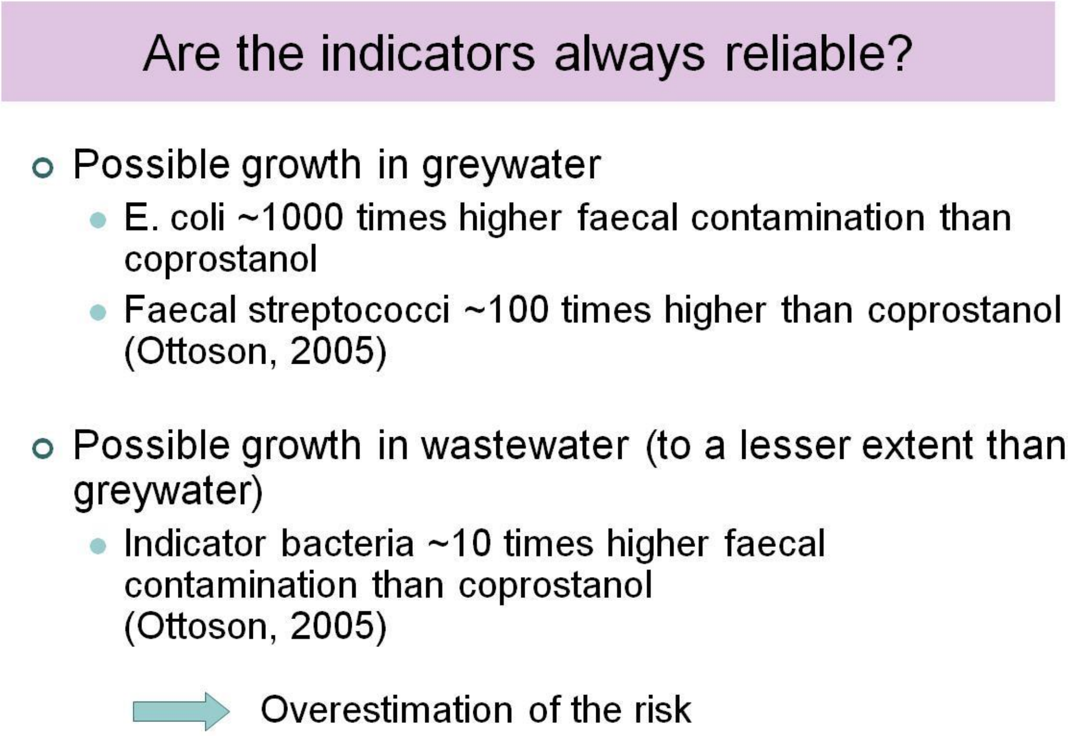
Guidelines and regulations for waste products now rely less on indicators and rather focuses on combinations of safety measures. Also in drinking water production (as in food production), the HACCP idea (Hazard Analysis and Critical Control Points), where controls are made at several points in the process. Monitoring the whole chain is preferred and HACCP implemented, rather than only relying on control of the end-product. In this way higher safety for consumers and protection of their health is obtained.

Alternative indicator

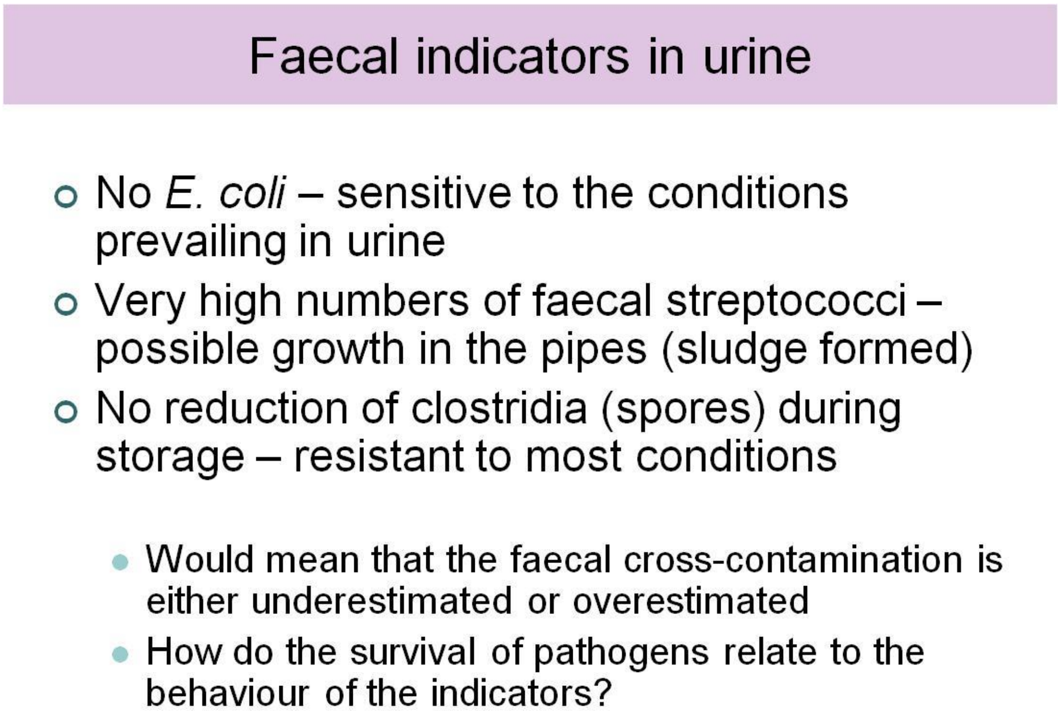
- Faecal sterols, e.g. coprostanol, cholesterol
- Chemical indicator found in faeces, with the exception of very young children
- Not used routinely
- Have been used for research purposes
  - Tracing the origin of faecal pollution (human/animal)
  - Estimating faecal contamination (used in risk assessments)

Faecal sterols, e.g. coprostanol and cholesterol are chemical compounds found in faeces, with the exception of very young children.

It has not been used routinely so far, mainly for research purposes such as tracing the origin of faecal pollution (to see whether it has human or animal origin) or estimating faecal contamination that may be necessary for input in risk assessments, as the example given in module 3.5.



How reliable are the indicators in the respect of estimating faecal contamination and associated pathogen risk? Comparing the concentration of coprostanol and the density of faecal indicator bacteria in greywater resulted in about a 1000 times higher degree of faecal contamination if using the results for *E. coli*, and about a 100 times higher degree of looking at faecal streptococci. This ought to be the result of bacterial growth, since coprostanol is stable in greywater (as well as in wastewater and urine). It is also possible for bacteria to grow in mixed wastewater as was indicated by the 10 times higher contamination comparing faecal streptococci to coprostanol. It can thus be concluded, that if analysing for these indicator bacteria in greywater or wastewater the risk for exposure to pathogens will be overestimated.



In the research performed in Sweden on risks related to reuse of human urine (further described in module 3.5) it was found that no *E. coli* were present in the collected urine (in samples from urine collection tanks). On the other hand high numbers of faecal streptococci were found. It was later on found that *E. coli* are killed within days and that faecal streptococci could grow in the sludge formed in the urine pipes (leading from the toilet). Thus, neither of these bacteria had any value of indicating the degree of faecal contamination (occurring by misplacement of faeces in the urine diverting toilet). Furthermore, there was no reduction of clostridia spores, which supports the known resistance of this indicator.

Alternatives for guidelines/recommendations
– related to sanitation and agricultural practises

- Quality guidelines (e.g. WHO)
  - indicators limited value
  - expensive, time-consuming to monitor
- Process guidelines (e.g. sludge treatment)
  - monitoring of process parameters
  - validation may be needed
- Other practical recommendations
  - e.g. restrictions for use
- Combinations of the above

Regulations and guidelines, which usually are considered as recommendations and not legally binding, can be designed in different ways. If we consider waste fractions or water there can be quality guidelines. That is set limits for what the material is allowed to contain. We have for example the WHO guidelines for wastewater and excreta where such limits are set for faecal coliforms and intestinal nematodes (see coming slides in this module). As described, we are often dependent on faecal indicators since analytical methods for pathogens generally are time-consuming and expensive, and since there are such a wide range of pathogens that could be tested. (However, nematode eggs may be considered a hardy organism, implying that if these eggs are inaactivated then also other pathogens are inactivated.) The value of faecal indicator bacteria have been questioned since pathogens may be more resistant to a treatment or environmental conditions.

Process guidelines are another alternative, where it is assumed that a given process achieves the reduction needed for the product to be safe. Regulations for sewage sludge are an example where different processes are given. To ensure that the methods accomplish what is believed, validations initially or on a regular basis may be needed.

Regulations and guidelines may also include practical considerations, for example not using the fertilizer product on certain crops, as also will be shown later on in this module.

The regulatory framework related to sanitation and agricultural practises varies between countries. In Europe, some countries do not allow the use of human excreta, whereas for example the Swedish EPA has proposed to specifically address urine in their revised regulations, formerly mainly including sewage sludge, where proper treatment to reduce pathogens in waste products and agricultural use in order to recycle phosphorous and nitrogen are crucial parts. Within the Swedish-based EcoSanRes programme aimed at developing countries, guidelines related to hygiene, agriculture and technology have been developed for treatment and use of urine, faeces and greywater (www.ecosanres.org). The different types of recommendations could of course be combined, which also is proposed by e.g. WHO and the Swedish EPA.

Recommendations for the use of human urine – large systems

Storage temperature	Storage time	Pathogens in the urine*	Recommended crops
4°C	>1 month	viruses, protozoa	food and fodder crops that are to be processed
4°C	>6 months	viruses	food crops that are to be processed, fodder crops
20°C	>1 month	viruses	food crops that are to be processed, fodder crops
20°C	>6 months	probably none	all crops

Inactivation affected by pH (~9) and ammonia, avoid dilution of the urine

*From potential faecal cross-contamination and possibly remaining after storage

For urine storage is the recommended treatment method. Pathogens will be affected by the elevated pH (around 9), ammonia and the temperature, that in turn depends on climate. These recommendations were originally developed for Swedish conditions and therefore based on inactivation of microorganisms at quite low temperatures. Depending on storage conditions the urine is recommended for use on different types of crops, where a shorter time is needed for processed crops compared to vegetables. The guidelines from WHO regarding urine builds on this table but addresses higher temperatures in the text. Furthermore, more recent results for pathogen reduction during storage at higher temperatures is available from Swedish research, supporting the current recommendations, but also stating that the storage time could be decreased at higher temperatures.

No indicator value is included in guidelines for reuse of urine, basically for the reasons described above (growth and rapid inactivation of indicator bacteria) and it is not considered viable to analyse for presence of pathogens since they probably seldom are present, and IF present, in low densities.

Recommendations for the use of human urine

- For crops that are to be consumed raw, one month should pass between application and harvesting (withholding/waiting period)
- For single households the urine mixture can be used for all type of crops, provided that
  - the crop is intended for own consumption
  - one month passes between fertilisation and harvesting
- Can we apply even simpler or less strict guidelines for urine?
  - Compared to faeces – low risk (high fertiliser value)
  - If system seems to function well – no visible faecal cross-contamination
  - Information to workers (e.g. farmers) handling the urine
  - Shorter storage at higher temperatures?

The former table is valid for large systems, i.e. where the collected urine is used outside the household from where it was collected. For crops that are to be consumed raw, one month should pass between application and harvesting (withholding/waiting period). For single households the urine mixture can be used for all type of crops, provided that the crop is intended for own consumption and that one month pass between fertilization and harvesting. This can be recommended since the risks from reusing urine within a household are considered low, and more or less insignificant compared to other possible transmission routes.

It has been discussed whether even simpler or less strict guidelines for urine should be applied since the risk is low (and the fertilizer value high) compared to faeces. If a system seems to function well with no visible faecal cross-contamination and information to workers (e.g. farmers) handling the urine, shorter storage could perhaps be considered. And, as discussed, shorter storage at higher temperatures could be recommended. It can also be mentioned that urine collected from urinals is considered safer, and storage times could be shortened.

Why risk assessment?

- Surveillance systems underestimate number of cases
- Emerging pathogens
- Indicator organisms
  - Coliforms, enterococci, clostridia, bacteriophages
  - Difficult to detect pathogens
- Epidemiological investigations
  - Limited detection level
  - Expensive
  - Retrospective
- To refine the establishment of guidelines
- Prospective studies
  - Compare ”future” systems, e.g. sanitation systems

The area of microbial risk assessment is rather new but now much requested.

Some reasons to do microbial risk assessments include:

- We want to find out how many individuals that actually may be infected, and even if risk assessments include assumptions we also know that surveillance systems, that is the official reporting of infectious diseases, underestimate the number of cases.

- There are also new, emerging pathogens that we find out about and to investigate their effect in the society risk assessments may be valuable.

- Indicator organisms may be useful but sometimes they do not relate to the actual pathogen. The pathogen in itself can be hard to detect even if new methods have been developed. Risk assessments may also be a way to interpret what the results from indicator analysis mean.

MRA cannot replace epidemiological studies, but often epidemiological studies cannot be done because they are expensive and also have a limited detection limit. These studies are retrospective and give us information about what actually has happened. However it is often of interest to do prospective studies. One example could be to compare future sanitation systems. As we will see, risk assessments can also be a tool in the establishment of guidelines.

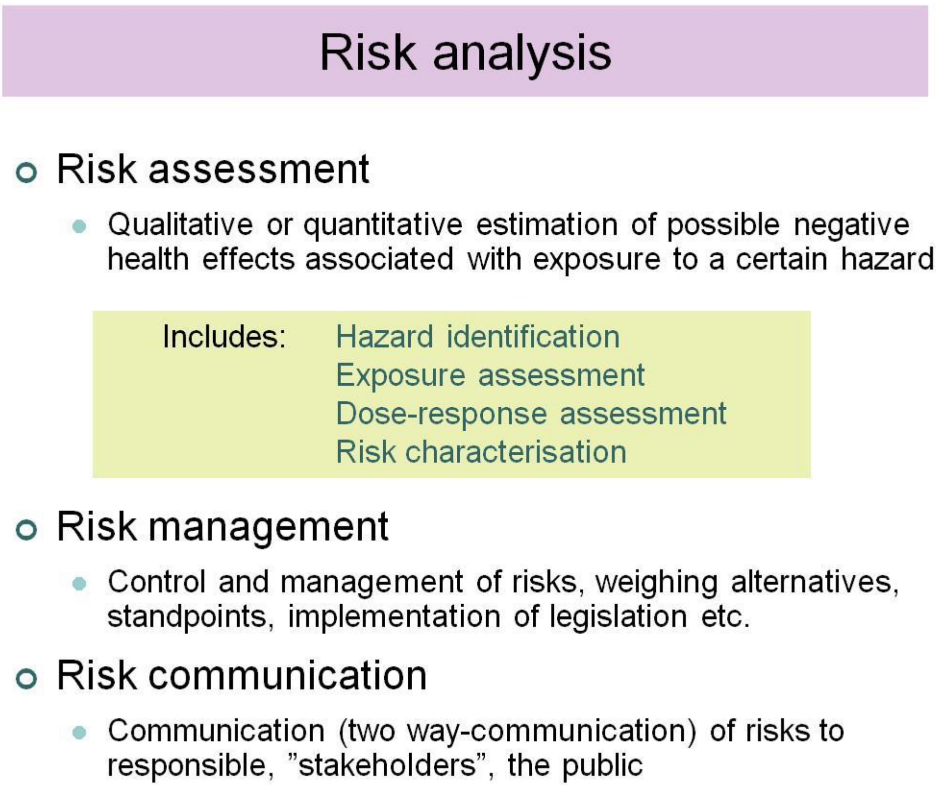
Risk terminology

- Risk
  - The probability of injury, illness or death for individuals, or in a population, at a specific situation/event
  - In quantitative terms the risk is expressed in values between 0 (e.g. harm will not be done) and 1 (harm will be done)
- Risk assessment/analysis
  - The qualitative or quantative characterization and estimation of potential adverse health effects associated with exposure of individuals or populations to hazards (materials or situations, physical, chemical, and/or microbial agents)

(Haas et al., 1999)

Risk can be described as “The probability of injury, illness or death for individuals, or in a population, at a specific situation/event”. In quantitative terms the risk is expressed in values between 0 (e.g. harm will not be done) and 1 (harm will be done).

Risk assessment or risk analysis can be defined as “The qualitative or quantitative characterization and estimation of potential adverse health effects associated with exposure of individuals or populations to hazards (materials or situations, physical, chemical, and/or microbial agents)”.



This is the vocabulary used also for chemical risk analysis, in which microbial risk analysis (or assessment) has its origin. The risk assessment starts by a problem formulation where the hazards are identified, the different transmission routes and exposure scenarios are detected. Then a dose-response assessment is performed and by adding the former exposure information a risk characterization can be done, that is to determine the risk per year or likewise.

The risk management deals with how to handle risks and the need for precautions to be taken. Here other aspects like technology, values and economics may be included.

The risk communication involve as it says the communication of risks to stakeholders etc.

Microbial risk assessment - Examples of application (1)

- Assure the quality of provisions (food) during production and further handling
- From an accepted level of infection in society determine if the drinking water treatment is satisfactory
- In new systems, e.g. local reuse of faeces or greywater, assess different exposures and how the transmission can be avoided
- In comparisons of e.g. different wastewater systems

Further possible applications in more detail include: To assure the quality of provisions (food) during production and further handling; From an accepted level of infection in society determine if the drinking water treatment is satisfactory; In new systems, e.g. local reuse of faeces or greywater, assess different exposures and how the transmission can be avoided; In comparisons of e.g. different wastewater systems such as if a centralized or de-centralized system implies a higher risk.

Microbial risk assessment -
Examples of application (2)

- Predict the “burden” of waterborne diseases in the society during endemic and epidemic situations
- Find the most cost-effective alternative to reduce health risks for food consumers

One of the largest problems with all types of risk assessments is the quality of available data

Microbial risk assessment can also be used to predict the “burden” of waterborne diseases in the society during endemic and epidemic situations and to find the most cost-effective alternative to reduce health risks for food consumers. It is however important to remember that one of the largest problems with all types of risk assessments is the quality of available data and all assessments include a range of assumptions that can only rely on expert judgement.

Methods to estimate the concentration of pathogens – Hazards and exposure (dose)

- Direct counts
  - problematic if the risk density must be below the detection level
    e.g. 500 samples á 2000 L to detect "acceptable" Cryptosporidium risk
- Analysis of index organisms
  - the density assumed to be proportional to pathogen(s)
    e.g. Clostridium perfringens for viruses/protozoa (in water treatment)
- Indirect measurements
  - measure the density in incoming water and the reduction of indexorganism, e.g. 10 Cryptosporidium/20 L raw water and the reduction of Bacillus spores in the treatment plant indicates a 2,9 $\log_{10}$ reduction
- Estimates from e.g. reported cases (surveillance, epidemiological data, urine example)

The hazard identification includes determining what pathogens that are of interest in a specific system. In the exposure assessment the transmission routes need to be identified and then the density (concentration) of the pathogen in the material that people are exposed to need to be determined. However, as stated it is not always easy to take representative samples and analyse for one or several pathogens. Some examples to estimate the concentration of pathogens include:

Direct counts – can be problematic if the risk density must be below the detection level, e.g. 500 samples á 2000 L to detect "acceptable" Cryptosporidium risk can be required in drinking water monitoring.

Analysis of index organisms – here the density of an organism is assumed to be proportional to the pathogen(s) e.g. Clostridium perfringens for viruses and/or protozoa (in water treatment)

Indirect measurements - measure the density in incoming water and the reduction of an index organism. E.g. if it is known that there are 10 Cryptosporidium oocysts/20 L raw water and that the reduction of Bacillus spores in the treatment plant indicates a 2.9 $\log_{10}$ reduction (measured for the spores and applied to the Cryptosporidium oocysts), the density of Cryptosporidium oocysts in the treated water can be calculated.

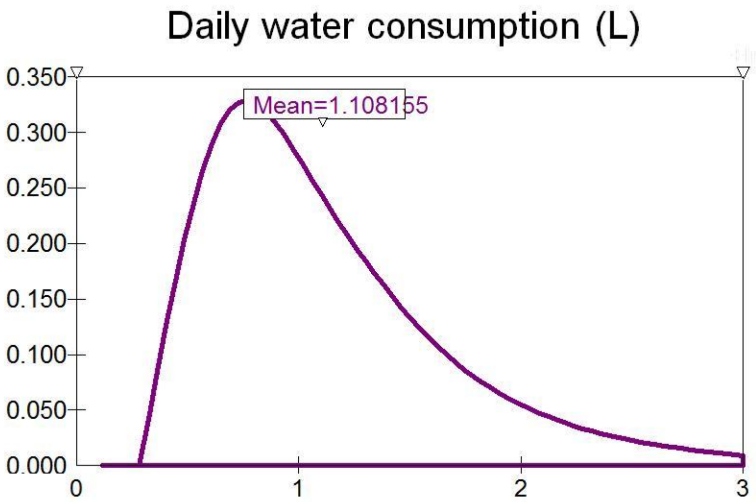
Estimates from e.g. reported cases (surveillance, epidemiological data), is also possible to use (as in the urine example, module 3.5).

Exposure assessment - examples

Exposure	Median	Max	Reference
Shower	6.8 min	20 min	Finley et al. 1994
Ingestion of soil (children)	81 mg/day	5.6 g/day	Calabrese et al. 1989

Data that for example can be needed in an exposure assessment is the duration of a shower (combined with the volume of water that is ingested per minute of showering) or the amount of soil that a child is likely to ingest, or if calculating a worst-case scenario, the maximum amount that can be ingested. Median, minimum and maximum values can all be included in the assessment if the calculations of doses are done using interval estimates (probability density functions) rather than point estimates.

Water consumption - drinking



- American study non-boiled water (Roseberry och Burmaster 1992)
- Large variations in the world

Another example is drinking water consumption that would be needed if calculating risks related to ingestion of drinking water. Large variations occur around the world, and in areas where drinking water quality is unreliable, it is probably uncommon to consume any water that has not been boiled.

Theoretical examples - Exposure

Ex. Ingestion of drinking water

contact rate 1.4 L/day

exposure frequency 365 days/year

if the drinking water is assumed to contain 0,001 virus/L

1.4 x 0,001 = **1.4 x 10^{-3} viruses/day** will be ingested

Ex. Ingestion of bathing water (surface water)

contact rate 50 mL/h

2.6 h/swim

exposure frequency 7 swims/year

→ daily average 7/365 x 2.6 x 0.05 = 0.0025 L/day

If the bathing water is assumed to contain 0.1 virus/L

0.0025 x 0.1 = **2.5 x 10^{-4} viruses/day** will be ingested

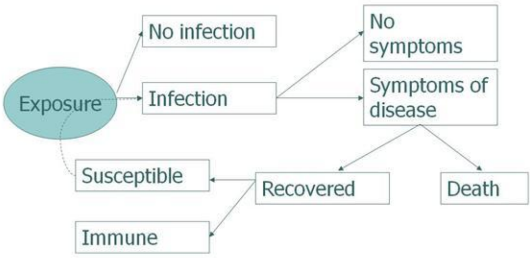
As a simple example from a book on Quantitative Microbial Risk Analysis (Haas, 1999), we have the ingestion of drinking water. 1.4 L is asumed to be ingested per day (the contact rate is1,4 L/day) and water is consumed every day (the exposure frequency is 365 days/year). If the drinking water is assumed to contain 0.001 virus/L, then 1.4 x 0.001 = **1.4 x 10^{-3} viruses/day** will be ingested. (The next step would be to calculate the probability of infection from this dose).

Another example is the bathing water where they make the assumption that a person (accidently) ingests 50 mL per hour of swimming. A (long) swim occurs during 2.6 hours and if swimming is done 7 times a year then the daily average ingestion will be 7/365 x 2.6 x 0.05 = 0.0025 L/day. If the bathing water is assumed to contain 0.1 virus/L, then

0.0025 x 0.1 = **2.5 x 10^{-4} viruses/day** will be ingested (which however can be considered a strange way to look at exposure, since pathogens give a direct effect from a single dose, and not accumulative as can be interesting for chemicals).

Infectious dose

- Minimum infectious dose
- ID_{50}
- Probability of infection
- Dose-response curves
- Clinical manifestation depending on
  - Ingested dose
  - The condition of the mechanical barrier
  - The stability of the normal enteric flora
  - Immunity
  - The nutritional status of the individual
- Calculated from outbreak data



Exposure to, and ingestion of, pathogens do not necessarily lead to infection or disease. To become infected a certain number of pathogens need to be ingested, corresponding to the infectious dose, which varies depending on pathogen/disease and also may vary from individual to individual. Even if an infection is established it does not necessarily involve symptoms. The individual having symptoms will either die or recover (but perhaps having a residual disability). After recovering you are either susceptible or immune to the infection in question. How long the immunity lasts depend on the infection.

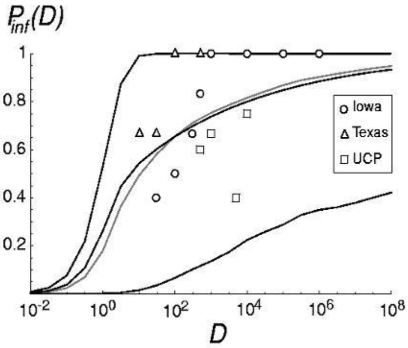
The infectious dose was earlier often reported as the minimum infectious dose – the lowest number of organisms known to result in infection, or as ID50, which is when 50% of the exposed individuals will become infected. More recently the probability of infection has been possible to establish for some pathogens through so called dose-response curves that build on experiments when healthy individuals have ingested a specific number of the pathogen in question.

The severity of the disease and symptoms (i.e. the clinical manifestation of the infection) may depend on the ingested dose, the condition of the mechanical barrier, the stability of the normal enteric flora, immunity and the nutritional status of the individual.

Infectious doses have also been calculated by using data from outbreak situations, where it has been possible to estimate the concentration of pathogens and exposure of a community, and relating this to the infection ratio.

Dose response

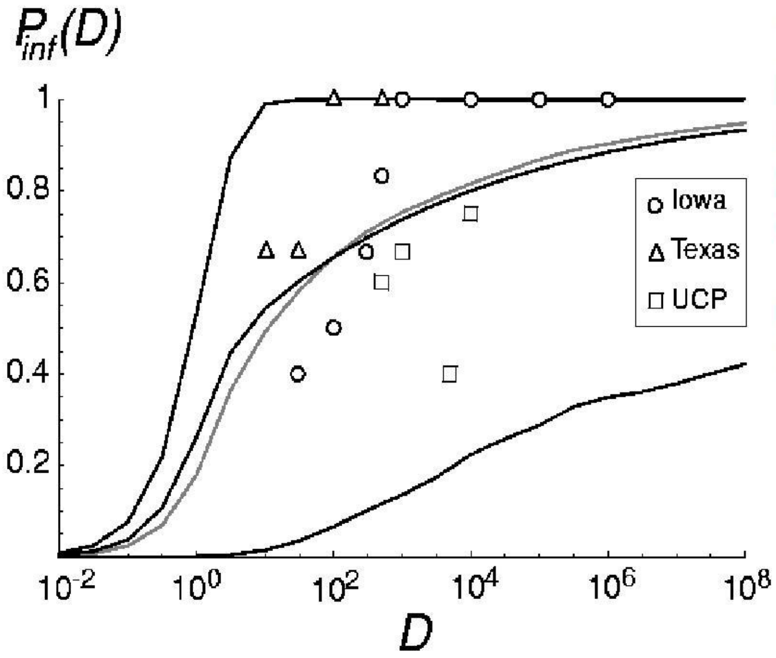
- Fit data from experiments on voluntary persons to mathematical models
- Is available for some organisms, however not for pathogens causing severe illness
- Possibility to fit data from outbreaks to mathematical models
- Probabilities 0-1
  - Infection (P_{inf})
  - Illness (P_{ill})
  - Death (P_{dth})



As stated, the dose-response models often build on experiments where healthy adults have ingested a defined number of pathogens to see if they acquire an infection or not. The data from these experiments are then fitted to mathematical models that can be used in calculations when determining the probability of infection. Such models are of natural causes not available for all type of pathogens, since it is not defendable to have people ingest the most ”dangerous” pathogens, resulting in severe disease. It is also possible to create models by fitting data from outbreaks to mathematical models.

In risk assessments and dose-response modeling, it is of interest to calculate the probability of infection, the probability of illness and perhaps the probability of death.

Hypergeometric model for 3 *Cryptosporidium* (bovine) strains



The graph shows best fitted curves and 95% confidence interval (Teunis *et al*. 2000)

D = dose
P_{inf} = probability of infection

This is an example of dose-response models for the protozoa Cryptosporidium. As can be seen different curves fit to different strains of the pathogen (Iowa, Texas and UCP), in this case the model is fitted to three different bovine (”cow”) strains.

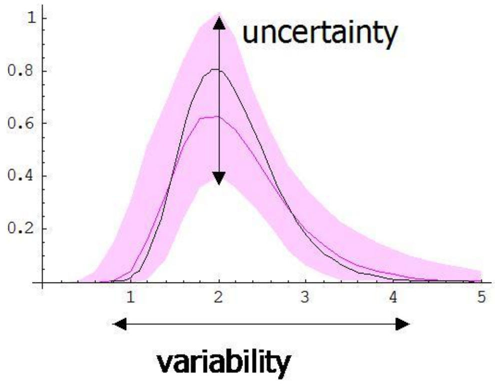
Drawbacks in microbial risk assessment

- Dose-response models based on healthy individuals
- Do not consider vulnerable population
  - The elderly and very young, immunocompromised, pregnant women
  - In total approx. 20% of the population
- Most models do not include a whole population
  - Secondary spread, immunity
  - Dynamic models
  - Requires complicated mathematics

As stated, quantitative risk assessments often include several assumptions in the exposure assessment. There are also other drawbacks, or limitations. The dose-response models are based on healthy individuals and do not consider vulnerable population, e.g. the elderly and very young, immunocompromised, and pregnant women, that constitutes approx. 20% of the population in total. The numbers of pathogens for which dose-response models are available are also limited. Most models do not include a whole population and do not consider secondary spread or immunity. It can be done, but requires dynamic models that are based complicated mathematics. Nevertheless, QMRA are used and accepted as a decision-making tool, that can be a part of a wider system analysis.

Risk characterisation

- Integration of earlier steps for calculation of the probability of infection, and importance in the society. In this step variation and uncertainty in the data used should be discussed.
- ”Variability” – internal variation in your data, can not be reduced
- ”Uncertainty” – variation in the data set, can be reduced by collection of more data (more extensive investigations)



Risk characterization is defined as an integration of earlier steps for calculation of the probability of infection, and importance in the society. In this step variation and uncertainty in the data used should be discussed. If a certain parameter varies widely it can have two separate reasons, either variability or uncertainty. Variability is an internal variation in your data, and cannot be reduced. Uncertainty is related to the variation in the data set, and can be reduced by collection of more data (more extensive investigations).

Point estimates vs interval estimates

- Earlier – only used point estimates in QMRA
- Examples
  - The average concentration of *Salmonella* in wastewater is 25 000 bacteria per liter
  - Wastewater treatment removes 99.9%
  - The infectious dose is 100 000 organisms
- Intervals – the model can get closer to ”reality”
- Variation can be included
  - The concentration of *Salmonella* in wastewater varies e.g. with the prevalence in the conected population
- Random sampling (e.g. 10 000 times) with Monte Carlo simulation or Latin Hybercube
- Example
  - The drinking water consumption can be described as a lognormal distribution with median 0.96 L and 95% confidence interval of 0.34-2.72 L

The numerical values used in the risk calculations are either point estimates or interval estimates. Earlier, only point estimates was used in QMRA, for example:
The average concentration of *Salmonella* in wastewater is 25 000 bacteria per liter; Wastewater treatment removes 99.9%; The infectious dose is 100 000 organisms.

With more advanced computer-based calculations intervals (as probability density functions, PDFs) can be used and the model can get closer to ”reality”. Variation that is obtained in the data collection can be included, as when the concentration of *Salmonella* in wastewater varies e.g. with the prevalence in the connected population. Random sampling (e.g. 10 000 times) with Monte Carlo simulation, or Latin Hybercube, is done of values within the PDF. An example could be the drinking water consumption that is described as a lognormal distribution with median 0.96 L and 95% confidence interval of 0.34-2.72 L.

Modelling in Excel with @Risk

- An add-on programme to Excel
- A free 10-day testversion of @Risk can be down-loaded from http://www.palisade-europe.com/html/trial_versions.html
- More advanced modelling is done in specific mathematical programmes, e.g. Mathematica or MathLab

@Risk is an add-on program to Excel that can be used for such calculations.

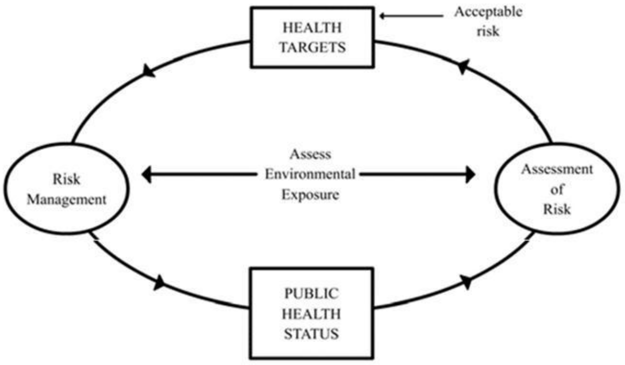
A free 10-day test version of @Risk can be down- loaded from http://www.palisade-europe.com/html/trial_versions.html

More advanced modeling is done in specific mathematical programs, e.g. Mathematica or MathLab.

Examples of risk assessments for sanitation systems are included in module 3.5.

Health-based targets and acceptable risk

- Acceptable risk (suggested)
  - US-EPA (drinking water) 1:10 000 per year (10^{-4})
  - Haas (1996) (waste products) 1:1 000 per year (10^{-3})
- Health-based target
  - Based on standard metric of disease (e.g. DALYs, WHO 10^{-6})
  - Appropriate health outcome (”prevention of exposure…”)



Simplified framework for WHO Guidelines (Bartram et al. 2001)

The acceptable or the tolerable risk for a system need to be defined, also since there is no such thing as zero risk, nothing is completely safe. Different general levels have been discussed, as the 1 in 10 000 risk per year for drinking water, and a higher acceptance in sanitation reuse systems. It can always be debated who is to decide, and the involvement of as many stakeholders as possible is wished for. In analogy, health-based targets define a level of health protection that is relevant to each hazard. A health-based target can be based on a standard metric of disease, such as a disability adjusted life year or DALY (e.g. 10^{-6} DALY as chosen in the WHO Guidelines), or it can be based on an appropriate health outcome, such as the prevention of exposure to pathogens in excreta and greywater anytime between their generation at the household level and their use in agriculture. To achieve a health-based target, health protection measures are developed. Usually a health-based target can be achieved by combining health protection measures targeted at different steps in the process. The health-based targets may be achieved through different treatment barriers or other health protection measures.

The resulting framework (Bartram et al. 2001), which is illustrated in simplified form, is an iterative cycle that encompasses assessment of public health concerns, risk assessment, the establishment of health-based targets and risk management. Feeding into this cycle is the determination of environmental exposure and the estimation of what constitutes a tolerable (or acceptable) risk.

Linking tolerable disease burden and source water quality for reference pathogens

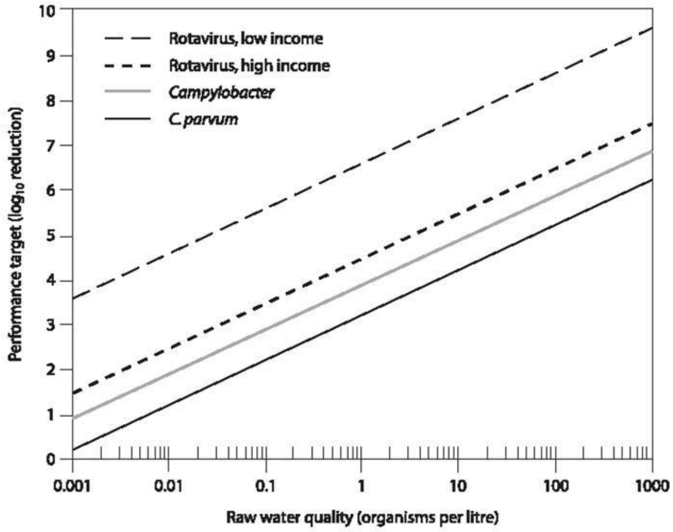
River water (human and animal pollution)		*Cryptosporidium*	*Campylobacter*	Rotavirus[a]
Raw water quality (C_R)	Organisms per litre	10	100	10
Treatment effect needed to reach tolerable risk (PT)	*Percent reduction*	*99.994%*	*99.99987%*	*99.99968%*
Drinking-water quality (C_D)	Organisms per litre	6.3×10^{-4}	1.3×10^{-4}	3.2×10^{-5}
Consumption of unheated drinking-water (V)	Litres per day	1	1	1
Exposure by drinking-water (E)	Organisms per day	6.3×10^{-4}	1.3×10^{-4}	3.2×10^{-5}
Dose–response (r)	Probability of infection per organism	4.0×10^{-3}	1.8×10^{-2}	2.7×10^{-1}
Risk of infection ($P_{inf,d}$)	Per day	2.5×10^{-6}	2.3×10^{-6}	8.5×10^{-6}
Risk of infection ($P_{inf,y}$)	Per year	9.2×10^{-4}	8.3×10^{-4}	3.1×10^{-3}
Risk of (diarrhoeal) illness given infection ($P_{ill\|inf}$)		0.7	0.3	0.5
Risk of (diarrhoeal) illness (P_{ill})	Per year	6.4×10^{-4}	2.5×10^{-4}	1.6×10^{-3}
Disease burden (db)	DALYs per case	1.5×10^{-3}	4.6×10^{-3}	1.4×10^{-2}
Susceptible fraction (f_s)	Percentage of population	100%	100%	6%
Disease burden (DB)	DALYs per year	1×10^{-6}	1×10^{-6}	1×10^{-6}
Formulas:	$C_D = C_R \times (1 - PT)$ $E = C_D \times V$ $P_{inf,d} = E \times r$			

Example calculation (WHO, 2004)

To relate the public health issues to sanitation guidelines and risk assessments this table can be studied as an example even if it relates to the setting of water quality standards. It connects the raw water quality with the treatment needed for specific pathogens in order to reach the health-based target which is set not to exceed a loss of 10^{-6} disability-adjusted life years (DALYs) per person per year (the disease burden, DB, last line in the table), by using risk assessment calculations including exposure data and dose-response. The probability of infection per day is obtained and related to probability of infection per year and probability of illness. The susceptible fraction of the population (i.e. the 5 that can become infected by exposure) is only 6% for rotavirus, since the infection often occurs during early childhood and results in some immunity. The table can be explained starting both from top and from bottom (starting point health-based target).

WHO Guidelines – risk

Performance targets for selected bacterial, viral and protozoan pathogens in relation to raw water quality (to achieve 10^{-6} DALYs per person a year) (WHO 2004)



The figure illustrates the targets for treatment performance for a range of pathogens occurring in the raw water (source water intended for treatment and then drinking), but can be extended to numbers expected in sewage. For example, 10 microorganisms per liter of source water will lead to drinking water performance targets of 4.2 logs (or 99.994%) for *Cryptosporidium* and 5.5 logs (99.99968%) for rotavirus in high-income regions.

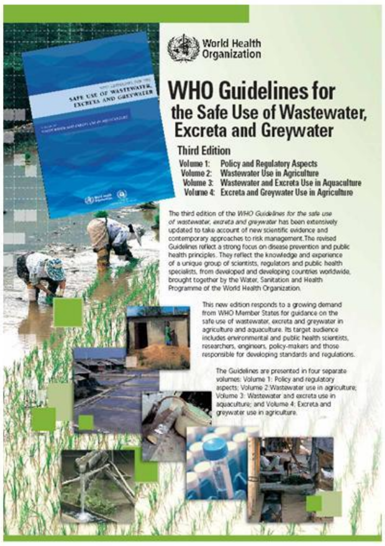
Wastewater, excreta and grey water use – Lessons learned

- Overly strict standards borrowed from other countries often fail
- Guidelines are not just numbers
  = good practice + microbial water quality standards
- Low-cost effective treatment technologies needed
- Risk reduction strategies necessary (and possible) where wastes receive no or inadequate treatment

A growing world population, unrelenting urbanization, increasing scarcity of good quality water resources and rising fertilizer prices are the driving forces behind the accelerating upward trend in the use of wastewater, excreta and greywater for agriculture and aquaculture. The health risks associated with this practice have been long recognized, but regulatory measures were, until recently, based on rigid guideline values whose application often was incompatible with the socio-economic settings where most wastewater use takes place

Guidelines are not just numbers; it is equal to good practice + microbial water quality standards. Low-cost effective treatment technologies are also needed and can result in significant pathogen reduction such as in wastewater storage and treatment reservoirs. Risk reduction strategies are necessary (and possible) where wastes receive no or inadequate treatment, to improve the situation from a low level does not have to be complicated or expensive.

WHO Guidelines – Safe use of wastewater, excreta and greywater in agriculture (2006)



WHO has recognised the potential of using wastewater and excreta in agriculture (and aquaculture) and in the (2006) published series of *Guidelines for the safe use of wastewater, excreta and greywater in agriculture and aquaculture*, a risk-benefit approach is used as the starting point. This involves creating an awareness of risks related to human excreta, but at the same time creating solutions to manage these risks in a systematic way and encouraging use of the "products", since it can lead to improvements in public health by increasing crop yields and implementation of appropriate sanitation that limits exposure to excreta in the environment.

The third edition of WHO's Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture was launched at the IWA World Water Congress in Beijing September 2006. The four volumes can be ordered from the WHO or downloaded free of charge from www.who.org. The guidelines are considered important for the political and institutional endorsement of reuse systems. They are quite extensive, but condensed and explanatory fact sheets can also be found at the WHO-website.

WHO Guidelines – Safe use of wastewater, excreta and greywater in agriculture (2006)

- **Objective:**
  Maximize the protection of human health and the beneficial use of important resources
- **Target audience:**
  Policy makers, people who develop standards and regulations, environmental and public health scientists, educators, researchers and sanitary engineers

- Advisory to national standard setting – flexible to account local social, cultural, economic and environmental context
- Risk-benefit - adaptation to local priorities for health gain
- Builds on:
  - Best available evidence - science and practice
  - Scientific consensus
  - Use global information and experience

The objective of the guidelines are to maximize the protection of human health and the beneficial use of important resources and the target audience is, among others, policy makers, people who develop standards and regulations, environmental and public health scientists, educators, researchers and sanitary engineers. The guidelines should be seen as advisory to national standard setting and should be flexible to account local social, cultural, economic and environmental contexts. A so called risk-benefit approach is used and should result in adaptation to local priorities for best health gain.

The guidelines builds on best available evidence from science and practice and scientific consensus with broad expert participation, and global information and experience have been used.

Wastewater, excreta and greywater use – Background and health concerns

- Wastewater use is extensive worldwide
  - 10% of world's population may consume wastewater irrigated foods
  - 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater
- The use of excreta (faeces & urine) is important worldwide
  - The extent has not been quantified
- The use of greywater is growing in both developed and less developed countries
- Direct Health Effects
  - Disease outbreaks (developing and developed countries)
  - Contribution to background disease (e.g. helminths, + others?)
- Indirect Health Effects
  - Impacts on the safety of drinking water, food and recreational water
  - Positive impacts on household food security and nutrition

Wastewater use is extensive worldwide, both raw and partly treated wastewater is considered a resource and it is believed that 10% of world's population may consume wastewater irrigated foods and that 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater. The use of excreta (faeces & urine) is important worldwide but he extent has not been quantified. The use of greywater is growing in both developed and less developed countries and may be culturally more acceptable in some societies.

The primary aim of the Guidelines is to maximize public health protection and the beneficial use of important resources. The purpose is to ensure that the use of excreta and greywater in agriculture is made as safe as possible so that the nutritional and household food security benefits can be shared widely in affected communities. Thus, the adverse direct and indirect health impacts of excreta and greywater use in agriculture should be carefully weighed against the benefits to health and the environment associated with these practices. Yet this is not a matter of simple trade-offs. Wherever excreta and greywater use contributes significantly to food security and nutritional status, the point is to identify associated hazards, define the risks they represent to vulnerable groups and design measures aimed at reducing these risks.

WHO Guidelines – Safe use of wastewater, excreta and greywater in agriculture (2006)

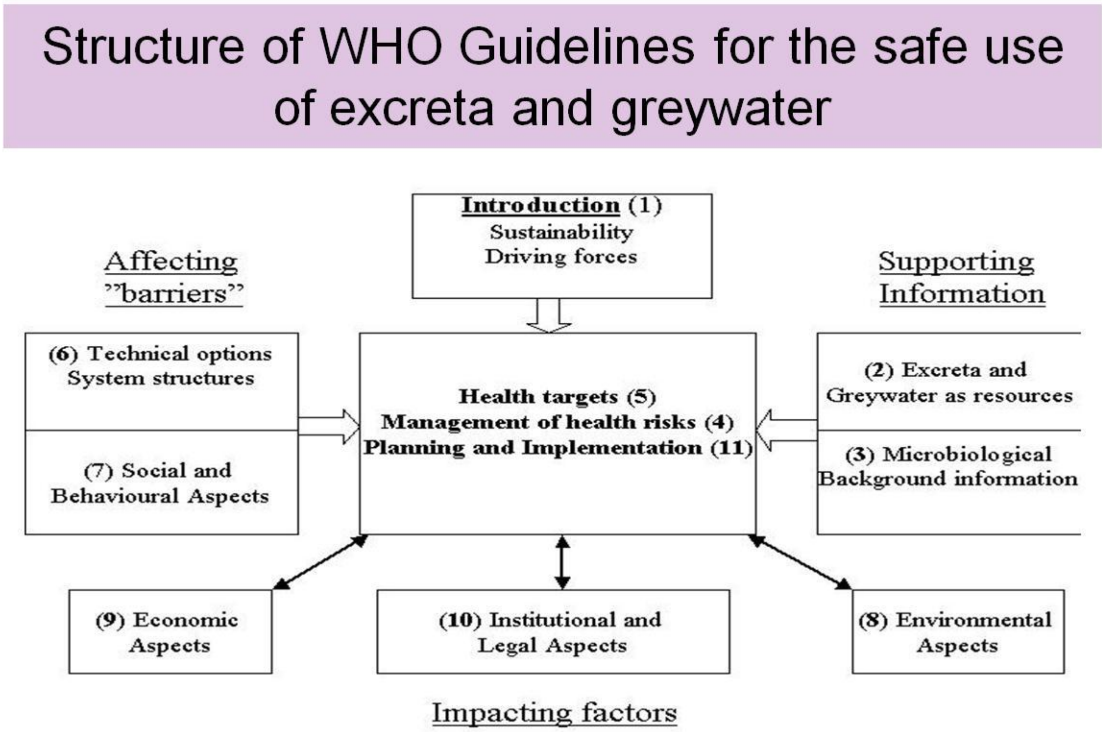
Guidelines provide an *integrated preventive management framework* for maximizing public health and environmental benefits of waste use.

Health components:
- Defines a level of health protection that is expressed as a health-based target for each hazard
- Identifies health protection measures which used collectively can achieve the specified health-based target

Implementation components:
- Establishes monitoring and system assessment procedures
- Defines institutional and oversight responsibilities

Requires:
- System documentation
- Confirmation by independent surveillance.

A health-impact target is provided in the guidelines, which in turn relates to this exposure. This target is a globally acceptable level of health protection and is based on the additional disease burden arising from the exposure (for example, from direct contact with treated excreta or greywater, or from consuming crops fertilized with these products). The risk target is set not to exceed a loss of 10^{-6} disability-adjusted life years (DALYs) per person per year, which is the same level of protection set for drinking-water. Neither the minimum good practices nor the health-based targets are mandatory limits. Rather, they provide a guiding principle for health and system assessment, and for monitoring. The approaches adopted by national or local authorities towards implementation of the guidelines, including health-based targets, may, therefore, vary depending on local social, cultural, environmental and economic conditions. They will be a function of available knowledge of routes of exposure, the nature and severity of hazards (e.g. prevalence of different excreta-related diseases) and the effectiveness of health protection measures available.



The full document of 11 chapters constituting the guidelines covers the area of sanitation in a broad sense, and may be a bit difficult to relate to in all its parts, since it is multidisciplinary, and people may be more or less experts in one or a few of the scientific areas. The structure of the document is covered in this figure. We have now elaborated on several of these issues and will go back to the core of the guidelines which is *Management of the health risks* (chapter 4).

A variety of health protection measures can be used to reduce health risks for local communities, workers and their families and for the consumers of the fertilized or irrigated products – that is managing the risks. Hazards associated with the consumption of excreta-fertilized products include excreta-related pathogens. The risk from infectious diseases is significantly reduced if foods are eaten after proper handling and adequate cooking.

The following health protection measures have an impact on food produce consumers:

-excreta and greywater treatment,
-crop restrictions,
-application procedures and withholding periods between fertilization and harvest to allow die-off of remaining pathogens,
-hygienic food handling and food preparation practices,
-health and hygiene promotion,
-produce washing, disinfection and cooking.

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

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

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

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

Treatment of excreta and greywater

- Faeces
  - Storage, composting and alkaline treatment
  - Further research and adaption to local conditions recommended
  - Compare to module 4.2-4-4 (builds on further research)
- Urine
  - As table above, builds on Swedish recomendations
  - Compare to module 4.2
- Greywater
  - Different techniques described, dependent on local conditions
  - Compare to module 4.5-4.7 (details on treatment processes)

For faeces, different treatment alternatives are available. In the Guidelines, proposed storage times at different temperature intervals are defined along with recommendations for alkaline treatment and composting. However, it is difficult to state exact time-parameter conditions for sufficient inactivation of pathogens, since the pathogens have varying features and resistance to environmental factors and the inactivation will be a result of combined factors. Developments of treatment procedures and results from further research in this field as well as adaptations to local conditions will therefore have to be incorporated when the Guidelines are transferred to national (local) regulations and recommendations. For greywater a number of different treatment techniques are described, whereof many are dependent on local conditions.

For all types of treated excreta, additional safety measures apply. These include, for example, a recommended withholding time of one month between the time of application of the treated excreta as a fertilizer and the time of crop harvest. Faeces should preferably not be used on crops that are to be consumed raw, excluding fruit trees. Nevertheless, treatment is considered as one of the most important health protection measures. A more direct view on treatment of excreta is included in chapter 4 and greywater treatment is also extensively covered in chapter 4.

Health protection measures - agriculture

- Waiting or withholding periods
  - Stopping irrigation several days before harvest to allow natural pathogen die-off can be implemented in a cooler season or climate but makes leafy vegetables look unfit for sale under hotter conditions.
- Application techniques
  - In some countries, like India or Kenya, drip kits are easily available while in others, they are rare.

- Crop restriction
  - Depending on local diets and market demand, some farmers have the option to change crops, while others are constrained in this respect.
- FAO supports reuse (recycling) by (own) guidelines

After treatment of excreta and greywater the health risks relate to exposure during reuse and food consumption. Many of these health risks can be minimized or even eliminated. In industrialized countries, wastewater treatment is doing a large part of this job. In most developing countries, where functional wastewater treatment facilities are rare for economic and financial reasons, other or at least additional barriers for the pathogens have to be put in place to manage the health risks. Farmers have an important role to play as they can manage their irrigation water and adopt their cropping system in ways that reduce risks for them and others. Extension workers have an important role in bringing relevant information from the guidelines to the farmer level, and in assisting farmers to implement them.

In response to requests from the guidelines' readership, WHO, together with FAO, IDRC, and IWMI, produced two information kits with targeted guidance notes, discussion papers, fact sheets, and policy briefs, to further clarify methods and procedures. One of the documents Fact Sheet for Farmers and Extension Workers http://www.who.int/water_sanitation_health/wastewater/factsheet_extensionworkers_farmers.pdf gives the following advice:

The Guidelines strongly support farmer action, if possible in combination with other locally appropriate risk reduction measures. Farm measures include simple on-farm treatment of wastewater and excreta to kill pathogens, the selection of crops which pose less risk for farmers and consumers and safer waste application techniques such as irrigation methods which direct the water to the roots but not to parts of the plants that are eaten. Simple methods that take advantage of the natural die-off of pathogens in the sun by withholding irrigation for some days before harvesting are also among recommended actions. The guidelines make a case for a variety of measures allowing farmers to protect themselves like wearing gloves and rubber boots, immunization and hand washing, and other post-harvest measures like produce washing before consumption. Each measure reduces health risks to some extent, but not completely. Thus, as many options as locally possible should be combined and their joint effect adds up to more or less full protection. Not all measures are suitable under all conditions. There is a need for local screening and adaptation to the particular irrigation system, crop and land through field experimentation involving farmers, extension workers and researchers.

Three examples:

A) Stopping irrigation several days before harvest to allow natural pathogen die-off can be implemented in a cooler season or climate but makes leafy vegetableslook unfit for sale under hotter conditions.

B) In some countries, like India or Kenya, drip kits are easily available while in others, they are rare.

C) Depending on local diets and market demand, some farmers have the option to change crops, while others are constrained in this respect.

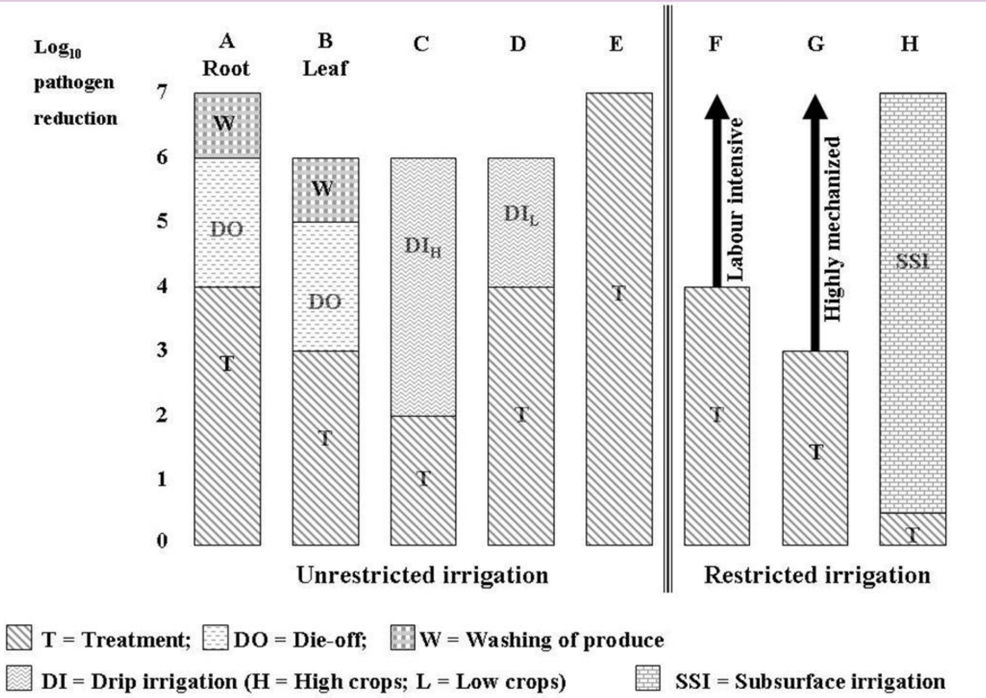
According to FAO management of water resources has become an urgent issue as urban and peri-urban farmers often apply water from municipal sewage, mostly in its untreated form, to irrigate and for plant nutrients, thereby increasing the risk for illnesses to both the farmers and the consumers. FAO's support of water in urban and peri-urban agriculture includes guidelines to assist safe reuse of treated wastewater and greywater, waste recycling such as eco-sanitation.

Pathogen reductions (log units) achieved by health-protection control measures

Control measure	Pathogen reduction (log units)	Notes
Wastewater treatment	1−6	The required pathogen removal to be achieved by wastewater treatment depends on the combination of health-protection control measures selected
Localized irrigation (low-growing crops)	2	Root crops and crops such as lettuce that grow just above, but partially in contact with, the soil.
Localized irrigation (high-growing crops)	4	Crops, such as tomatoes, the harvested parts of which are not in contact with the soil.
Spray/sprinkler drift control	1	Use of micro-sprinklers, anemometer-controlled direction-switching sprinklers, inward-throwing sprinklers, etc.
Spray/sprinkler buffer zone	1	Protection of residents near spray or sprinkler irrigation. The buffer zone should be at 50−100 m.
Pathogen die-off	0.5−2 per day	Die-off on crop surfaces that occurs between last irrigation and consumption. The log unit reduction achieved depends on climate (temperature, sunlight intensity), crop type, etc.
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	Fruit, root crops.
Produce cooking	5−6	Immersion in boiling or close-to-boiling water until the food is cooked ensures pathogen destruction.

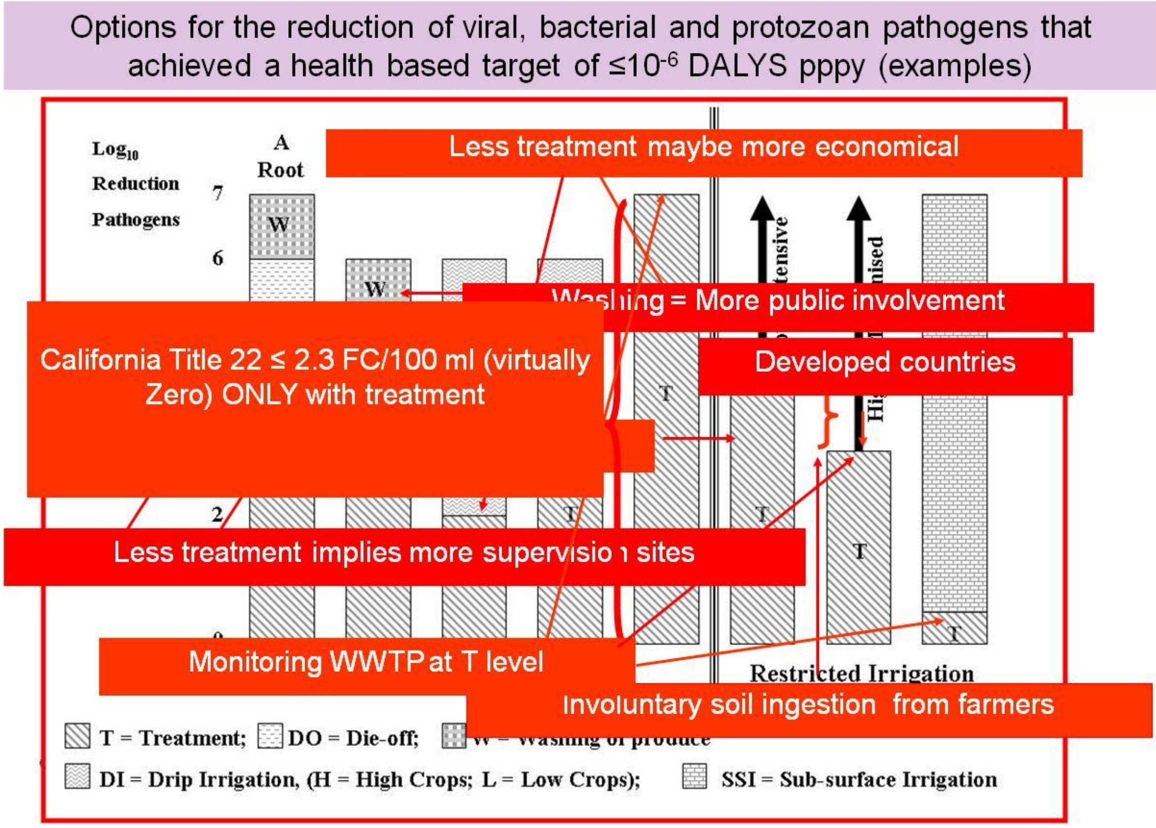
Potential pathogen reduction (in log-units) has been estimated in the guideline work. These measures can be added (combined) in order to achieve the required reduction to reach health-based targets.

Health protection measures – pathogen reduction



From WHO Guidelines for the Safe Use of Wastewater in Agriculture, 2006

In analogy with excreta, the pathogen reduction in wastewater reuse can consist of various barriers, i.e. combinations of health protection measures. For unrestricted irrigation (use on any crop) a reduction of 6-7 log is required in order to reach the health-based target of 10^{-6} DALYs per person and year (pppy). This can be achieved by more or less effective wastewater treatment in combination with type of irrigation method, withholding periods (die-off) and washing of food produce.



To all health protection measures additional issues are related. For example, with less treatment, more steps in the chain need to be monitored (or supervised). Relying on washing of produce requires more public involvement that in turn may require more information and education. Economical aspects are also crucial in most communities.

Definition of monitoring functions

Function	Definition
Validation	Testing the system or components thereof to ensure if it is meeting e.g. ”microbial reduction targets”. Mainly relates to new systems/components.
Operational monitoring	Relates to ”design specifications” e.g. temperature. Indicate proper functions and variations and is the base for ”direct corrective actions”.
Verification	Methods, procedures and tests to determine compliance with design parameters AND specific requirements (guideline values, E coli, helminth eggs, microbial and chemical analysis of crops).

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

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

Guideline values for verification monitoring

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.

The verification monitoring basically use the *E. coli* numbers for representing viral, bacterial and protozoan pathogens. This may need to be cautioned based on the local situation, where for example an x-log pathogen reduction by treatment does not necessarily relate to the stated *E. coli* reduction. Count of helminth eggs are only valid in situation where these occur in the human population.

Guideline values for verification monitoring

- Verification monitoring
- Greywater, faecal sludge and (dry) faeces
  - Harmonised with wastewater use in agriculture (volume 2)
- Mainly applicable in larger systems
- *E. coli* – caution due to growth
- Helminth eggs – where applicable
- Sampling and laboratory procedures

The barriers relate to verification monitoring, mainly in large-scale systems. Verification monitoring is not applicable to urine.

The microbial monitoring guideline values are harmonised in relation to level and parameters with what is applicable for wastewater monitoring in agriculture, and relates to the same risk levels. Subdivisions are made due to the size of the systems where higher emphasis are laid on operational monitoring, observations and system performance in smaller systems, than the verification monitoring. In relation to the guideline values the frequency of sampling is naturally necessary to decide, as well as actions in relation to non-compliance.

The verification monitoring for wastewater is partly focused on compliance with microbial guideline values, but need to account for periodic monitoring of chemicals especially in case of industrial discharges. Within this also factors related to crop productivity are included, for example crops with special sensitivity against, e.g. salinity or boron.

Performance targets for viable helminths eggs
in faecal matter and faecal sludges

Starting point:
Wastewater performance target for unrestricted irrigation ≤ 1 egg /l

Yearly helminth load from irrigation
(using an average of e.g. 500 mm/year):

≤ 500 helminth eggs/m²

Application of faecal matter (in same quantities as in good agricultural practice of manure application):

10 t manure/ha per year at 25 % TS

= 250 g TS/m² per year

⇨ [helminth eggs]tolerable ≤ 500/250 = 2 helminth eggs/g TS

The harmonisation with guidelines for wastewater regarding helminth egg quality guideline value of <1 egg per litre should result in approximately the same risk if exposed. This comparison shows that the guideline value in wastewater results in a tolerable value of 2 helminth eggs per g (TS) of faeces. Thus, the guideline value of <1 egg per g (TS) results in a somewhat lower risk for faeces compared to wastewater.