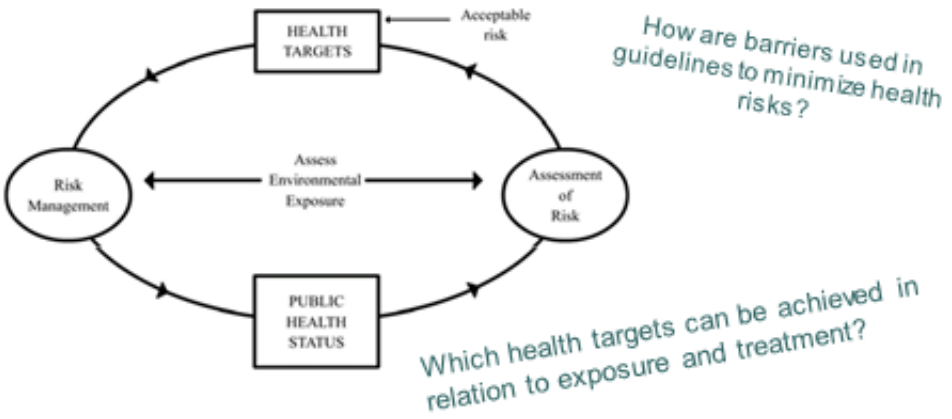
3.4 Health targets



Learning objective: to become familiar with the concept of risk and faecal indicators to understand their incorporation in guidelines for recycling of nutrients in excreta and greywater.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

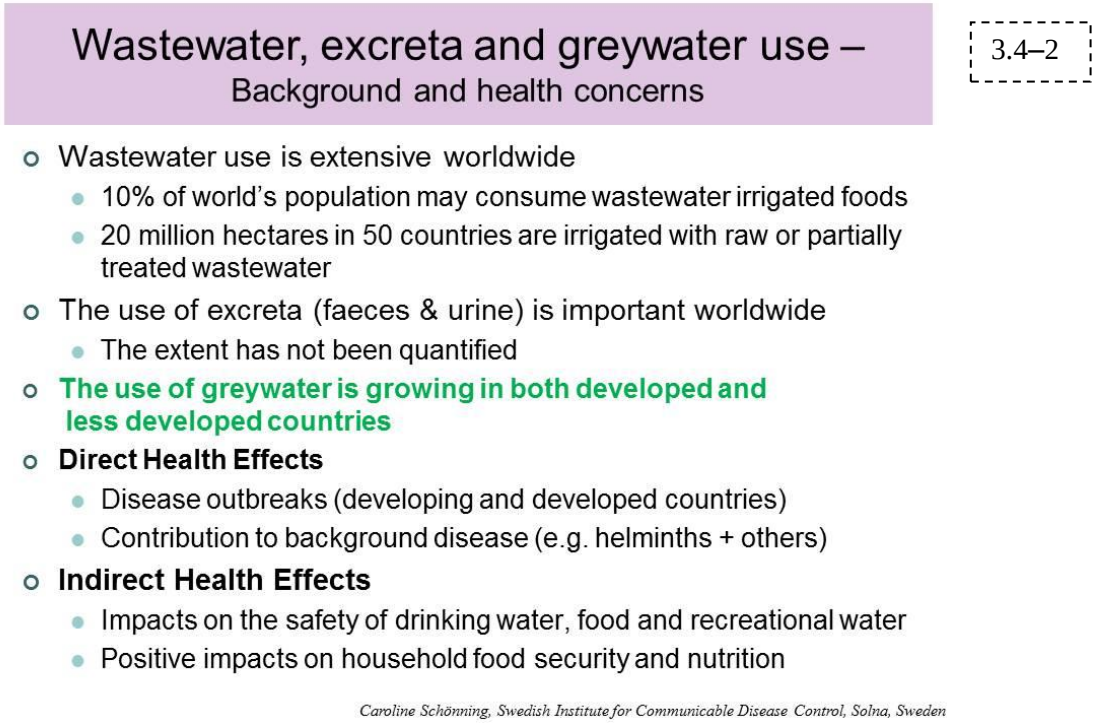
A growing world population, unrelenting urbanization, increasing scarcity of good quality water resources and rising fertilizer prices are driving forces behind the accelerating upward trend in the use of wastewater, excreta and greywater in agriculture and aquaculture according to WHO.

The health risks associated with this practice have been recognized for a long time. But regulatory measures were, until recently, based on rigid guidelines making application incompatible with the socio-economic places where most wastewater use takes place. The WHO (2006) promotes recycling of wastewater and excreta in agriculture (and aquaculture) in the *Guidelines for the safe use of wastewater, excreta and greywater in agriculture and aquaculture*, using a risk-benefit approach. The new guidelines provide "rules of thumb" to guide users and these are easy to apply and realistic under local conditions. Easy explanatory fact sheets are presented on the WHO website. The rules build on best available evidence from science and practice, and on scientific consensus with broad expert participation. Global information and experience have been sought.

The objectives of the guidelines are to maximize the protection of human health and the beneficial use of important resources. The target audience comprises, among others, policy makers, people who develop standards and regulations, environmental and public health scientists, agricultural experts, educators, researchers and sanitary engineers. The guidelines should be seen as an advisory document for setting national standards while ensuring that these are flexible to take into account local social, cultural, agricultural, economic and environmental contexts. A so-called risk-benefit approach is used that advocates adaptation to local priorities for best health gain as well as improved agriculture.

The potential of various types of monitoring in sanitation systems is also included. A more detailed description of treatment processes is included in Chapter 4.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



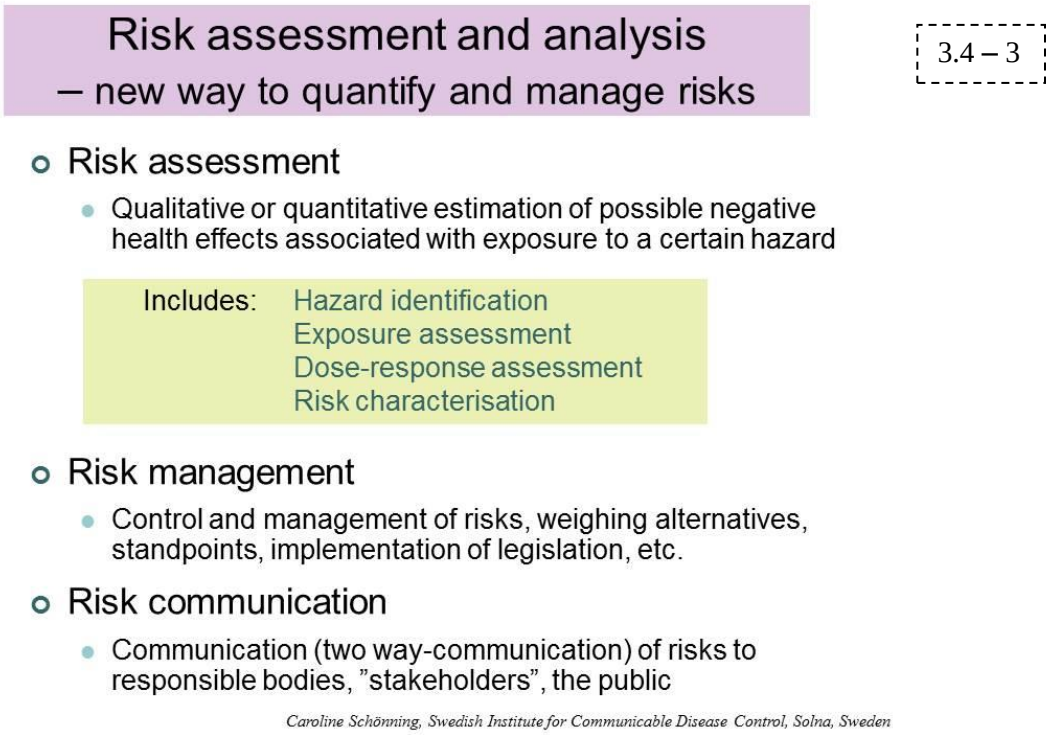
Wastewater is extensively used worldwide; both raw and partly treated wastewater are considered to be water and nutrient resources. A guesstimate is that some 10% of world's population consume foods irrigated with such wastewater and that 20 million hectares in 50 countries are irrigated. In addition, sludge is often disposed of on agricultural fields in countries with wastewater treatment plants. The use of excreta (faeces and urine) is important worldwide but the extent has not been quantified. The use of greywater is growing in both developed and less developed countries and is more culturally acceptable in some societies than in others.

The 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 a starting point. This involves creating an awareness of the risks related to human excreta, but at the same time creating solutions to manage these risks in a systematic way and encouraging the use of the "products", since it can lead to improvements in public health by increasing crop yields (See Module 5.1) and by encouraging the implementation of appropriate sanitation that limits exposure to excreta in the environment.

The primary combined aim of the WHO Guidelines is to maximize public health protection and the beneficial use of water and nutrient 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 concerned 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.

Two major issues need to be explained first – the concept of microbial risk assessment (MRA) and the faecal indicator concept.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



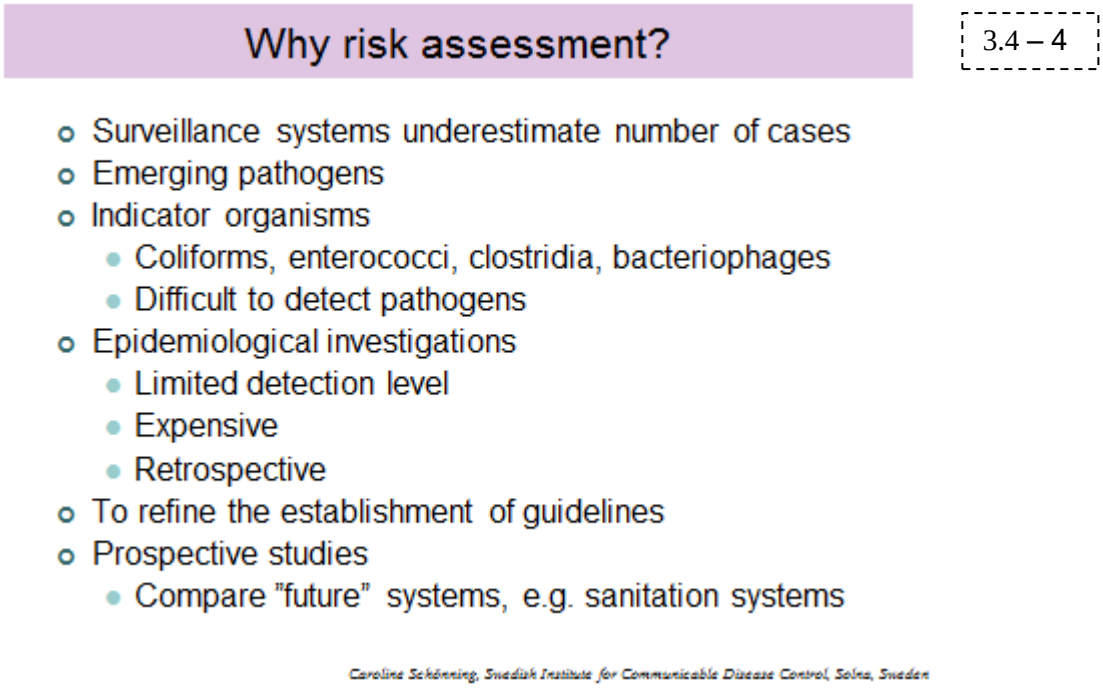
Risk is described as "*The probability of injury, illness or death of individuals at a specific situation/event*". In quantitative terms the risk is expressed in values between 0 (e.g. harm will not be done) and 1 (harm will be done). **Risk assessment** or risk analysis can be defined as "*The qualitative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

Risk assessment starts with the formulation of the problem: hazards are identified, and the different transmission routes and exposure scenarios are explored to find important routes. Then, a dose-response assessment is performed. From these data, risks are characterized and an estimated risk value or assessment can be done for a year or any other time period. This microbial risk assessment (MRA) method has its origin in chemical risk assessment which uses the same terminology (see Module 4.7).

MRA cannot replace epidemiological studies altogether. But, the expensive epidemiological studies studying certain number (level) of infected individuals can provide information used for the assessments. Epidemiological studies are retrospective and give us information about what actually happened (see 3.1-2). But, MRA can and is often used to do prospective studies. One example is to compare future sanitation systems. As has been seen from the WHO work, risk assessments can also be a tool to develop guidelines.

Risk management deals with how to handle risks and what precautions to take. Here other aspects like technology, values and economics may be included. The risk communication involves, as the term implies, the communication of risks to stakeholders.

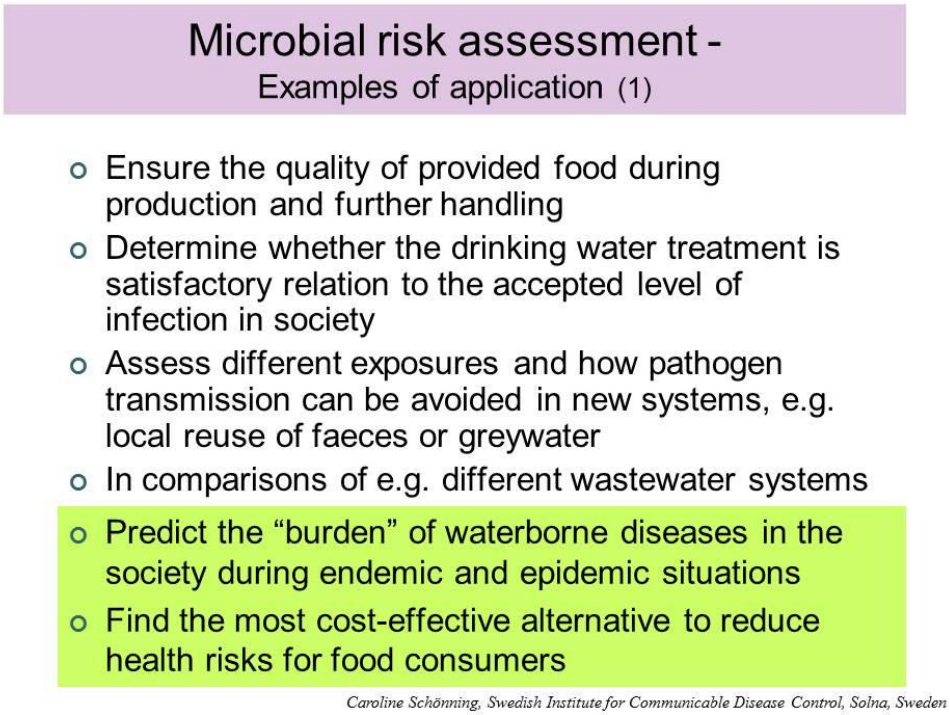
Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



Some reasons to do microbial risk assessments are given below:

- Wish to find out how many individuals that may be infected. Official reporting of infectious diseases by existing surveillance systems often underestimate the number of cases, however.
- 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 that all assessments include a range of assumptions that can only rely on expert judgement.
- There are also new, emerging pathogens that were not previously known, and risk assessments may be valuable to investigate their effect on the society.
- Indicator organisms may be useful, but sometimes they do not relate to the actual pathogen.
- The pathogen 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.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



Possible further, more detailed applications of MRA include:

- to ensure the quality of provisions (food) during production and further handling;
- to determine whether the drinking water treatment is satisfactory according to the accepted level of infection in society;
- to assess, in new systems (e.g. local reuse of faeces or greywater) different exposures and how transmission can be avoided;
- to compare, different wastewater systems e.g. to find out whether a centralized or de-centralized system implies a higher risk.

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 way 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 that all assessments include a range of assumptions that can only rely on expert judgement.

Now we go through the four general steps in developing a risk assessment as indicated in 3.4-4:

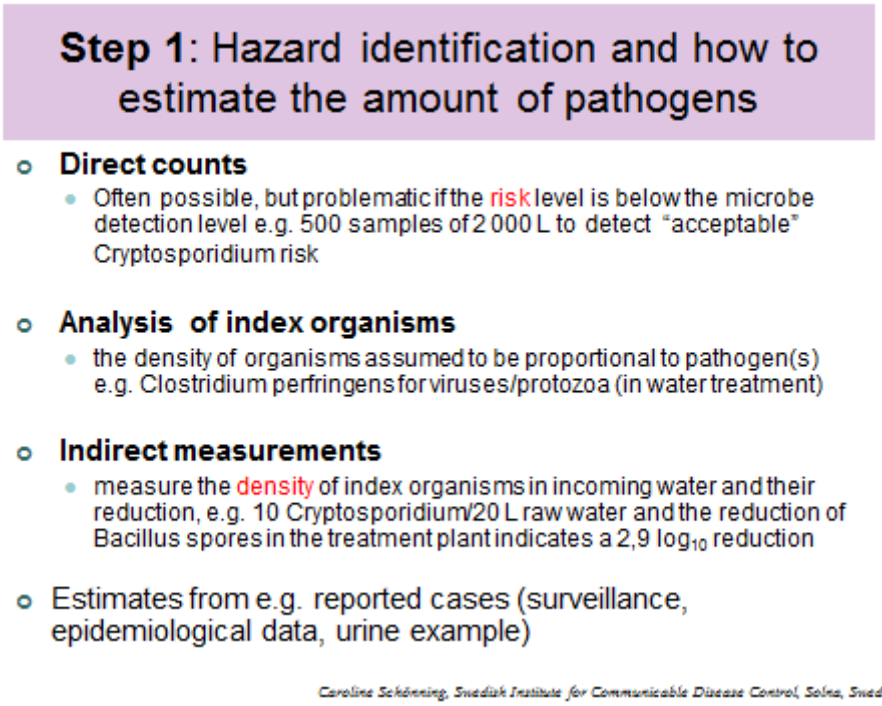
Step 1: hazard identification,

Step 2: exposure assessment,

Step 3: dose – response (incl. vulnerability) assessment, and

Step 4: concluding risk assessment.

Each of these steps may bring up uncertainties and therefore the final risk assessment is bound to depend on good judgements in the processes.



Hazard identification means to determine what pathogens are of interest in a specific system or environment. There are hundreds of species of pathogens and new ones are detected annually. Firstly, the situation is described and what hazard is at stake. Transmission routes need to be identified and the concentration of the pathogen in the material that people are exposed to need to be determined. However, it is not always easy to take representative samples and analyse for one or several pathogens. Some examples of methods used to estimate the concentrations of pathogens include:

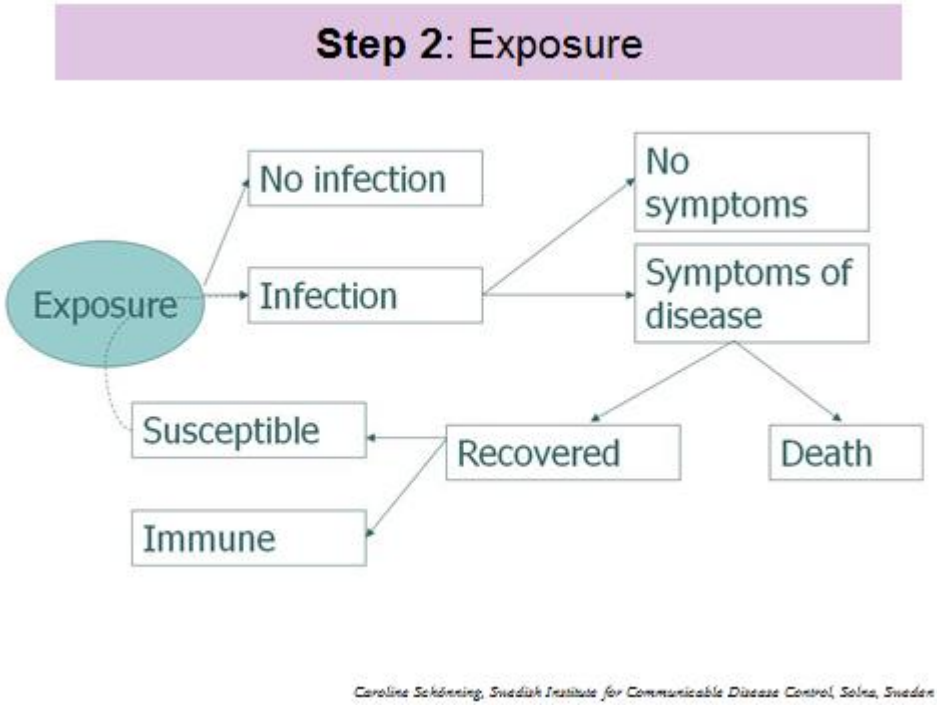
- **Direct counts** – often possible, but can be problematic if the risk level is below the detection level, e.g. that only 1 cryptosporidium oocyst is allowed in 500 samples of 2000 liters each (altogether 1 000 000 liters) as acceptable risk for drinking water

- **Analysis of index organisms** – the concentration of an index organism is assumed to be proportional to the concentration of a pathogen in a sample and lab tests have given the proportion factor to be used for each pathogen. The index organism can therefore be used to estimate the concentration of a pathogen from a measured concentration of the index organism 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 concentration of Cryptosporidium oocysts in the treated water can be calculated.

- **Estimates from reported cases:** it is also possible to use surveillance or epidemiological data from other studies or similar cases (as in the urine example, Module 3.5).

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



Given the concentration of pathogens in the studied environment or case, the next step is to identify how humans may be exposed to them. Even if exposed to pathogens or ingesting them, does not necessarily lead to infection or disease (See sketch). Therefore, finding points of exposure is more about identifying encounters than measuring health impacts as described below.

To become infected a certain number of pathogens need to be ingested, called the infectious dose, which varies depending on the pathogen/disease and may also vary from individual to individual (susceptibility). Even if an infection has taken place, it does not necessarily involve symptoms. The individual with symptoms will either die or recover (but perhaps suffer from a residual disability). After recovery the individual is either still susceptible or immune to this kind of infection. How long the immunity lasts depends on the infection.

With more advanced computer-based calculations, variation in the collected data can be included in calculations, as is the case when the concentration of *Salmonella* in wastewater varies e.g. with the prevalence in the population connected to the sewer. The calculation can allow intervals instead of point estimates (as probability density functions or PDFs) as parameter values, and obtain confidence intervals which provide more fine-tuned results closer to “reality”.

Another improvement relates to better statistical analysis. Random sampling (e.g. 10,000 times) with Monte Carlo simulation, or Latin Hypercube, is done of values within the PDF.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Step 2 a: Exposure (examples)

3.4 – 8

Ex. 1: 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 = **1.4×10^{-3} viruses/day** will be ingested

Ex. 2 : Ingestion of bathing water (surface water)
contact rate 50 mL/h
2.6 h/swim
exposure frequency 7 swims/year

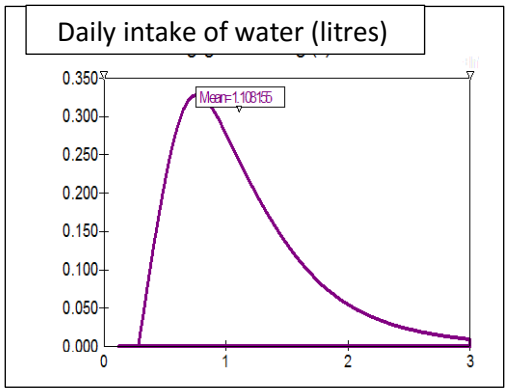
➡ daily average 7/365 x 2.6 x 0.05 = 0.0025 L/day

If the bathing water is assumed to contain 0.1 virus/L
0.0025 x 0.1 = **2.5×10^{-4} viruses/day** will be ingested

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Exposure to pathogens can occur in many ways. The slide provides two examples of exposure through ingestion, but it could also happen through skin penetration or breathing aerosols.

Large variations in **drinking water qualities are** found around the world. In areas where the quality is un-reliable, it is probably common to drink water that has not been boiled. Calculating risks related to the ingestion of drinking water comprises volume, exposure, infectious dose and susceptibility. The next step would be to calculate the probability of infection from this dose of $1.4*10^{-3}$. *(Roseberry and Burmaster 1992)*



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.

Bathing in surface water. The author makes the assumption that a person (accidentally) ingests 50 mL per hour while swimming. A (long) swim takes 2.6 hours and if swimming is done 7 times a year, which corresponds to a daily average ingestion of 7/365 x 2.6 x 0.05 = 0.0025 L/day. If the bathing water is found to contain for example 0.1 virus/L, then 0.0025 x 0.1 = **2.5×10^{-4} viruses/day** are ingested (which however can be considered a strange way to look at exposure, since pathogens give a direct effect from a single dose, and unlike some chemicals they do not have a cumulative impact).

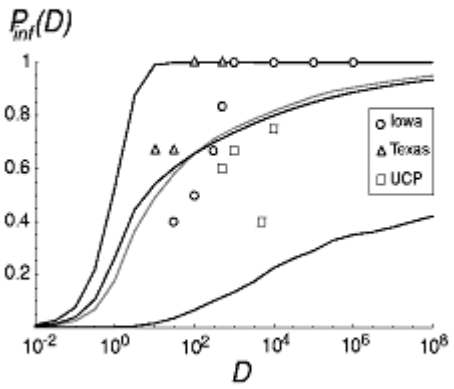
The amount of soil that a child is likely to ingest, or if calculating a worst-case scenario, the maximum amount that can be ingested e.g. median 81 mg/day for children and maximum 5.6 g/day (Calabrese et al. 1989).

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Step 3: Dose-response assessment

3.4–9

- Probability of infection
- Dose-response curves
- Clinical manifestation depends 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



Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

In risk assessments and dose-response modelling, it is of interest to calculate the probability of infection, the probability of illness and perhaps the probability of death. This is not as straightforward as it may sound, however. We illustrate some of the encountered challenges of this task.

At one time, the infectious dose was often reported as the minimum infectious dose – the lowest number of organisms known to result in infection, or as ID_{50}, which is the dose at which 50% of the exposed individuals will become infected. More recently it has been possible to calculate the probability of infection for some pathogens through so-called dose-response curves that build on experiments involving healthy individuals who have ingested a specific number of the pathogen in question to see if they acquire an infection or not.

The data from such experiments are then used to construct a probability curve of best fit of being infected. Since volunteers are used, such probability curves are not available for all types of pathogens. Therefore, infectious doses have also been calculated by using data from disease outbreak situations where it has been possible to estimate the concentration of pathogens and the degree of exposure of a community, and relating this data to the infection ratio.

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, the degree of immunity, and the nutritional status of the individual (See 4.3 – 8).

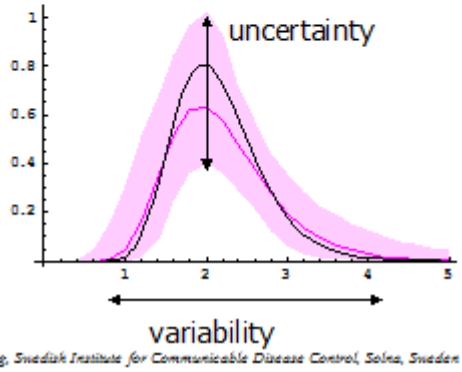
The graph shows best fitted curves and 95% confidence interval for different strains of the protozoa Cryptosporidium (Teunis et al. 2000). The x-axis gives the dose/number of pathogens per 100 ml (D) and y-axis the probability of infection (P_{inf}). As can be seen different curves fit to different strains of the pathogen In this case the model is fitted to three different bovine ("cow") strains (Iowa, Texas and UCP).

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Step 4: Risk characterisation

3.4–10

- Data from steps 1-3 are needed to calculate the probability of being infected and the health burden for the society. In step 4 variation and uncertainty in the data are being discussed.
- "Variability" – internal variation in data cannot be reduced
- "Uncertainty" – variation in the data set can be reduced by collecting more data from additional studies



Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Risk characterization is defined as an integration of earlier steps for calculating the probability of infection. It can also relate to a calculation or estimation of the importance of the infection in society.

The data collected in the previous steps may now be used to calculate the probability to become infected by a specific pathogen. The idea is simple but to calculate such probabilities is complex. We illustrate the method with an example.

Here follows some illustrative examples:

1. Bathing. Let us say that there are 100 pathogens in 100 ml of lake water (Step 2), and a child ingests 50 ml while playing in the water (Step 3a). Assuming the child is prone to be infected if the dose exceeds 40 pathogens (Step 3b), he or she is expected to be infected but not necessarily fall ill.

In Step 4, variations between individuals or circumstances will impact on the resulting disease burden. Such variations are given, and cannot be changed. Uncertainty in the data is common since the number of studies or measurements are limited and do not allow detailed knowledge. In this case, uncertainty can be reduced by collecting more data by conducting more investigations.

2 Wastewater. The average concentration of *Salmonella* in a certain wastewater is found to be 25,000 bacteria per liter and the wastewater treatment removes 99.9%. Thus, 25 bacteria remain per liter. The infectious dose is 100,000 organisms, and therefore 1 out of 4 000 persons run the risk to be infected.

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

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Linking tolerable disease burden and quality of water source for some reference pathogens

3.4 – 11

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_{infd})	Per day	2.5×10^{-6}	2.3×10^{-6}	8.5×10^{-6}
Risk of infection (P_{infy})	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:	$C_D = C_R \times (1 - PT)$ $E = C_D \times V$ $P_{intd} = E \times r$			

Example calculation (WHO, 2004)

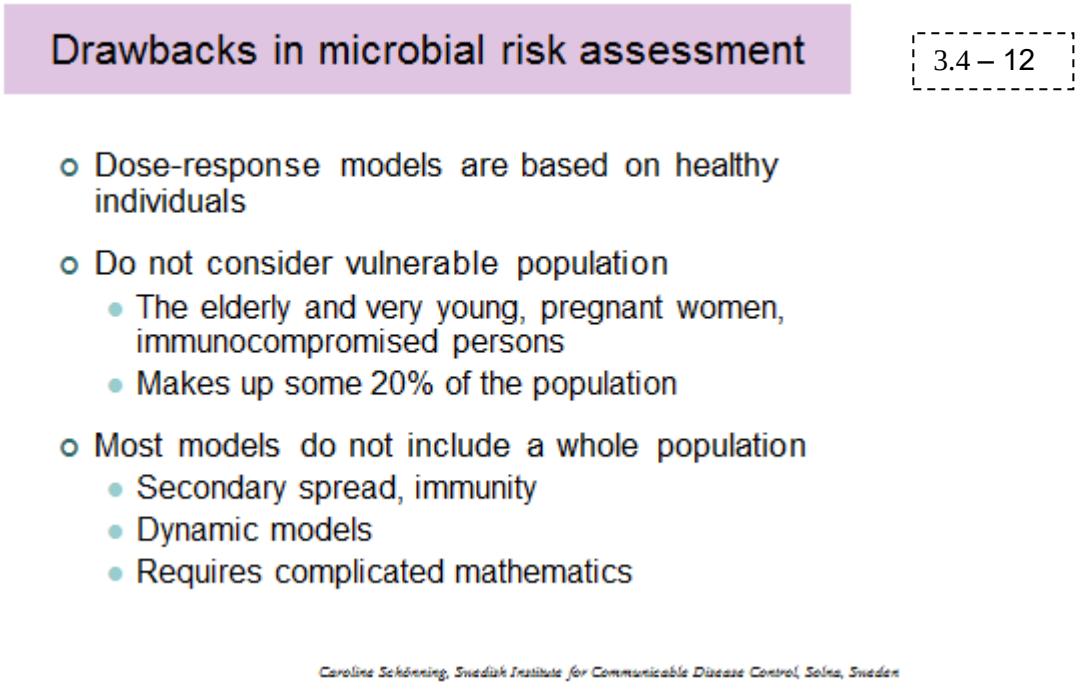
So far, the focus has been on risk assessments for individuals. Now, public health issues come to the fore. Water quality standards given in sanitation guidelines and risk assessments such as the WHO-table (2004) provide valuable data. Raw water quality is associated with the treatments needed for specific pathogens in order to attain the health-based target of not to exceed a loss of 10^{-6} disability-adjusted life years (DALYs) per person per year (See 3.1-3+4). The disease burden, DB, is given in the last row in the table. This is arrived at by using risk assessment calculations including exposure and dose-response data.

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. those who can become infected by exposure, is only 6% for rotavirus, since this infection often occurs during early childhood and results in some immunity. The table can be interpreted starting both from top and from the bottom (starting point health-based target).

There is an ongoing discussion about Guideline values. The threshold for faecal coliform bacteria in drinking water recommended in the WHO Guidelines of 1984 is zero per 100 ml of water, and 10 other coliforms are accepted. In 1977 Feachem et al. suggested the following more achievable standards (even though they were well aware that typhoid is infectious in extremely low doses):

"Water sources containing between 10 and 100 faecal coliforms is of good quality and should be treated if possible but supplied untreated if treatment is not feasible. A water source containing between 100 and 1000 coliforms is of poor quality and should be treated if possible. If not, it should either be supplied untreated or abandoned according to a series of decisions. Water containing more than 1,000 coliforms is regarded as grossly polluted and, if treatment in not possible , it should be abandoned unless the proposed supply will not increase the number of users of a single raw water source."

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



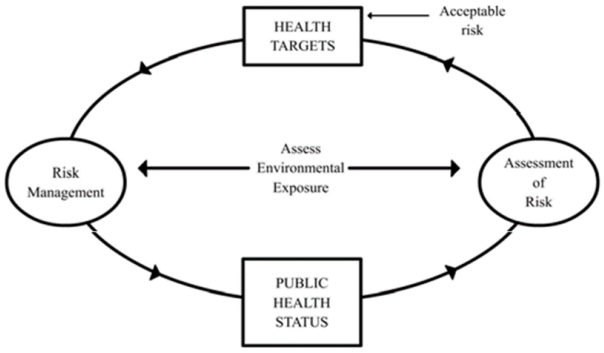
Quantitative microbial risk assessments (QMRA) often include several assumptions. There are also other drawbacks, or limitations. The dose-response models are based on healthy individuals and do not consider vulnerable populations such as the elderly, the very young, pregnant women, or immunocompromised individuals. Together these groups make up some 20% of the total population.

The number of pathogen species for which dose-response models are available is also limited. Most models do not include a whole population and do not consider secondary spread or immunity. These factors could be considered, but to do so requires dynamic models that are based on complicated mathematics. Nevertheless, QMRA are used and accepted as a decision-making tool that can be a part of a wider system analysis.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Health-based targets and acceptable risk

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



Since there is no such thing as zero risk, an acceptable or tolerable risk has to be defined for any system or product. Various general *risk levels* have been discussed, such as one disease episode per 10 000 persons per year for drinking water, and a higher acceptable risk in a recycling sanitation systems of one episode per 1 000 persons and year. It can always be debated who is to decide, and the involvement of as many stakeholders as possible in deciding is wished for.

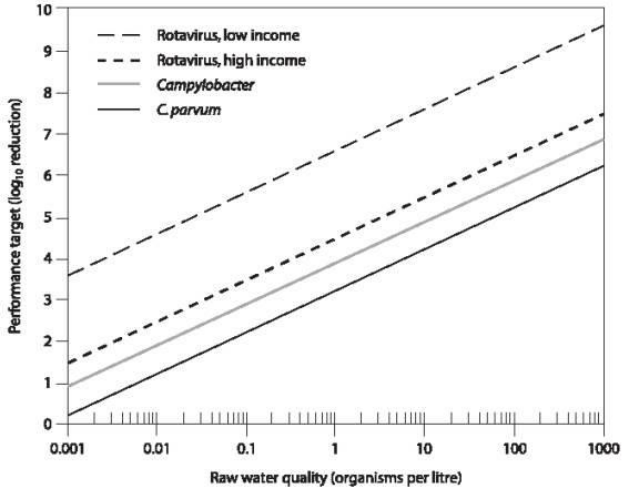
Health-based targets, on the other hand, define a level of health protection that is relevant to each hazard. A health-based target can be based on a standard metric of disease, such as a disability adjusted life year or *DALY* (3.1-3). The WHO Guidelines choose the level of 10^{-6} DALY for drinking water. This means that the person is sick for four minutes in a lifetime caused by drinking water. The risk can also be based on an appropriate *health outcome*, such as the prevention of exposure to pathogens in excreta and greywater between their generation in the household and their use in agriculture. Usually a health-based target can be achieved by combining health protection measures targeted at different steps in the process such as different treatment barriers or other health protection measures (see Module 3.2).

The resulting framework (Bartram et al. 2001), which is illustrated in simplified form in the diagram above, 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 decision of what constitutes a tolerable (or acceptable) risk.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

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)



Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Over the years, a lot of research has been carried out about water-related diseases. The results are compiled in simple tables telling how much treatment is required for a given raw water to secure a certain quality level (often in DALYs). The table can then be used by practitioners as a support tool to know what treatment is required for the raw water quality they have found.
If, for example, 10 microorganisms have been found per liter of raw water, the treatment must reduce the number by 4.2 logs (or 99.994%) for *Cryptosporidium* and 5.5 logs (99.99968%) for rotavirus to secure drinking-water quality.

The figure above illustrates the performance targets for treatment for three common pathogens occurring in raw water. Rotavirus is common in low-income countries compared to high-income countries and therefore represented by one line for each. The treated raw water is intended for drinking and the table tells how much reduction of pathogens that is required, depending on actual raw water quality, in order to have less than 10^{-6} DALYs per person and year.

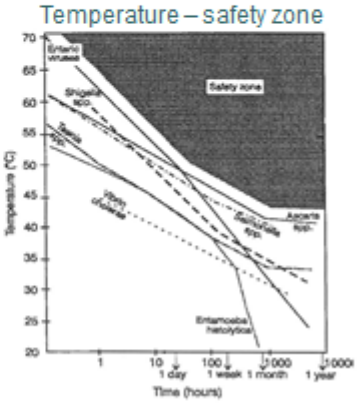
The y-axis of the logarithmic table indicates reductions from 0 (= no reduction), 1 (= 10 % reduction), 3 (= 99.9 % reduction) etc. The x-axis tells the number of the particular pathogen per liter of raw water from 0 (= 1 pathogen), 1 (= 10 pathogens), 10 (= 100 pathogens) etc.

How can we use the indicators?

3.4 – 15

An ***indicator*** is used to:

- indicate presence of other organisms e.g. pathogens
- mimic the behaviour of another organism (*index organism)*
- represent a whole group of organisms (*model organism)*
- trace movements of viruses in soil (bacteriophages)
- indicate reduction processes (Ascaris)



Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

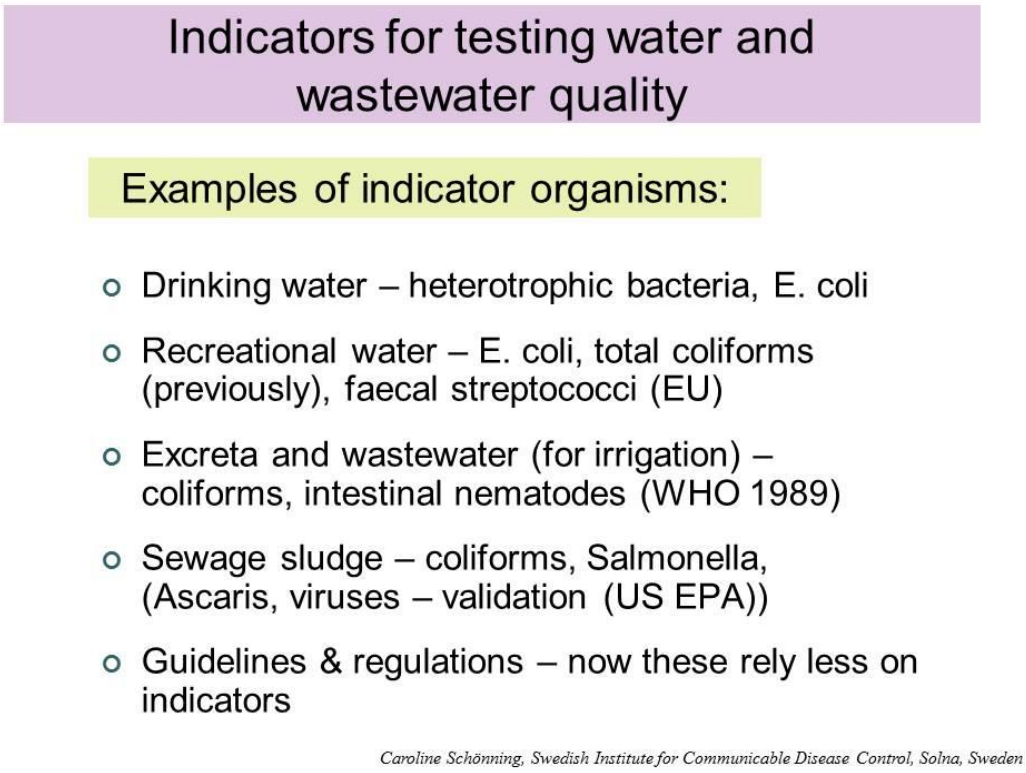
Source: Feachem 1983; EC 2001

Besides being an actual indicator of the presence of pathogens, *indicator organisms* can be used for other purposes as well. It may be used as a substitute for a specific pathogen for other reasons such as Clostridia-crypto illustrates. A second use is as an *index organism* to mimic the behavior of another organism. For example, in studies of water treatment processes clostridia spores can be used instead of Cryptosporidium oocysts because they are much easier to analyze and can be added in large numbers and are non-pathogenic. A *model organism* can be said to represent a whole group of organisms, since it may not be possible or affordable to analyze for several viruses, or include them all in risk assessments. For instance, rotavirus is chosen as a model organism to represent enteric viruses in a risk assessment of urine (see Module 3.5). It is however important to note that two different organisms never will have exactly the same behavior or constitute the exact same risk.

As described in Module 3.2 *bacteriophages* can be used as tracers for transport of viruses in soil and therefore able to establish routes beyond doubt. They can also be called model organisms. They can also function as a tracer, model or process indicator in water treatment processes such as sand filtration. Thus, the terminology is in many respects a bit mixed.

Ascaris eggs are hardy organisms, as illustrated by the above graph where Ascaris is more persistent to temperatures around 40–45°C than the other organisms shown. Even this is not true in all situations (more research studies have been performed since 1983 when the graph was first published). It gives an indication that Ascaris can function as a process indicator, so that if the Ascaris eggs have been inactivated or killed it can be concluded that all other pathogens 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 in 3.4, a multiple barrier approach is recommended. A new verification modelling concept is described later in this module which should not be used as the sole means of assessing the presence of pathogens in sanitation systems and verification monitoring is not a tool on its own in sanitation systems.

In the following slides a number of applications are presented.



Indicators have commonly been used in developing quality standards (regulations) or guidelines. Especially for water quality, the presence of indicator is used to assess potential risks of faecal contamination. For example, presence of heterotrophic bacteria in drinking water is a general sign of bad quality or failure in the treatment processes, while the presence of E. coli indicates that a potentially hazardous contamination has occurred. For recreational water, the presence or absence of E. coli, total coliforms and faecal streptococci (in the EU regulation) have been used to measure water quality.

For excreta and wastewater (for irrigation) coliforms and intestinal nematodes were used in earlier versions of the WHO guidelines (WHO 1989). The present requirements for verification monitoring are presented later 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 whether a process has the potential to reduce pathogens to acceptable levels.

Guidelines and regulations for waste products now rely less on indicators and instead focus on combinations of safety measures. The HACCP (Hazard Analysis and Critical Control Points) concept is used also in drinking water production as well as in food production. When applying HACCP controls of both process results and operation, they are applied at several points in the process. Monitoring the whole chain by implementing HACCP is the preferred method and not to rely exclusively checking the end-product. In this way higher safety is achieved for consumer health.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Presence of indicator bacteria in waste

3.4–17

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

CFU/g ww or CFU/ml measure the number of colony–forming units per gram of wastewater or per milliliter respectively

(Geldreich 1978; Stenström 1996; Sundin 1999)

The above table gives numbers of colony-forming units (CFU) which is a count of the number of colonies of bacteria on a petri-dish on which bacteria have been fed by a growth substrate, where each colony is said to represent (originates from) one bacteria. The number of indicator bacteria is very large and fulfills the ideal requirement to be much larger than the indicated pathogens. The four indicator organisms show slightly different numbers for their presence in faeces, in incoming and outgoing wastewater from wastewater treatment plants, and in raw sludge.

The purpose here is to give an indication of the reduction rate of indicators in wastewater treatment. Initially, the concentration of indicators in faecal matter is lowered through dilution when mixed with other wastewaters. Next, it can be clearly seen that an aggregation of the bacteria occurs in sludge, i.e. the bacteria content is higher than in wastewater but still lower than in faeces. The treated effluent has a rather low content of bacteria. Simultaneously, the data in the table indicates the risk level associated with the different waste flows and where the material has to be cautiously handled.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Pathogens are often present in low concentrations compared to indicator organisms, and hard to detect - like looking for a needle in a haystack. The presence of a proper faecal indicator in a material, e.g. water, will tell us that there is likelihood that the material has been infected by enteric pathogens. Therefore, a faecal indicator organism is searched for and counted to indicate whether a sample (of e.g. water) might be contaminated by human or animal faeces from sewage or other waste. The indicator organism is easier and cheaper to detect and count than the pathogen itself. Also, a single indicator species can be used to cover the hundreds of pathogens that theoretically could be tested for.

The ideal features of a faecal indicator are that it is:

- a natural member of the intestinal microflora
- present in greater number than the pathogens (slide 3.4-6)
- does not multiply in the environment
- is non-pathogenic
- its presence is an indication that pathogens will also be present
- detectable by using easy, rapid and affordable analytical 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 formulating regulations as we will see.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Faecal indicators – abundant in faeces

3.4 – 19

Indicator bacteria	% presence	Number 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 (presumptive)	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)

An ideal indicator organism should be present in large numbers in faecal matter. The ones in the table partly fulfill these criteria. However, they each also have different features that need to be considered when interpreting their presence. Since they are all bacteria they may multiply or perish in the environment and therefore exaggerate or underestimate numbers when stored before counting. The table gives numbers of bacteria per gram of faecal material. Also, the presence in human faeces of each indicator bacteria is given as an estimated percentage of individuals.

Total coliforms are present in faecal material, but can also be found in other material such as soil and they are therefore not specific indicators for faecal pollution, and thus a problematic indicator. ***E. coli***, on the other hand, is specific for faeces and is considered a faecal indicator. There are however, specific, much more unusual strains that can be pathogenic (disease-causing).

As can be seen in the table, **faecal streptococci** are similar to enterococci. The terminology has been changed over the years, and nowadays faecal enterococci is the group that is analyzed (comparisons of results and conclusions from studies using any of the two terms are still valid). Faecal streptococci are often considered more persistent than *E. coli*, for example in sea water.

Clostridia is said to be the most persistent indicator since this bacteria is spore-forming. It has a dormant stage that can withstand most environmental pressures and requires sterilization for elimination. One disadvantage with clostridia is that they are not present in all humans (only 13-35 %), and they can also be found in other materials such as soil.

Coliphages are a bacteriophage that has *E. coli* as a host (varying strains). Bacteriophages are viruses that infect bacteria and can thus be used to mimic viral behavior e.g. transport of viruses in soil (see Module 3.2).

Faecal sterols, e.g. **Coprostanol** and cholesterol are chemical compounds found in faeces, except in the case of very young children. Faecal sterols have not yet been used routinely as indicators of faecal pollution. They are used mainly for research purposes such as tracing the origin of faecal pollution (to see whether it is of human or animal origin) and for estimates of faecal contamination when such estimates are necessary for making risk assessments.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Faecal indicators in urine

3.4 – 20

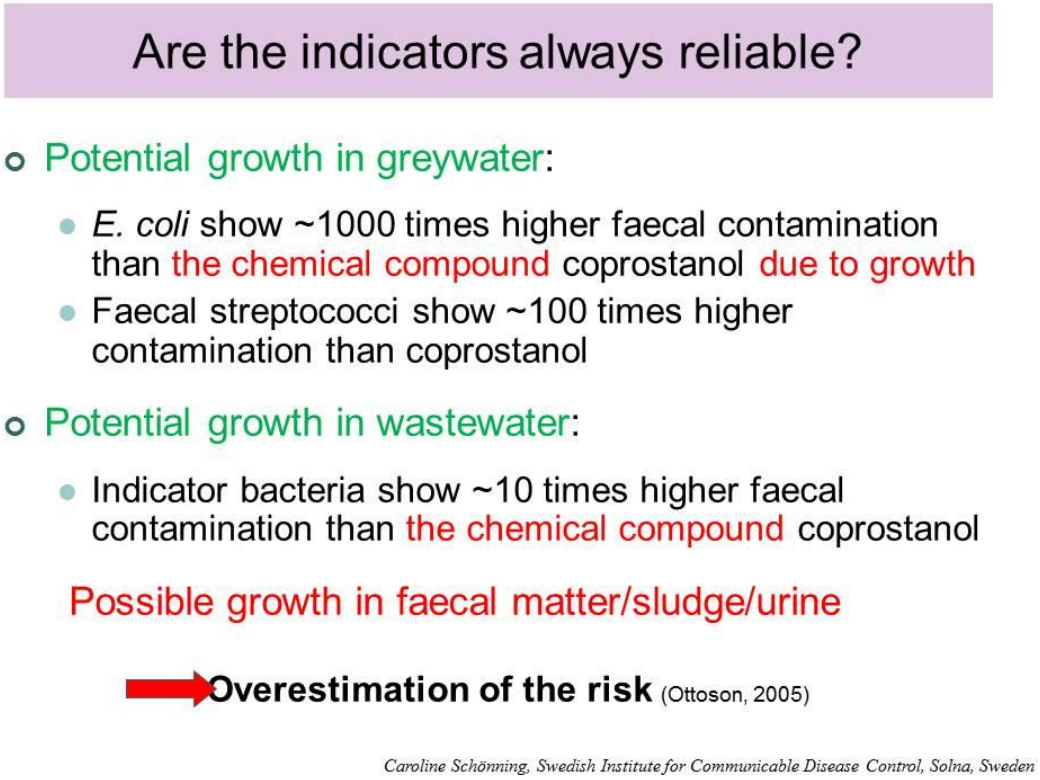
- Number of *E. coli* – sensitive to the conditions prevailing in urine
- Very high numbers of faecal streptococci – possible growth in the pipes (sludge formed)
- No reduction of clostridia (spores) during storage – resistant to most conditions
  - Would mean that the faecal cross-contamination is either underestimated or overestimated
  - How does the survival of pathogens relate to the behaviour of the indicators?

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Research on the risks related to the reuse of human urine found no *E. coli* in samples taken from urine collection tanks (see Module 3.5). On the other hand, high numbers of faecal streptococci were found. Later, supporting evidence was found that *E. coli* perishes within days in urine and that faecal streptococci can grow in the sludge formed in urine pipes (from the urine-diverting toilet). Thus, neither of these bacteria are reliable indicators for the degree of faecal contamination occurring due to the misplacement/cross-contamination of faeces in the urine diverting toilet.

Furthermore, tests found there was no reduction of clostridia spores, which supports the known persistence of this indicator. This brings us to the conclusion that an indicator does not always provide reliable information since each system and environment is unique. This is the purpose of introducing risk-analysis as an additional way to estimate presence of disease-causing factors.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

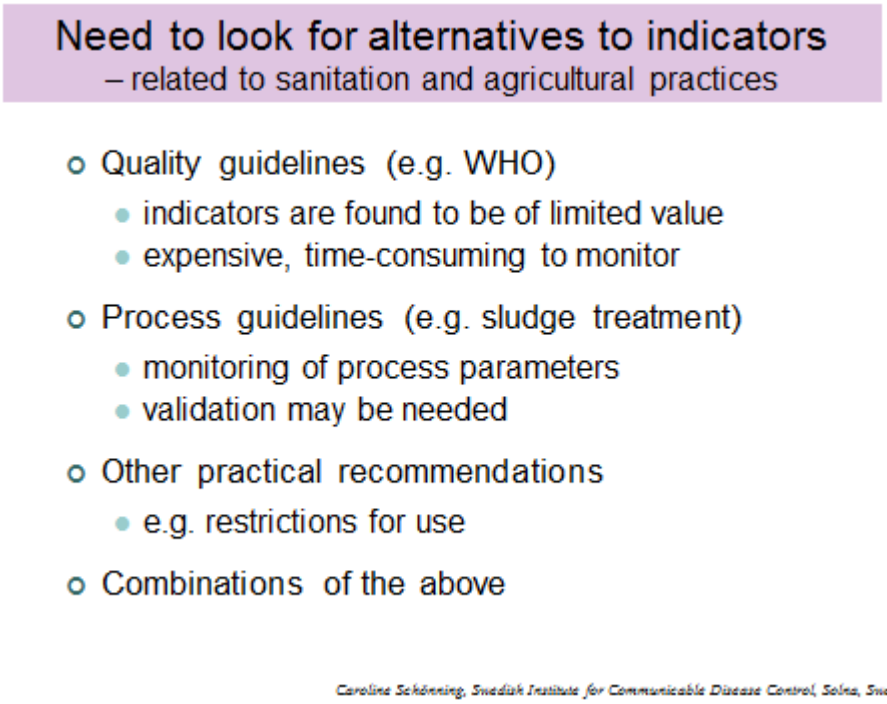


The requirement on ideal indicators does not allow for growth or multiplication of bacteria. How reliable are then bacterial indicators for estimating faecal contamination and associated pathogen risk?

An answer to this question is indicated in the following. Using the chemical Coprostanol (which cannot multiply or perish) as an indicator for the presence of faecal bacteria in greywater resulted in an estimate of faecal contamination that was about a 1000 times higher than the result obtained when using *E. coli* as an indicator, and about a 100 times higher than when using streptococci as an indicator. This difference ought to be the result of bacterial growth, since the chemical substance Coprostanol is stable in greywater (as well as in wastewater and urine). It is also possible for bacteria to grow in mixed wastewater as is indicated by the fact that faecal streptococci contamination is 10 times higher than Coprostanol contamination. It can thus be concluded that exposure to pathogens is very likely to be overestimated when using these indicator bacteria in greywater or wastewater.

A similar overestimation is not found for drinking water mainly due to the fact that there is less feed for bacterial growth.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



Regulations and guidelines are usually recommendations and not legally binding. They can be designed in different ways. For example, waste fractions and water can fulfill *quality guidelines*. That is, limits are set for what quantities of microorganisms or compounds the material is allowed to contain. We have for example the WHO guidelines for wastewater and excreta with limits for numbers of faecal coliforms and intestinal nematodes. Faecal indicators are used since other analytical methods for testing for the presence of pathogens are generally time-consuming and expensive, and since there is 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 inactivated then other pathogens are also inactivated.) The value of faecal indicator bacteria has been questioned since pathogens may be more resistant to a treatment or environmental conditions.

An alternative is *Process Guidelines*, using earlier research results that a given process achieves a certain reduction needed for the product to be safe. For example, regulations for sewage sludge may prescribe a specific process. To ensure that the process accomplish what is intended, validations may be needed initially or on a regular basis.

Regulations and guidelines may also include practical restrictions or *rules of thumb*. For example, a certain waste-generated fertilizer product should not be applied on certain crops.

The regulatory frameworks related to sanitation and agricultural practices vary between countries. In Europe, some countries do not allow the use of human excreta, whereas the Swedish EPA for example intends to specifically address urine in their revised regulations, which previously related mainly to sewage sludge. Proper treatment for reducing pathogens in waste products for agricultural use in order to recycle phosphorous and nitrogen are crucial parts of the new guidelines. The Swedish-based EcoSanRes programme developed guidelines for treatment and use of urine, faeces and greywater related to hygiene, agriculture and technology (www.ecosanres.org). The different types of recommendations could of course be combined, which also is proposed by the WHO and the Swedish EPA.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Recommendations for the use of human urine
indicator-free recommendation for large systems

3.4 – 23

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

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

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

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Previously, there were no limits given for maximum number of an indicator organism in urine, because few farmers applied urine in agriculture. When urine-diverting toilets became a toilet alternative, WHO decided to formulate recommendations built on various research of urine use on farms as well as in individual gardens. The above table is valid for large systems, i.e. where the collected urine is used outside the households from where it was collected.

Storage is the sole recommended treatment method. The rapidly elevated pH (to around 9), the presence of ammonia in the urine, and high temperature are detrimental to pathogens survival (see Module 4.5). The required storage time varies for different pathogen species. Also, depending on what crop is grown. Vegetables is included in the 'All crops' category'. A shorter storage time is allowed for processed crops than for vegetables. The WHO guidelines regarding urine build on the above table but addresses higher temperatures as well. More recent research on pathogen reduction during storage at higher temperatures supports the above recommendations, and also shows that the storage time could be decreased at higher temperatures.

These recommendations are cost effective and as useful as any measurement in a lab. Such rules-of-thumb are easy to grasp and apply, and users are not required to command information on microorganisms and their numbers, survival times, etc. The required detailed knowledge is with those who formulate the rules, however, which will be discusses in the following. If the process or management of material flows goes wrong when using these rules-of-thumb, the same could happen to any system with lots of lab data available.

When and where to apply human urine?

3.4 – 24

- For crops that are to be consumed raw, one month should pass between application and harvesting (withholding/waiting period)
- Urine from a single household can be applied for all types of crops, provided that
  - the crop is intended for consumption in the grower´s household
  - one month passes between fertilisation and harvesting
- We can apply even simpler or less strict guidelines for urine if
  - The system seems to function well – with no visible faecal cross-contamination
  - Information is given to workers (e.g. farmers) who handle the urine
  - Higher temperature of the urine allows for shorter storage time

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

For crops that are to be consumed raw, the urine should be applied on the soil, not on leaves. One month should pass between application and harvest (withholding/waiting period). During that period the number of pathogens is reduced due to UV radiation and predation (see Module 3.3). Such early application of fertilisers is also beneficial for plants since they need more nutrients when they establish roots and leaves (Module 5.1).

For single households the urine and flush water can be used for all types of crops, provided that the crop is intended for consumption by the grower's household and provided that at least one month passes between fertilization and harvesting. The reasons are that the die-off rate on crops is high (see 4.7-27) and that potential pathogens transmitted from a household member to urine is insignificant compared to the likelihood to be transmitted and exposed via door knobs and 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 provided adequate information is given to workers (e.g. farmers) and household members handling the urine, shorter storage times could perhaps be considered. And, as discussed, shorter storage times could be recommended in areas where temperatures are higher. It can also be mentioned that urine collected from urinals is considered safer than urine collected from urine diverting toilets, and storage times could be shortened.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Health protection measures

3.4 – 25

- Aimed at different groups at risk of exposure
  - Food produce consumers
  - Workers and their families
  - Local communities
- Different types of measures, examples
  - Technical barriers: treatment, application methods
  - Behavioural aspects: hand hygiene, food preparation, use of personal protective equipment
  - Medical: Immunization
  - Education: health and hygiene promotion
  - Environment: Vector control

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

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.

Protection measures need to be adapted to local conditions in order to become effective. Overly strict standards borrowed from other countries often fail. Often, low-cost effective treatment technologies are available as indicated below. Guidelines are therefore not just numbers, but go together with good practices.

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

- containment of excreta
- 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
- washing of food stuff, disinfection and cooking.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

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 such as handwashing after defecation
- 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 farming 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:

- containment of faecal matter
- 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, such as handwashing after defecation
- disease vector and intermediate host control
- reduced vector contact.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Treatment of excreta and greywater

3.4 – 26

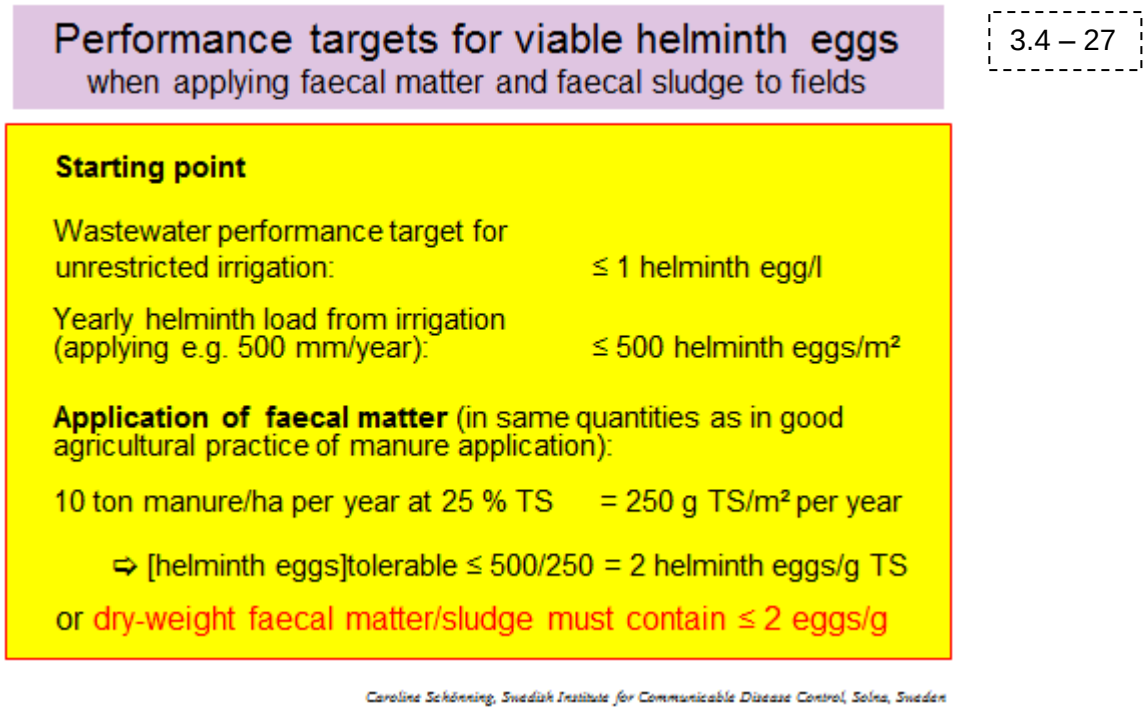
- **Faeces**
  - Storage, composting and alkaline treatment
  - Further research and adaption to local conditions recommended
  - Compare to Modules 4.2-4-4 (which build on further research)
- **Urine**
  - As table above, builds on Swedish recommendations
  - Compare to Module 4.2
- **Greywater**
 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

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

For faeces, a variety of treatment alternatives are available. The WHO Guidelines proposes certain storage times at different temperatures along with recommendations for alkaline treatment and composting. However, since pathogen species have specific properties and resistances to environmental factors, the time for safety will be the result of a combination of factors. The development 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 translated into national (local) regulations and recommendations. For greywater a number of different treatment techniques are described (Modules 4.5-4.7), and many of them are dependent on local conditions.

For all types of treated excreta, additional safety measures are recommended, for example, a 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 account of the treatment of excreta is included in Chapter 4 and greywater treatment is also extensively covered in Chapter 4.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden



The WHO guideline for unrestricted application of wastewater to agricultural fields allows that the water contains not more than 1 helminth egg per liter. Thus, if more irrigation water is applied the total load will increase. The underlying assumption must be that access to water is restricted. If, for example, as much as 500 mm is applied in a year (which equals the annual precipitation in many countries) the helminth load is 500 eggs per m^2.

If the same health risk is accepted for helminth eggs, when applying faecal matter or faecal sludge instead of wastewater, and the applied dose of faecal matter equals the common dose of 10 tons of manure (providing sufficient amount of nutrients for most crops), less than 2 helminth eggs/g dry substance are allowed. This level of concentration of helminth eggs in faecal matter requires treatment/long storage of the material before application.

The harmonization with guidelines for wastewater quality regarding helminth eggs would require a guideline value of <1 egg per liter. The guideline for faecal matter applied on soil is harmonised with wastewater regarding Ascaris. A comparison shows that the guideline value in wastewater results in a tolerable value of 2 helminth eggs per g (dry matter) of faeces.
Thus, a guideline value of <1 egg per g (DM) results in a somewhat lower risk for faeces compared to wastewater.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Health protection measures - agriculture

3.4 – 28

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

- 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.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

After treatment of excreta and greywater the health risks arise from exposure during reuse and food consumption. Many of such microbial health risks can be minimized or even eliminated. In many industrialized countries, wastewater treatment is doing a large part of this job. In other countries, where functional wastewater treatment facilities are rare still, other pathogen barriers can be put in place to manage the health risks. Farmers have an important role to play as they can manage their irrigation water and adapt their cropping system in ways that reduce risks for themselves and the consumers. Extension workers have the crucial task to bring relevant guideline information to farmers, and in assisting them in implementation.

In response to requests from Guidelines' readers, the WHO together with the FAO, the IDRC (International Development Research Centre, Canada), and the IWMI (International Water Management Institute), 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, the "Fact Sheet for Farmers and Extension Workers" 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.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Thus, as many locally available options should be combined, and their cumulative effect adds up to more or less full protection. Not all measures are suitable under all conditions, however. 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." (http://www.who.int/water_sanitation_health/wastewater/factsheet_extensionworkers_farmers.pdf)

Three examples of potential protection measures are:

A) Stopping irrigation several days before harvest to allow natural pathogen die-off are appropriate in a cooler season or climate, but makes leafy vegetables look unfit for sale under hotter conditions.

B) In some countries, like India and Kenya, drip irrigation kits are easily available while in other countries they may be rare.

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

According to the 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 reap plant nutrients, thereby increasing the risk for illnesses to both the farmers and the consumers. FAO's encouragement of recycling water in urban and peri-urban agriculture includes guidelines to assist safe reuse of treated wastewater and greywater, waste recycling such as eco-sanitation.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

3.4 – 29

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

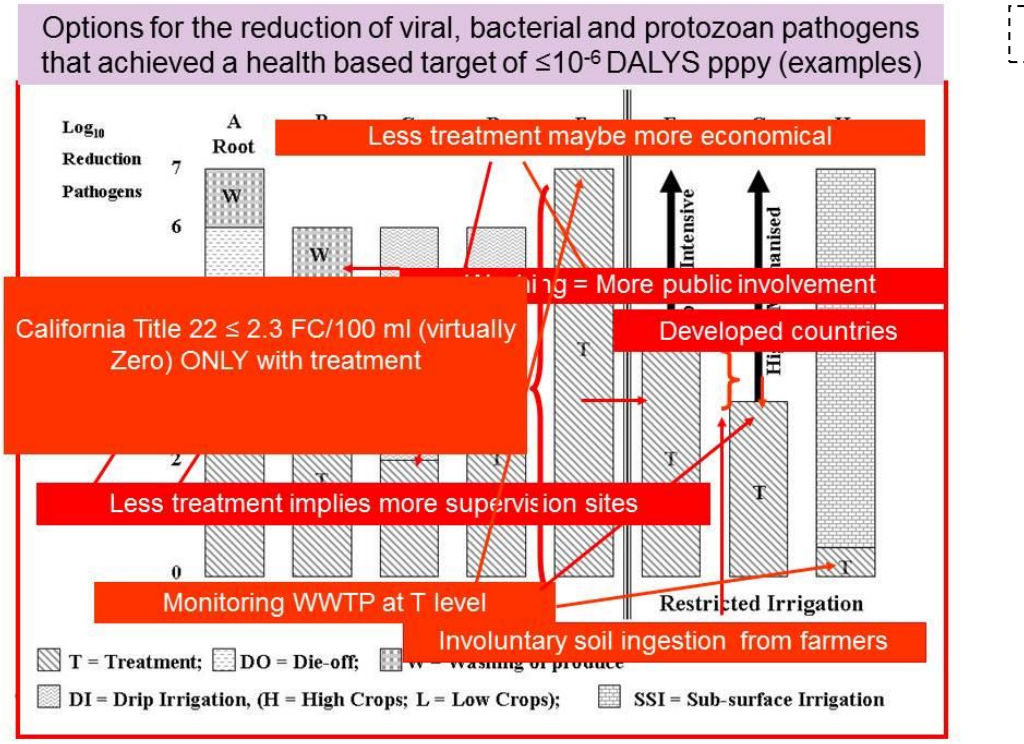
Control measure	Pathogen reduction (log units)	Notes
Wastewater treatment	1–6	The required pathogen removal to be achieved by wastewater treatment depends on the combination of health-protection control measures selected
Localized irrigation (low-growing crops)	2	Root crops and crops such as lettuce 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.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

The information on potential pathogen reduction (in log-units) was estimated by WHO from various research reports. The list includes measures that farmers and household can take to protect health. These measures can be combined and thereby reaching a cumulative reduction. For instance, by withholding irrigation for three days leads to a reduction of 1.5 – 6 log, and if the household cook the produce another 5-6 log is added. These two measures reduce pathogen load thousand times more than any wastewater treatment.

The list of activities provides a manageable menu of options that can be carried out without knowledge of pathogen species, die-off rates etc. and put a powerful tool in the hands of rich and poor to protect their health. In this perspective, the role of extension, media cover, school training material etc. becomes critically important.

3.4 – 30



Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

The diagramme displays some examples of pathogen reduction from the previous slide. 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) i.e. some 4 minutes per year. For restricted irrigation, a reduction of 0.5-4 log (depending on irrigation/application method) is required to reach the same health-based target. Both cases can be achieved by more or less effective wastewater treatment in combination with the choice of an appropriate irrigation method, withholding periods (die-off) and washing of food produce.

All health protection measures bring with them additional related issues. 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 and may in turn require more information and education. Economic aspects are also crucial in most communities.

3.4 – 31

Definitions of monitoring functions

Function	Definition
Validation	Testing the system or components thereof to assess performance, e.g. to see if it is meeting ”microbial reduction targets”. Relates mainly to new systems/components.
Operational Monitoring	Relates to ”design specifications” e.g. temperature. Indicate proper functions and variations and is the basis 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).

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

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.

Each of the three functions of monitoring is used for different purposes at different times. Validation is performed when a new system is developed or when new processes are added. It is also used to test or prove that the system is capable of meeting the specified targets. Operational monitoring is used on a routine basis to determine whether 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, greywater, or crops) meets the 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 breakthrough. However, verification monitoring in larger systems can indicate trends over time (e.g. if the efficiency of a specific process is improving or decreasing).

Guideline values for verification monitoring (1)

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.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Verification monitoring basically uses the number of E. coli to represent viral, bacterial and protozoan pathogens. This practice of using E. coli for verification monitoring may need to be replaced by some other organism, if there are specific pathogens that need to be considered 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. Counts of helminth eggs are only valid in situations where these occur in the human population.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Guideline values for verification monitoring (2)

3.4 – 33

- Verification monitoring
- Greywater, faecal sludge and (dry) faeces
  - Harmonised with wastewater use in agriculture (WHO, volume 2. 2006)
- Mainly applicable in larger systems
- *E. coli* – caution due to growth
- Helminth eggs – where applicable
- Sampling and laboratory procedures

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Verification monitoring is used mainly to check on barriers in large-scale systems. Verification monitoring is not applicable to urine.

The guideline values for risk levels are harmonised with what is required for wastewater monitoring in agriculture. In smaller systems, greater emphasis is placed on operational monitoring, observations and system performance, than on verification monitoring. The guidelines need to deal with frequency of sampling and also with the consequences of non-compliance.

Verification monitoring for wastewater is partly focused on compliance with microbial guideline values, but needs to include periodic monitoring of chemicals, especially in case of industrial discharges. In chemical monitoring, factors related to crop productivity are included. For example, special consideration is given to crops with sensitivity to salinity or boron.

Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden