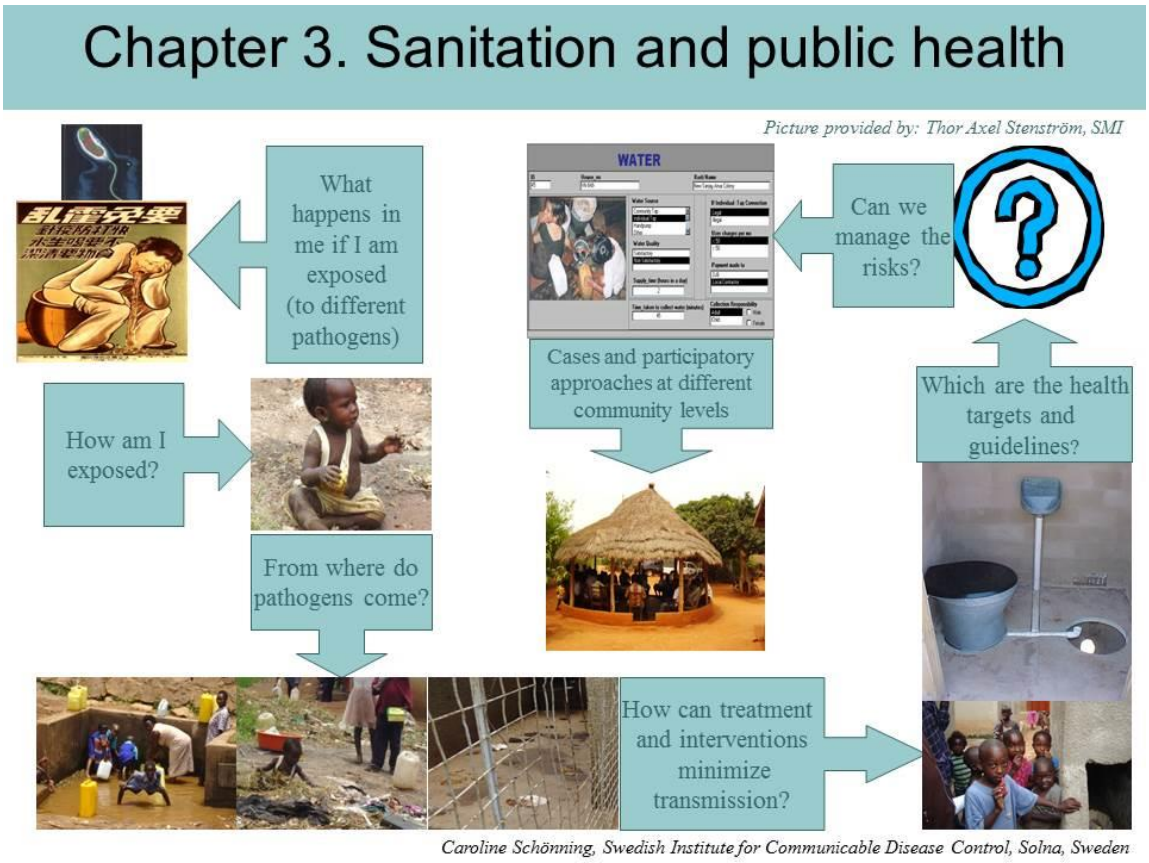

This chapter deals with the public health aspects of sanitation. The focus is on disease-causing microorganisms and how risks can be reduced. The picture above illustrates the transmission of disease from pathogens in the environment. It deals with exposure and potential effects on humans.

Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. The word ‘sanitation’ also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal (WHO, 2010). Inadequate sanitation is a major cause of disease worldwide and improving sanitation is known to have a significant beneficial impact on health both in households and across communities.

Around 1.1 billion people globally do not have access to improved water supply sources whereas 2.4 billion people do not have access to any type of improved sanitation facilities. About 1.5–2 million people die every year due to diarrheal diseases. Most of them are children less than 5 years of age. The most affected populations are in developing countries, living in extreme poverty, usually in peri-urban or rural areas. Among the main problems which are responsible for this situation are: lack of priority given to the sector, lack of financial resources, lack of sustainability of water supply and sanitation services, poor hygiene behaviours, and inadequate sanitation in public places including hospitals, health centres and schools. Providing access to sufficient quantities of safe water, the provision of facilities for a sanitary disposal of excreta, and introducing sound hygiene behaviours are essential to reduce the burden of disease caused by these risk factors. (WHO, 2010).

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This chapter deals with the risk of spreading of infectious diseases in sanitation systems and how these risks can be managed with proper facilities, handling and behavior. The importance of sanitation and the wide perspective that is needed can be understood by the following facts given by WHO:

- Examples of diseases transmitted through water contaminated by human waste include diarrhea, cholera, dysentery, typhoid, and hepatitis A. In Africa, 115 people die every hour from diseases linked to poor sanitation, poor hygiene and contaminated water.
- Studies show that improved sanitation reduces diarrhea death rates by a third. Diarrhea is a major killer and is largely preventable. It is responsible for 1.5 million deaths every year, mostly among under-five children living in developing countries.
- Adequate sanitation encourages children to be at school, particularly girls. Access to latrines raises school attendance rates for children. An increase in girls' enrolments can be attributed to the provision of separate, sanitary facilities
- Hygiene education and promotion of hand washing are simple, cost-effective measures that can reduce diarrhea cases by up to 45%. Even when ideal sanitation is not available, instituting good hygiene practices in communities will lead to better health. Proper hygiene goes hand-in-hand with the use of improved facilities to prevent disease.
- The economic benefits of sanitation are a persuasive. For every US$ 1 invested in improved sanitation, it shows an average of US$ 9 return in value. Those benefits are experienced specifically by poor children, and in the disadvantaged communities that need them most
- The Millennium Development Goals target 75% global sanitation coverage by 2015. The cost to reach the milestone is estimated at US$ 14 billion annually through the period. Among other health gains, sanitation is estimated to reduce diarrhea cases by 391 million worldwide each year

  http://www.who.int/features/factfiles/sanitation/facts/en/index9.html

Module 3.1 includes facts and figures related to sanitation and infectious diseases, and explains basic epidemiology and burden of disease terminology**.** In Module 3.2 we describe how pathogens are spread in the environment through sanitation systems, resulting in a potential threat to humans and animals. Module 3.3 provides a theoretical and practical background to how pathogens can be eliminated, thus reducing the risk of disease transmission. More practical advice and rules of thumb for treatment of excreta are given in Chapter 4. Module 3.4 deals with health targets and guidelines, including theoretical information on faecal indicators and microbial risk assessment (MRA) that are directly linked to these risk management tools. Module 3.5 provides an overview of risk management, including a few examples of quantitative risk assessment (QMRA) and epidemiological studies.

In addition to sanitation as such, the chapter discusses the sustainable use of "sanitation products" or "waste products", such as treated excreta, in agriculture.

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3.1 Exposure and effects in humans

How are infectious diseases transmitted?

What happens when people are exposed to pathogens?

Learning objective: to become familiar with the most important pathogens found in water and sanitation systems, with the symptoms they cause and with their effect on individuals and populations.

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Microorganisms are a natural part of our environment and our bodies, and they are necessary for our survival and health. However, the harmful ones, known as pathogens, may cause disease and/or death if we are exposed to sufficient amounts. Exposure can either occur in the environment or through direct contact with other people or animals. In this module the exposure to pathogens and the effects of pathogens on humans are addressed in a general manner. Pathogens of concern in sanitation systems are described, with some details given, but further reading of relevant fact sheets is encouraged. The effect that sanitation is considered to have on public health on a global scale is also discussed. We introduce a standard terminology that will facilitate the presentations in the Sourcebook.

3.1 - 3

DALYs – a general measure for health

The Global Burden of Disease (GBD)
Murray and Lopez, 1996

- Disability Adjusted Life Years (DALY)
  - morbidity: years lived with a disability
  - mortality: years lost
- DALY (loss of healthy lived years) = n x t x S
  - n = number of affected persons
  - t = the duration of the health effect
  - S = measure of the severity of the health effect (mortality = 1)

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A large number of publications address the burden of disease, a concept that was originally introduced the report by Murray and Lopez in 1996 *(The Global Burden of Disease* (GBD)) in which they developed the indicator, Disability Adjusted Life Year (DALY).

Disability Adjusted Life Years (DALYs) are a measure of the health of a population, or of the *burden of disease* caused by a specific disease or risk factor. DALYs are used to measure, using one indicator, the total time that is lost due to the combined effects of ill-health, disability and early death. A DALY includes the time lost due to the acute stage of a disease (e.g. from being ill for one week), plus the time lost due to disability (reduced ability due to the disease) and the time lost due to premature death. DALYs are calculated by adding the years lost due to the acute incident, premature death and the years lived with a disability. Years lost are calculated by using age-specific mortality rates and the expected length of life in a given population. Years lived with a disability are calculated by multiplying the number of cases by the average duration of the disease and a *severity factor* that varies between 1 (death) and perfect health (0) and is dependent on the disease. Watery diarrhea, for example, has a severity factor between 0.09 and 0.12, depending on age group. DALYs is an important tool for comparing health effects since it considers acute, later developing and chronic effects, and includes both morbidity and mortality. It also makes it possible to compare different types of health effects, e.g. cancer compared to giardiasis, and this can aid in risk management.

DALY is a health gap measure that extends the concept of potential years of life lost due to premature death (PYLL) to include equivalent years of ‘healthy’ life lost by virtue of being in states of poor health or disability. The DALY combines in one measure the time lived with disability and the time lost due to premature mortality. One DALY can be thought of as one lost year of ‘healthy’ life and the burden of disease can be seen as a measurement of the gap between current health status and an ideal situation where everyone lives into old age free of disease and disability. For relating to this information it is however only necessary to know that it is a measure (a unit) that can be used to understand the magnitude of the impact various risk factors have on public health.

Disease burden related to cases of disease vary widely in different localities, and DALYs can be used as a measure of these variations. For example, the disease burden per 1000 cases of rotavirus diarrhea is 480 DALYs in low-income regions, where child mortality frequently occurs. However, it is only 14 DALYs per 1000 cases in high-income regions, where hospital facilities are accessible to the great majority of the population. Many diseases are linked to starvation since malnutrition affects individuals' immune systems and infections manifest more easily if the immune system is suppressed.

Further reading:

The Global Burden of Disease (GBD) provides systematic epidemiological estimates for an unprecedented 150 major health conditions. It explains methods and presents results, including: disaggregated death and disability data; projections to the year 2020; and risk factor evaluations. While it minutely examines causes of death, the GBD is unique in its inclusion of disability. The authors explore the technical bases and moral implications of incorporating social, physical, and mental disabilities in health assessments, explicating the indicator they have developed, the disability-adjusted life-year (DALY). The GBD provides indispensable global and regional data for health planning, research, and education.

http://whqlibdoc.who.int/publications/2008/9789241596435_eng.pdf

http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(08)60925-3/fulltext?version=printerFriendly

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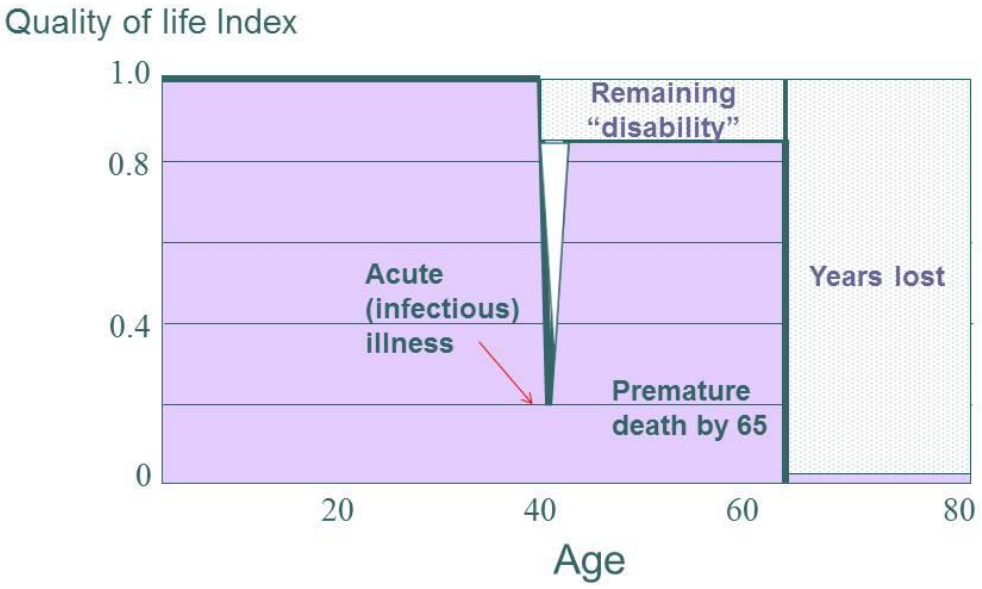
Hypothetical example of DALYs

3.1 - 4



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This is an example of how DALYs could be calculated for an individual. At age 40 a person suffers from an acute illness. The person recovers but is left with a disability corresponding to a severity factor of 0.1(seen as the dotted (grey) area between 1.0 and 0.9 up to the age of 65). As a result of the illness he then dies at 65 instead of the predicted 80 in the population, resulting in 15 years lost.

The total DALY for this individual (this case of infection) is thus (1 x 25 x 0.1) + (1 x 15 x 1) + the acute phase (exact time not identified), since n=1 person, t=25 years for the disability with S=0.1 and t=15 years for mortality (S=1). This corresponds to the formula in the previous picture, adding three time periods with different severity factors.

In quantitative microbial risk assessments DALYs can be included as a final step to present results for the assessment (see Module 3.4) but the definition is mainly given here in order to explain the factors included when assessing the health impacts of sanitation.

Leading DALYs in in the world 1990 & 2020

3.1 - 5

Murray *et al.* (1996) Science 274:740-743

Disease/Injury	1990		2020	
	Rank	%DALYs	Rank	%DALYs
Lower respiratory	1	8.2	6	3.1
Diarrhoeal	2	7.2	9	2.7
Perinatal period	3	6.7	11	2.5
Depression	4	3.7	**2**	**5.7**
Heart disease	5	3.4	**1**	**5.9**
Tuberculosis	7	2.8	7	3.1
Road accidents	9	2.5	**3**	**5.1**
HIV	28	0.8	10	2.6
Lung cancers	33	0.6	15	1.8

"The sanitary revolution" - the most important medical milestone since 1840 !? (BMJ, 2007)

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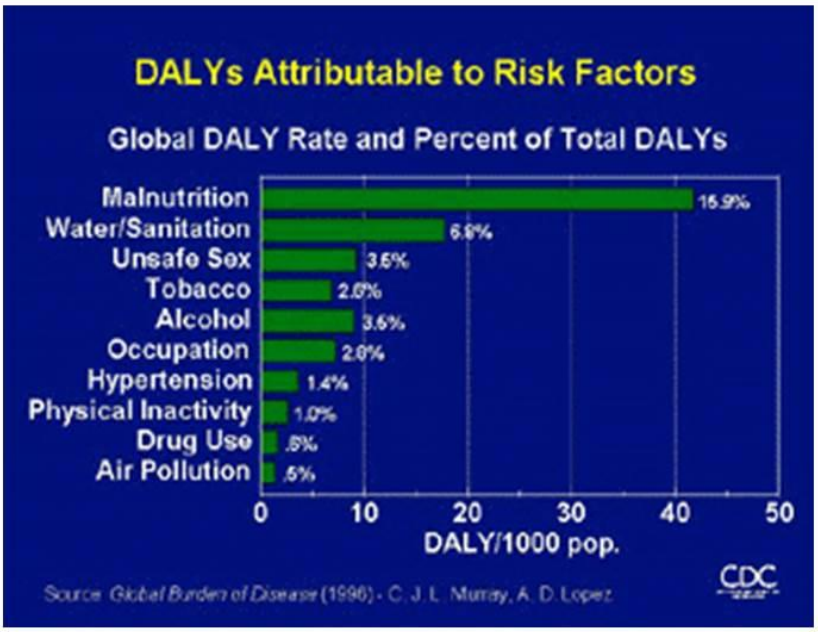
The above table shows the rank of some diseases and injuries and the expected future global situation. It is anticipated that what can be called (economic) development will result in an increase in heart disease (e.g. due to changes in food intake), depression and road injuries. The positive effect of predicted improvements in water and sanitation is probably one part of the explanation for a much lower percentage of DALYs related to diarrhea in the future.

A poll of more than 11, 300 readers of the *British Medical Journal* chose the introduction of clean water and sewerage – "the sanitary revolution" – as the most important medical milestone since 1840. Readers were given 10 days to vote on a shortlist of 15 milestones, and sanitation topped the poll, followed closely by the discovery of antibiotics and the development of anaesthesia. The work of the 19th century lawyer Edwin Chadwick, who pioneered the introduction of piped water and sewerage to people's homes, attracted 15.8% of the votes, while antibiotics took 15%, and anaesthesia took 14%.
(http://www.bmj.com/content/334/7585/111.2.extract)

DALYs attributable to risk factors

3.1 - 6



Water and sanitation causes a major part (9%) of GBD, that largely could be prevented. (WHO, 2008)

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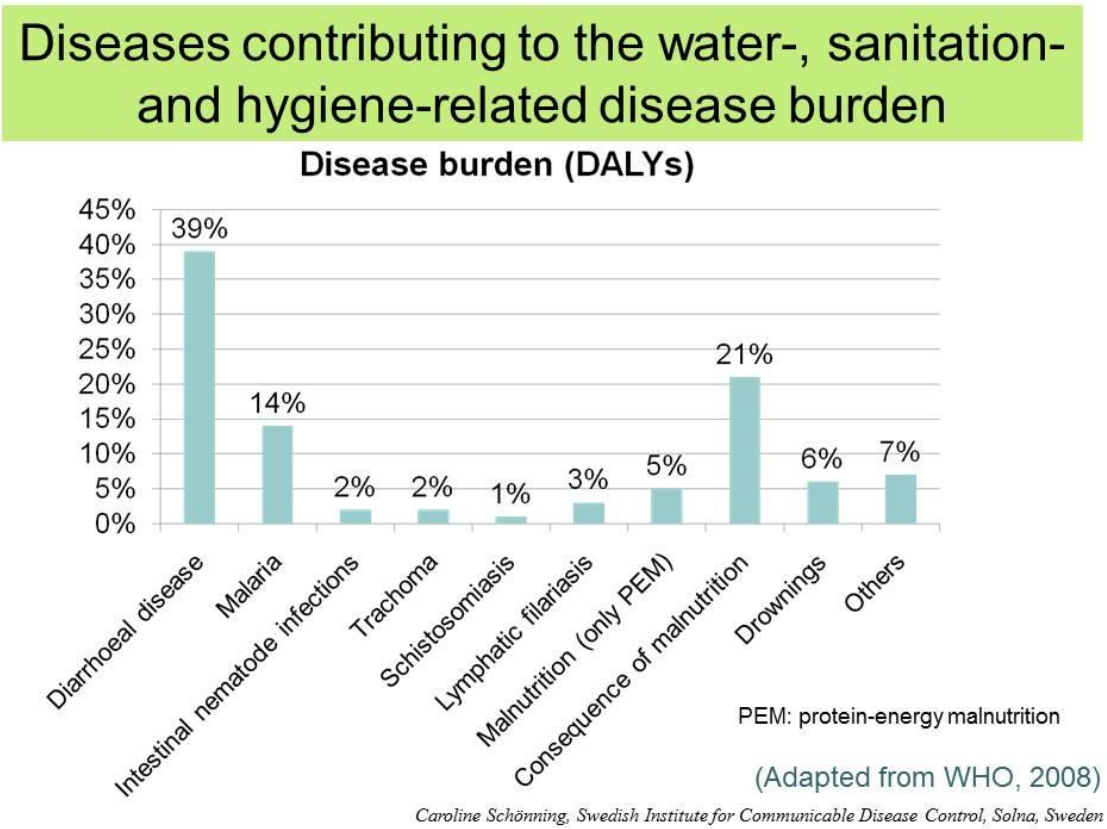
The above picture shows the 10 most important risk factors on a global scale. Malnutrition is by far the largest risk factor, resulting in almost 16% of the total global DALYs. Water and sanitation was in second place at the time the Global Burden of Disease report was published in 1996. It was responsible for 7% of the DALYs.

A more recent message regarding water and sanitation is that it causes a major part (9%) of GBD, and that it largely could be prevented. (WHO, 2008)
http://whqlibdoc.who.int/publications/2008/9789241596435_eng.pdf

According to WHO, the world is on track to achieve the MDG target for access to safe drinking-water but more needs to be done to achieve the sanitation target. Fewer children are now dying and fewer are underweight, compared to 1990.

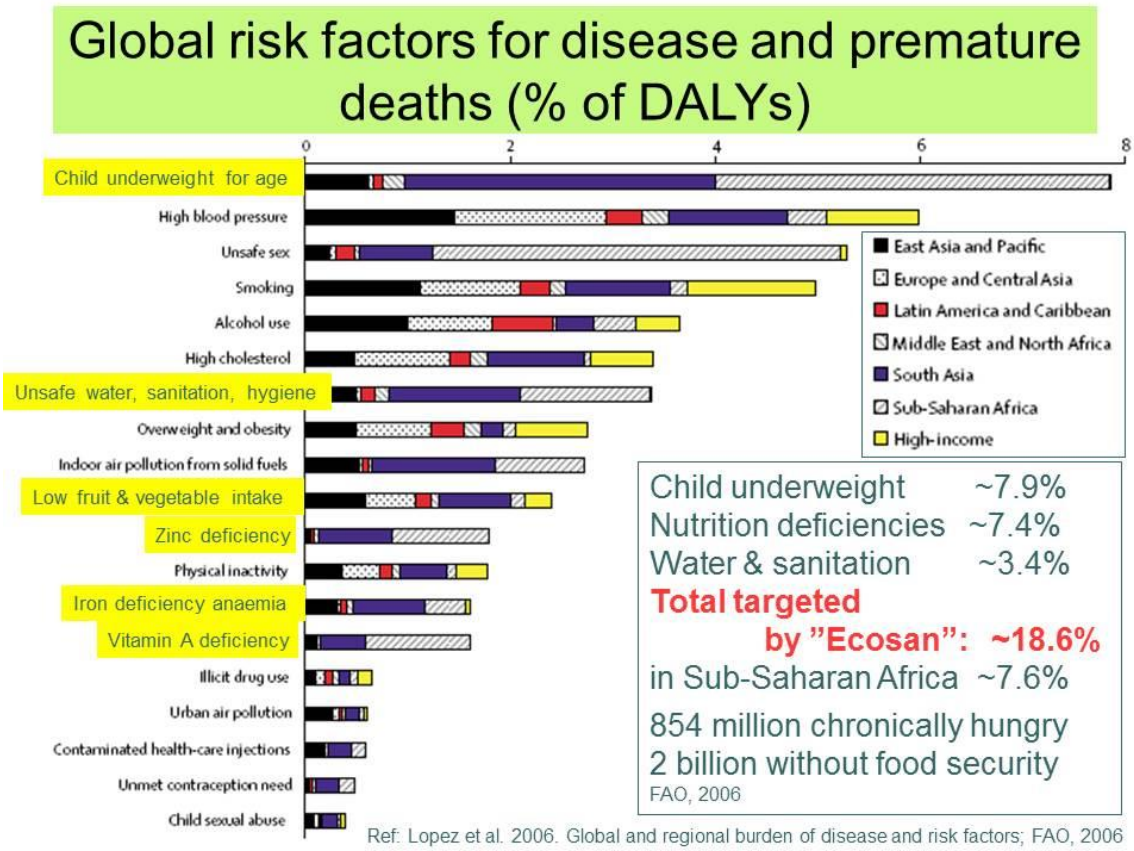
3.1 - 7



WHO try to address the health burden related to water, sanitation and hygiene including infectious diseases and malnutrition as well as drowning. As stated above, it is estimated that altogether 9% of this burden is caused by problems related to water supplies and sanitation and that most of these problems could be prevented by improvements related to drinking water, sanitation, hygiene and water resource management* (http://whqlibdoc.who.int/publications/2008/9789241596435_eng.pdf)

*The numbers will vary in this training material, due to differences in the literature cited. Estimates of the burden of disease related to various health problems, and related to various risk factors, are understandably difficult to calculate and estimate.

3.1 - 8



This graph is more detailed and shows the division of DALYs in the world. About 52% of the total burden of disease and premature deaths is specified in the diagram. The publication estimates that in 2006, 3.4% of the total worldwide DALY was related to water and sanitation. However, 7.9% was attributable to children being underweight and 7.4% to nutrition deficiencies. Theoretically most of this "ill-health" could be remedied with sanitation systems that protect water and the environment, and which contain and/or reuse the nutrients in excreta (e.g. "ecological sanitation").

About half of the burden due to underweight children is in Sub-Saharan Africa, and the main other part is in South Asia. The situation is similar for unsafe water, inadequate sanitation, zinc deficiency and vitamin A deficiency, while iron deficiency and low fruit and vegetable intake are more evenly distributed. Zinc is found in meat, poultry, , beans, nuts, whole grains and some seafood. Iron is found in liver and blood food, meats, seafood, fish, beans, peas, spinach and whole grains. Vitamin A is found in liver, beef, chicken, eggs, whole milk, fortified milk, carrots, mango, orange fruits, sweet potato, spinach, kale, and other green vegetables. Vitamin A is crucial for maternal and child survival and vitamin A deficiency also causes blindness.

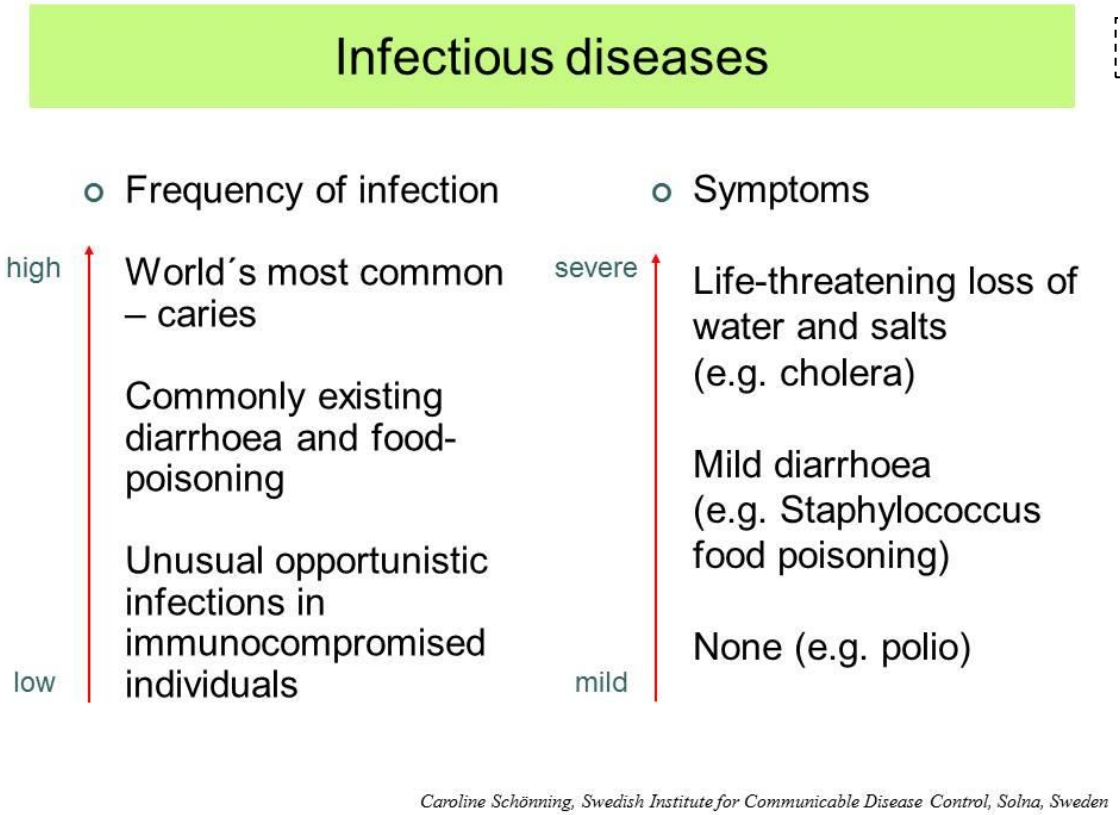
Nutrients in excreta and the use of excreta for fertilizer are discussed in Module 4.8.

Further reading:

Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T. and Murray, C.J.L. (2006) Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. Lancet (North American Edition) 367 (9524): 1747-1757.

FAO. 2006. The state of food insecurity in the world. Eradicating world hunger – taking stock 10 years after the world food summit. FAO. Rome, Italy.

Download: 2006 ftp://ftp.fao.org/docrep/fao/009/a0750e/a0750e00.pdf .



Infectious diseases are caused by microorganisms that invade the body and multiply. Normally, the body's natural defenses prevent microorganism from causing illness. Often, however, the microorganisms resist the body's defenses and cause infection. The severity of infections can range from mildly annoying, such as with a cold or diarrheal illness, to life threatening, as with meningitis or AIDS. The severity of the infection depends on the overall health of the patient and the virulence (strength) of the microorganism.

Infectious diseases are caused by different types of microorganisms: bacteria, viruses, parasitic protozoa, helminthes or fungi. The most common is caries (the highest frequency as presented in the above picture). Caries are caused by bacteria. The common cold is another example of a common and widespread infection, usually caused by viruses. Some diarrheal diseases are caused by common pathogens whereas others are rare. Infections vary in the symptoms they cause. There may be no symptoms at all as exemplified with polio above (also see slide 13). Some gastrointestinal infections may be asymptomatic in some individuals whereas others, like cholera, often result in watery diarrhea that may be life-threatening.

The field of Epidemiology

3.1 - 10

- Definitions
  - (1) The study of the relationships of the various factors determining the frequency and distribution of diseases in a human community.
  - (2) The field of medicine that attempts to determine the exact causes of localized outbreaks of disease.
    (Ologies & -Isms. Copyright 2008 The Gale Group, Inc)
- The start in the middle of the 19th century
  - Cholera epidemics in London - consumption of water implied an increased risk for disease (John Snow)
  - Established that germs or bacteria cause infectious disease (Pasteur, 1857)

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To further understand the modules in Chapter 3 and to be able to discuss the issues they deal with, basic information on epidemiology is needed. A short introduction with definitions is given to provide a common understanding of the terminology. For deeper studies of health issues, we refer to the *Further reading* section at the end of each module.

There are several common definitions for epidemiology. One of them is, in two parts (Ologies & -Isms. Copyright 2008 The Gale Group, Inc):

1. The study of the relationships of the various factors determining the frequency and distribution of diseases in a human community.
2. The field of medicine that attempts to determine the exact causes of localized outbreaks of disease.

Historically it can be said that epidemiology started during the cholera epidemics in London in the middle of the 19th century. John Snow recognized that the consumption of water from particular sources was associated with an increased risk of contracting the disease, although the disease-causing agent (*Vibrio cholerae*) had yet to be isolated and identified. In 1857 Pasteur established the theory that infectious disease is caused by germs or bacteria. The 19th century cholera epidemic in London is considered to be the first recorded outbreak of a waterborne disease. Other early recorded waterborne diseases included typhoid, dysentery and polio.

Occurrence of disease

3.1 - 11

- Prevalence
  - The number of cases in a defined population at a specified point in time
- Incidence
  - The number of new cases arising in a given period in a specified population

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Epidemiological terms used to describe the health situation in a population include “prevalence” and “incidence”.

Prevalence is the number of cases in a defined population at a specified point in time.

Incidence is the number of new cases arising in a given period in a specified population.

These measures are needed both for estimating health risks from water and sanitation systems and to be able to record improvements in the health status of a population after interventions (see Module 3.5).

Transmission of infectious agents

3.1 - 12

- Direct transmission
  - Touching
  - Kissing
  - Sexual intercourse
  - Other contact
  - Airborne, short distance via droplets, coughing, sneezing
  - Transfusion (blood)
  - Transplacental
- Indirect transmission
  - Vehicle-borne (contaminated food, water, towels, farm tools etc.)
  - Vector-borne (insects, animals)
  - Airborne, long distance via dust and droplets
  - Parenteral (injections with contaminated syringes)

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Transmission of infectious diseases by pathogens (disease-causing microorganisms, infectious agents) occurs by direct transmission or by indirect transmission.

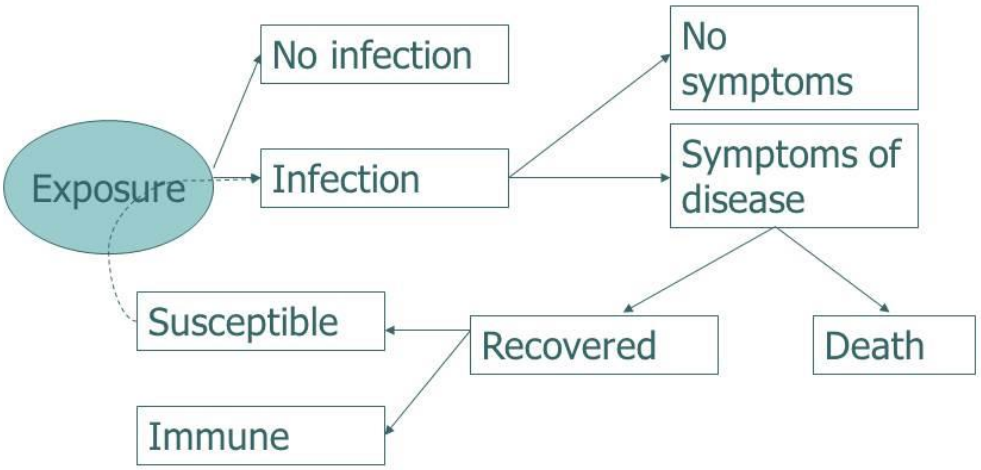
Direct transmission includes transmission from person to person by various types of contact, e.g. by touching and sexual intercourse, by exchange of blood during transfusions or from mother to child through the placenta. It also includes airborne transmission over short distances, such as coughing or sneezing.

Indirect transmission includes transmission via materials such as food and water that are ingested, but also possible exposure to pathogens by touching contaminated surfaces and then ingesting pathogens (i.e. hand-mouth). It also includes vector-borne transmission where animals in some way transport the pathogens, long distance airborne transmission e.g. by dust or droplets (aerosols) and finally parenteral transmission ("taken into the body or administered in a manner other than through the digestive canal") through injections with contaminated syringes.

When it comes to disease transmission related to water and sanitation it is thus indirect transmission we are dealing with. Exposure to pathogens and possible transmission of disease can occur when humans (and animals) come in contact with wastewater, faecal material, polluted or drinking water. How this exposure occurs is further described in Module 3.2.

Consequences of exposure

3.1 – 13



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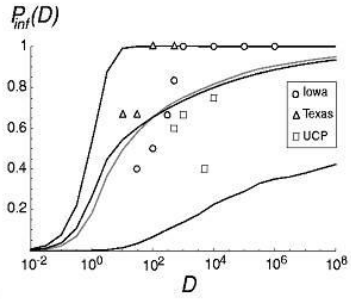
Exposure to pathogens does not necessarily lead to infection or disease. To become infected a certain number of pathogens needs to be ingested, corresponding to the infectious dose, which varies depending on pathogen/disease and also may vary from individual to individual. Even if an infection is established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

Symptoms can be mild or severe, and may vary during the course of the infection. Some infections have different stages, with for example initial symptoms (e.g. diarrhea) and long-lasting or chronic complications of another type (e.g. arthritis). Long-lasting symptoms which occur after the departure of the original disease are called sequela.

Infectious dose

3.1 - 14



- Minimum infectious dose
- ID_{50}
- Probability of infection
  - Dose-response curves
- Severity of disease depending on
  - Ingested dose
  - The condition of the mechanical barrier
  - The stability of the normal enteric flora
  - Immunity
  - The nutritional status of the individual

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The infectious dose was often reported as the minimum infectious dose – the lowest number of organisms known to result in infection, or as ID50, the dose at which 50% of exposed individuals will become infected. More recently, it has been possible to establish the probability of infection for some pathogens through so called dose–response curves that build on studies of healthy individuals who have ingested a specific number of the pathogens in question (see Module 3.4).

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 possessed by the individual and the nutritional status of the individual.

3.1 - 15

Immunity – vulnerable groups

Vulnerable groups in society:

- The old (elderly)
- Infants
- Pregnant women
- Immunocompromised
- Malnourished

http://www.oldpeoplearefunny.com/pictures/

These groups comprise about 20% of the general population and are growing

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Vulnerable groups are more sensitive to pathogens and thus a lower dose is required to cause an infection. These groups include the old, the very young, pregnant women and immunocompromised individuals such as HIV/AIDS patients and cancer patients. Together they comprise about 20% of the population and this percentage is increasing. There are however, large differences in the sizes of the groups in different parts of the world. When it comes to infectious diseases and risks from water and sanitation systems, one question is how to deal adequately with individuals in vulnerable groups. This is because when assessing risk and when estimating the demands on treatment systems, the starting point is often a health target or tolerable risk level, based on healthy individuals (see further Module 3.4). The actual level of vulnerability among children, for example, is seen during emergencies (e.g. flooding) when they are more exposed diarrheal disease and are very sensitive to dehydration.

The combination of malnutrition and infectious disease can be particularly pernicious. Protein-energy malnutrition (PEM) can impair the immune system, leaving malnourished children less able to battle common diseases such as measles, diarrhea, respiratory infections, tuberculosis, pertussis, and malaria. Vitamin A deficiencies are often worsened by infectious disease, and reciprocally, poor vitamin A status is likely to prolong or exacerbate the course of an illness such as measles. (Andrew Tomkins and Fiona Watson, *Malnutrition and Infection: A Review* (United Nations Administrative Committee on Coordination/Subcommittee on Nutrition, WHO, Geneva, 1989, pp. 5–6).

Epidemiology - Definitions

3.1 - 16

Pandemic: An epidemic (a sudden outbreak) that becomes very widespread and affects a whole region, a continent, or the world.

By contrast:
An **epidemic** affects more than the expected number of cases of disease occurring in a community or region during a given period of time.

An **endemic** is present in a community at all times but in low frequency.

(http://www.medterms.com/script/main/art.asp?articlekey=4751)

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Epidemic: An epidemic affects more than the expected number of cases of disease occurring in a community or region during a given period of time. A sudden severe outbreak within a region or a group as, for example, AIDS in Africa or AIDS in intravenous drug users.

Pandemic: An epidemic (a sudden outbreak) that becomes very widespread and affects a whole region, a continent, or the world.

Endemic: An endemic is present in a community at all times but in low frequency. An endemic is continuous as in the case of malaria in some areas of the world or as with illicit drugs in some neighborhoods.

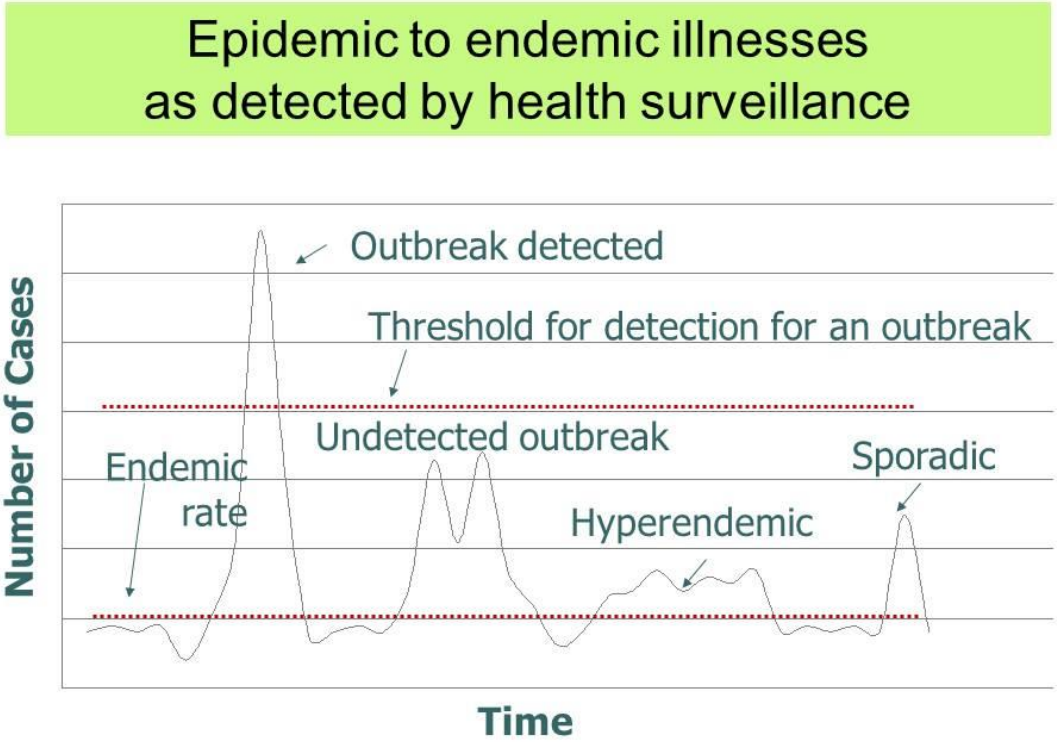
The word "pandemic" comes from the Greek **pan** ("all") + **demos** ("people or population") = **pandemos** ("all the people"). A pandemic affects all (nearly all) of the people. By contrast, **epi-** means "upon." An epidemic is visited upon the people. **En-** means "in." An endemic is in the people. (http://www.medterms.com/script/main/art.asp?articlekey=4751)

However, in 2009 during the "flu pandemic" the definition of pandemic (according to the WHO) was debated and also changed. Originally three conditions had to be met before a disease to be declared a pandemic:

- The disease had to be new to a population, or had not surfaced for a long time
- This disease had to be caused by agents that infected humans, causing serious illness; and
- The agents had to be capable of spreading easily and sustainably among humans.

The original definition also contained two other conditions – there had to be a high morbidity and a high mortality rate. In other words, a lot of people had to fall seriously ill, and a lot of them had to die. This did not happen with the H1N1 flu. Although many people caught the illness, most experienced only mild symptoms. Only a small percentage became seriously ill, and a smaller percentage died. At the time of the pandemic declaration, nearly 30,000 people in 74 countries had been infected but only 144 people died. The death rate was less than 0.5 percent, which is very low. In contrast, SARS (severe acute respiratory syndrome) had a death rate of about 15 percent but SARS was not declared a pandemic because few people got infected.

3.1 - 17



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At any given time some infections are always occurring. This is the so-called endemic background level (the endemic rate). This level varies depending on country and region. To detect disease outbreaks, the number of cases needs to exceed a certain number. Sporadic cases (at rates higher than the endemic level) and smaller outbreak situations may be difficult to detect.

Health surveillance is the obligatory or voluntary reporting of diseases in a society. For an infectious disease to be reported several steps need to be taken:

1) The infected person must seek medical help
2) The doctor needs to arrange for a clinical sample to be taken
3) The correct analysis must be ordered from the laboratory
4) The laboratory must identify the disease-causing organism
5) The clinical result must be reported to the health surveillance system.

The efficiency of health surveillance systems varies greatly between societies. It is however well recognized that surveillance systems always underestimate the actual number of cases. Targeted epidemiological investigations can be a complement to general surveillance for determining the prevalence of a disease in a society. Such investigations are often expensive and cumbersome to conduct since clinical samples must be collected from a large number of persons.

3.1 - 18

Diarrhoea and sanitation

- Causes ~1/5 of deaths in children <5 years (1.5 million)
- Has decreased, in 1980´s estimated 2/3 of deaths
- Less significant decrease in diarrhoeal disease in low-income countries
- Infections related to water and sanitation
- 4.1% of the total DALY
- 88% of the burden attributable to unsafe water supply, sanitation and hygiene
- Improved sanitation can reduce diarrhoea by ~32%
- 391 million cases averted if MDG target met

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

Diarrhea causes approximately 1/5 of deaths in children under 5 years of age (about 1.5 million deaths per year). The impact of diarrhea has decreased since the 1980s when it was estimated to account for 2/3 of deaths. However there has not been a significant decrease in diarrheal disease in low-income countries. In 2004 diarrheal disease accounted for an estimated 4.1% of the total DALY global burden of disease and is responsible for the deaths of 1.8 million people every year (WHO, 2004). It was estimated that in 2004 88% of that burden was attributable to unsafe water supply, sanitation and hygiene and mostly affects children in developing countries.

A significant amount of disease could be prevented especially in developing countries through better access to safe water supplies, adequate sanitation facilities and better hygiene practices.

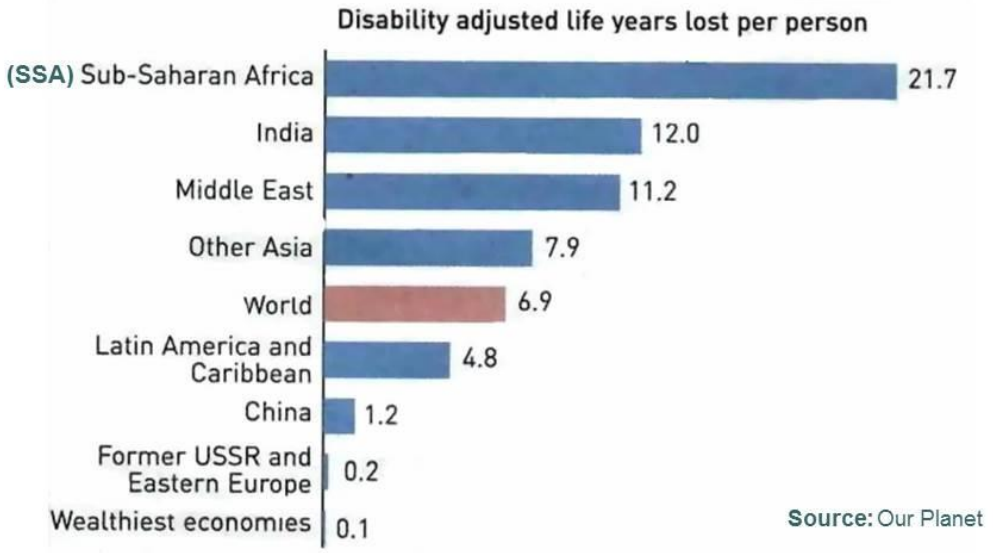
Improved sanitation has been calculated to reduce diarrhea by 32%. IF the sanitation part of the MDG target to “reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation” by 2015 is met, 391 million cases of diarrhea will be averted each year.

http://www.who.int/water_sanitation_health/diseases/burden/en/index.html

http://www.who.int/water_sanitation_health/hygiene/securingsanitation1.pdf

Regional differences in average health burdens from diarrhoeal diseases

3.1 - 19



Current annual diarrhea cases in SSA:
1.2 billion which lead to 769,000 dead children, mostly under 5 years

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

This is the number of DALYs per person that are lost due to diarrhea in different parts of the world. The situation is worst in Sub-Saharan Africa where there are 1.2 billion annual cases, resulting in around 800,000 children losing their lives.

Diarrhoeal diseases – Outbreaks related to water and sanitation

3.1 - 20

- Cholera
  - 36 reported outbreaks from 2006-2009 (WHO)
  - Risk during flooding
  - "Natural environmental" spread
- Typhoid fever
  - Also endemic
- Shigellosis

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

Outbreaks may occur when major failures in water or sanitation systems occur. The definition of an outbreak is that a larger number of persons (in theory however two is enough) gets infected by the same type of pathogen from the same source, approximately at the same time. However, the incubation time (the time from exposure to the onset of disease) may vary substantially. Outbreaks may also include secondary cases caused by person-to-person transmission.

Globally, cholera is one of the more severe diarrheal diseases that often occur in outbreak-type situations. Cholera is caused by a waterborne pathogen that infects 3 to 5 million people annually and leads to an estimated 120,000 deaths each year. It is considered to be one of the largest problems during major floods. The WHO reported 36 outbreaks from 2006 to 2009.

In 2010 Dr Rita Colwell received the Stockholm Water Prize for her findings that the causative agent for cholera, *Vibrio cholera*, could survive by attaching to zooplankton. This led to her groundbreaking discovery that certain bacteria, including the *Vibrio* species, can enter a dormant stage that is able to revert to an infectious state under the proper conditions. This means that even when there are no disease outbreaks, rivers, lakes and oceans can serve as reservoirs for these bacteria. These findings refuted the conventional assumption that cholera was only spread from person to person, food or drinking water and that its presence in the environment could only be due to the release of sewage. As a result of her work, scientists are now able to link changes in the natural environment to the spread of the disease.

Typhoid fever is a bacterial disease, caused by *Salmonella typhi* (see below) that is endemic in several parts of the world with an estimated 16 million cases per year. It is transmitted through the ingestion of food or drink contaminated by the faeces or urine of infected people. It also occurs in outbreak situations, for example in the Democratic Republic of the Congo from September 2004 to January 2005 there were 42,564 cases and 214 deaths. Very poor sanitary conditions and a lack of drinking water have been reported in areas where there have been typhoid fever outbreaks.

Shigella is a genus of bacteria that are a major cause of diarrhea and dysentery (diarrhea with blood and mucus in the stools) throughout the world. The bacteria are transmitted by the ingestion of contaminated food or water, or through person-to-person contact. All outbreaks reported by the WHO during the 21st century have been in Africa.

For example in Lesotho there was an outbreak in which there were 1,862 cases with 28 deaths (from November 1999 to January 2000). Adults were more affected than children. Problems identified were a "*lack of protection of latrines and inadequate water supplies*". All unprotected water springs/wells which were inspected were contaminated while most of the protected springs had good quality water.

3.1 - 21

Cholera epidemic

- Acute watery diarrhoea, very deadly without rapid treatment
- Affects adults as much as children, especially informal caretakers
- High political profile : can be used as a political leverage

- Characteristics for cholera outbreaks
  - high attack rate
  - low mortality
  - economic and social burden
- Factors of spread
  - density of population
  - transportation facilities
  - living conditions
  - environmental reservoirs

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

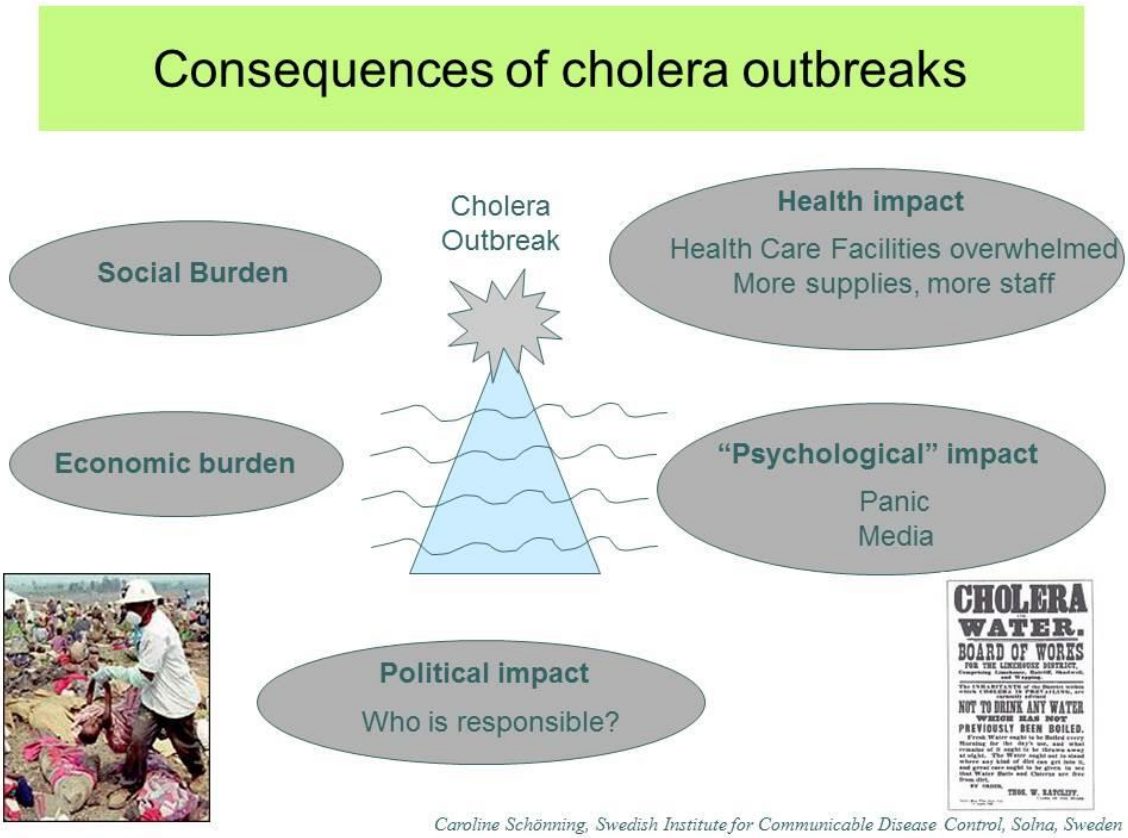
Cholera outbreaks can occur sporadically in any part of the world where water supplies, sanitation, food safety and hygiene practices are inadequate. Overcrowded communities with poor sanitation and unsafe drinking-water supplies are most frequently affected.

Cholera is an acute infection of the intestine which begins suddenly with painless watery diarrhea, nausea and vomiting. Most people who become infected have very mild diarrhea or are symptom-free but some groups of the population, particularly malnourished people, experience more severe symptoms. Severe cholera cases present with profuse diarrhea and vomiting. Severe, untreated cholera can lead to rapid dehydration and death. If untreated, 50% of people with severe cholera will die, but prompt and adequate treatment reduces this to less than 1% of cases.

In the year 2000 cholera cases and deaths officially reported to the WHO came from 27 countries in Africa, 9 countries in Latin America, 13 countries in Asia, 2 countries in Europe, and 4 countries in Oceania. Control of cholera is a major problem in several Asian countries as well as in Africa. In the year 2000, some 140,000 cases resulting in approximately 5,000 deaths were officially notified to the WHO. Africa accounted for 87% of these cases. After almost a century of no reported cases of the disease in Latin America, cholera reappeared in 1991. However, the number of cases reported in Latin America has been steadily declining since 1995.

http://www.who.int/water_sanitation_health/diseases/cholera/en/

3.1 - 22



The consequences of outbreaks, and especially of cholera due to the high mortality, are multi-faceted.

Classification of communicable diseases related to water and sanitation

3.1 - 23

- **Water-borne diseases:** caused by the ingestion of water **contaminated by human or animal faeces or urine** containing pathogenic bacteria or viruses or parasites; include cholera, typhoid, amoebic and bacillary dysentery and other diarrhoeal diseases.
- **Water-washed diseases:** caused by poor personal hygiene and skin or eye contact with contaminated water; include scabies, trachoma and flea, lice and tick-borne diseases.
- **Water-based diseases:** caused by parasites found in intermediate organisms living in water; include dracunculiasis, schistosomiasis and other helminths.
- **(Other) Water-related diseases:** caused by insect vectors which breed in water; include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever.

(WHO, 1996)

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

Another term for infectious diseases is "communicable diseases". They can also be called contagious diseases. To classify the types of transmission of diseases via water the following division can be made:

- **Water-borne diseases:** caused by the ingestion of pathogenic bacteria, viruses or parasites contained in water contaminated by human or animal faeces or urine. They include cholera, typhoid, amoebic and bacillary dysentery and other diarrheal diseases.
- **Water-washed diseases:** caused by poor personal hygiene and skin or eye contact with contaminated water. They include scabies, trachoma and flea, lice and tick-borne diseases.
- **Water-based diseases:** caused by parasites found in intermediate organisms living in water. They include dracunculiasis, schistosomiasis and other helminths.
- **(Other) Water-related diseases:** caused by insect vectors which breed in water. They include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever.

In the following material we deal mainly with the first group – waterborne diseases, since they by definition are directly linked to excreta and sanitation. The other groups may also be of concern when it comes to sanitation systems. Waterborne diseases are of concern in all settings, whereas many of the other diseases mainly are confined to tropical areas. More recently the term **water-related diseases** have been used to cover all these groups.

Waterborne pathogens
– important in water and sanitation systems

3.1 - 24

- **Bacteria**
  - The leading cause of gastrointestinal infections according to surveillance systems
  - *Salmonella*, *Shigella*, *Campylobacter, E. coli (toxinprod.)*
  - EHEC
  - *Legionella*
  - Opportunistic e.g. *Aeromonas hydrophila*
- **Virus**
  - Probably the cause of many outbreaks, difficult to detect
  - Noroviruses (Calici-, Norwalk like), rotavirus, hepatitis A

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

Pathogens can be bacteria, viruses, protozoa or helminths. Fungi may also infect humans but are not commonly considered of importance in water and sanitation systems.

Common bacterial causes of gastrointestinal infections are *Salmonella*, *Shigella*, *Campylobacter* and toxin-producing *E. coli (Escherichia coli)*. These can thus be present in wastewater and may contaminate other water (see Module 3.2). EHEC (enterohaemorrhagic *E. Coli)* is one type of *E. coli* that causes severe disease. Waterborne outbreaks have been detected. A Swedish outbreak from food but caused by water is described in Module 3.2. *Legionella* is transmitted through aerosols, from e.g. showers, not by drinking water. There are also so-called opportunistic pathogens that generally are harmless but may cause disease in immuno-compromised individuals.

Viruses are more difficult to detect than bacteria but are probably a cause of many waterborne outbreaks where the causative agent (microorganism) is not found. In the Western/developed world viruses are assumed to cause the majority of gastrointestinal infections, for example norovirus is common. Hepatitis A is a common waterborne and foodborne virus and rotavirus is common around the world, causing many deaths among children in developing countries. Viruses generally have lower infectious doses than bacteria.

Some of these bacteria and viruses are described in more detail below.

Waterborne pathogens (con´t)
– important in water and sanitation systems

3.1 - 25

- **Protozoa**
  - Complicated life cycles with resistant stages (chlorine)
  - *Giardia*, *Cryptosporidium, Entamoeba*
  - Low infectious dose
  - In Milwaukee (USA) in 1993, 400,000 were infected by *Cryptosporidium*
- **Helminths (worms)**
  - Varying transmission routes, e.g. soilborne
  - *Ascaris, Trichuris, Schistosoma* (bilharzia), hookworm
  - A large problem in many developing countries

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

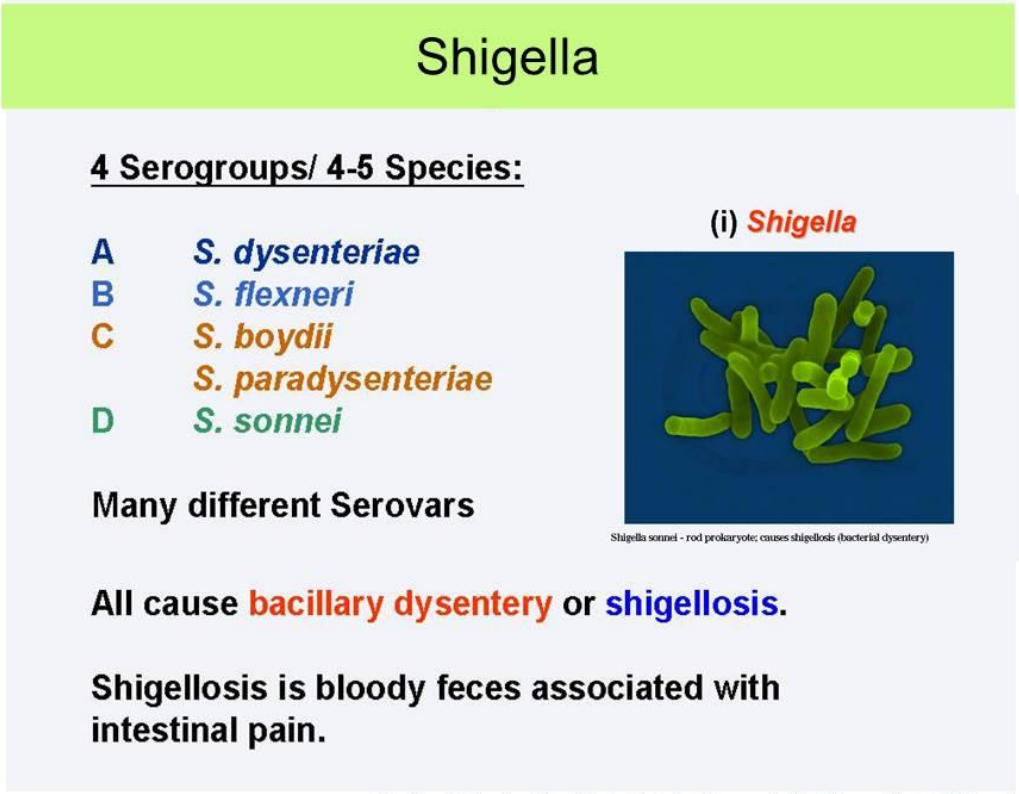
Parasitic protozoa have complex life cycles that often include a stage that is very resistant to various environmental pressures/factors and chlorine. *Giardia*, *Cryptosporidium* and *Entamoeba* are known to have caused waterborne disease outbreaks. The largest reported outbreak was caused by *Cryptosporidium* in Milwaukee 1993. An estimated 400,000 people were infected by insufficiently treated drinking water.

Helminths are mainly a problem in developing regions. They have varying transmission routes, for example the eggs that are excreted in faeces from an infected person may require a latency period in soil before becoming infectious. Common helminths include *Ascaris, Trichuris, Schistosoma* (bilharzia), and hookworm.

Protozoa and helminths generally have low infectious doses.

Some important diseases are presented in more detail below.

3.1 - 26



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

Shigellosis is an infectious disease caused by a group of bacteria called *Shigella*. Most that are infected with *Shigella* develop diarrhea, fever, and stomach cramps starting a day or two after they are exposed to the bacteria. The diarrhea is often bloody. Shigellosis usually resolves in 5 to 7 days. Persons with shigellosis in developed countries rarely require hospitalization. A severe infection with high fever may be associated with seizures in children under two years old. Some persons who are infected may have no symptoms at all, but may still pass the *Shigella* bacteria to others.

In the developing world, *Shigella flexneri* predominates. Epidemics of *S. dysenteriae* type 1 have occurred in Africa and Central America with fatality rates of 5–15%.

A small inoculum (10 to 200 organisms) is sufficient to cause infection. As a result, spread can easily occur by the fecal-oral route and occurs in areas where hygiene is poor. Epidemics may be foodborne or waterborne. *Shigella* can also be transmitted by flies and sexual contact.

(http://www.cdc.gov/nczved/divisions/dfbmd/diseases/shigellosis/technical.html)

3.1 - 27

Salmonella infection – Salmonellosis and Typhoid fever

Salmonellosis – diarrhea, fever, and abdominal cramps

- Caused by a variety of serotypes, e.g. *Salmonella* Typhimurium and *Salmonella* Enteridis
- Foods contaminated with animal faeces
  - Animal origin (meat, poultry, eggs), vegetables
  - Pets – handwashing important

Paratyphoid and Typhoid fever - fever and other symptoms

- Life threatening
- Caused by *Salmonella* Typhi
- Transmitted by contaminated food or water
- More common in areas with low sanitary standards

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

There are many different kinds of *Salmonella* bacteria. The *Salmonella* serotype Typhimurium and *Salmonella* serotype Enteridis are the most common in the United States. Most persons infected with *Salmonella* develop diarrhea, fever, and abdominal cramps 12 to 72 hours after infection. The illness usually lasts four to seven days, and most persons recover without treatment. However, in some persons, the diarrhea may be so severe that the patient needs to be hospitalized. In these patients, the *Salmonella* infection may spread from the intestines to the blood stream, and then to other body sites and can cause death unless the person is treated promptly with antibiotics. The elderly, infants, and those with impaired immune systems are more likely to have a severe illness. *Salmonella* live in the intestinal tracts of humans and other animals, including birds. *Salmonella* are usually transmitted to humans by eating foods contaminated with animal feces. Contaminated foods usually look and smell normal. Contaminated foods are often of animal origin, such as beef, poultry, milk, or eggs, but any food, including vegetables, may become contaminated. Thorough cooking kills *Salmonella*. Food may also become contaminated by the hands of an infected food handler who did not wash hands with soap after using the bathroom.

Salmonella may also be found in the faeces of some pets, especially those with diarrhea, and people can become infected if they do not wash their hands after contact with pets or pet feces.

(http://www.cdc.gov/nczved/divisions/dfbmd/diseases/salmonellosis/technical.html)

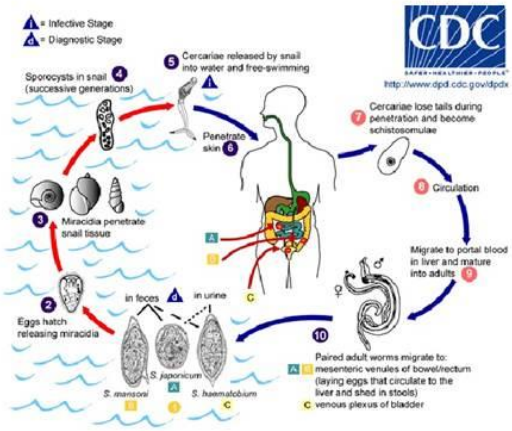
Paratyphoid and typhoid fever are life-threatening illnesses caused by *Salmonella* Paratyphi and *Salmonella* Typhi, respectively. In the United States about 400 cases occur each year, and 75% of these are acquired while travelling internationally. Typhoid fever is still common in the developing world, where it affects about 21.5 million persons each year. *Salmonella* Typhi lives only in humans. Persons with typhoid fever carry the bacteria in their bloodstream and intestinal tract. In addition, a small number of persons, called carriers, recover from typhoid fever but continue to carry the bacteria. These people can be a source of infection for others.

You can get typhoid fever if you eat food or drink beverages that have been handled by a person who is shedding *S. Typhi* or if sewage contaminated with *S. Typhi* bacteria gets into the water you use for drinking or washing food. Therefore, typhoid fever is more common in areas of the world where hand washing is less frequent and where water is likely to be contaminated with sewage.

Once *S. Typhi* bacteria are eaten or drunk, they multiply and spread into the bloodstream. The body reacts with fever and other signs and symptoms.
(http://www.cdc.gov/nczved/divisions/dfbmd/diseases/typhoid_fever/)

3.1 - 28

Schistosoma



- Also known as bilharzia
- 200 million people are infected worldwide
- Variety of symptoms
- Freshwater contaminated by urine or faeces
- Life-cycle requires specific snail as host

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

Schistosomiaisis, also known as bilharzia, is a disease caused by parasitic worms. You become infected when your skin comes in contact with contaminated freshwater in which certain types of snails that carry schistosomes are living. More than 200 million people are infected worldwide each year.

Schistosomiaisis in humans is caused mainly by infection with *Schistosoma mansoni*, *S. haematobium*, or *S. japonicum*. Within days of becoming infected, individuals may develop a rash or itchy skin. Fever, chills, coughs, and muscle aches can begin within 1–2 months of infection.

Fresh water becomes contaminated by *Schistosoma* eggs when infected people urinate or defecate in the water. The eggs hatch, and if certain types of snails are present in the water, the parasites grow and develop inside the snails. The parasite leaves the snail and enters the water where it can survive for about 48 hours. *Schistosoma* parasites can penetrate the skin of persons who are wading, swimming, bathing, or washing in contaminated water. Within several weeks, worms grow inside the blood vessels of the body and produce eggs. Some of these eggs travel to the bladder or intestines and are passed into the urine or stool.

Eggs travel to the liver or pass into the intestine or bladder, causing inflammation or scarring. Children who are repeatedly infected can develop anaemia, malnutrition, and learning difficulties. After years of infection, the parasite can also damage the liver, intestines, lungs, and bladder. Rarely, eggs are found in the brain or spinal cord and can cause seizures, paralysis, or spinal cord inflammation.

Symptoms of schistosomiasis are caused by the body's reaction to the eggs produced by worms, not by the worms themselves. The reaction to the eggs in tissues causes inflammation and disease.

http://www.cdc.gov/ncidod/dpd/parasites/schistosomiasis/factsht_schistosomiasis.htm

Schistosomiasis is endemic in 76 countries, most of which are in Africa. Schistosomiasis is a water-based disease which is considered the second-most important parasitic infection after malaria in terms of public health and economic impact.

In Asia, cattle and water buffalo can be important reservoirs of hosts eggs. Those who work in irrigation or fishing are at increased risk of contracting schistosomiasis. With the increase in wilderness or "off-track" tourism, more tourists are becoming infected.

At least 600 million people are at risk of infection and 200 million are infected with schistosomiasis. Of these 20 million are severely affected and 120 million have symptoms. An estimated 80% of transmission takes place in sub-Saharan Africa.
http://www.who.int/water_sanitation_health/diseases/schisto/en/

The life cycle of *Schistosoma haematobium*

Schistosoma haematobium has a complex life cycle, which takes place in humans, and in a freshwater snail which acts as an intermediate host. *Schistosoma* needs the right conditions to complete its life cycle, including both hosts (humans and snails) and fresh water. Humans become infected when they come into contact with the infective stage of the life cycle (the cercaria) in water, where the snail hosts are found.

Eggs are passed out with the urine. If this is into water (e.g. a pond or lake) the eggs will hatch into miracidia. The miracidia then enter a fresh water snail (*Bulinis sp.*). In the snail the larvae go through further stages of development and multiplication.

The next stage of the schistosome development is cercaria, which are released from the snail. If these come into contact with humans, e.g. when they are swimming, bathing or wading in the water, the cercariae can enter unbroken skin – often on the feet or ankles (shedding their tail as they do so). Once inside a person, the larvae migrate through the blood system to the liver. In the veins of the liver, the schistosomes undergo further development and mature into adults.

The adults leave the blood system of the liver to migrate again, finally ending up in blood vessels around the urinary bladder (and less often, other organs). Here, eggs are released against the bladder wall. These eggs then penetrate into the inside of the bladder, where they are passed out with the urine – to begin the cycle again.

Viral gastroenteritis

3.1 - 29

- What is viral gastroenteritis?
  - Inflammation of the stomach and small or large intestines
  - Results in vomiting and/or diarrhea
  - Often called ”stomach flu"
- What causes viral gastroenteritis?
  - Not caused by the influenza viruses
  - Caused by many different viruses e.g. rotaviruses, adenoviruses, caliciviruses, astroviruses, Norwalk virus, and a group of Norwalk-like viruses (later called calicivirus, norovirus)

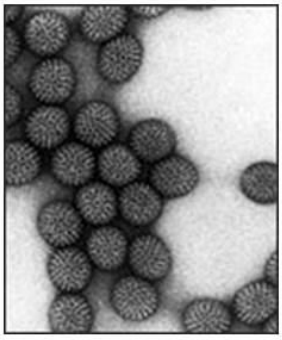
Caroline Schönning, Swedish Institute for Communicable Disease Control, Solna, Sweden

Viral gastroenteritis is an inflammation of the stomach and small or large intestines. It is an infection caused by a variety of viruses and results in vomiting or diarrhea. It is often called the "stomach flu," but is not caused by the influenza viruses. Many different viruses can cause gastroenteritis, including rotaviruses, adenoviruses, caliciviruses, astroviruses, Norwalk virus, and a group of Norwalk-like viruses. The infectious doses for these viruses are generally low.

Rotavirus

3.1 - 30

- Rotavirus is the most common cause of severe diarrhea among children
- Globally, rotavirus is estimated to cause 527,000 deaths in children annually
- Vomiting and watery diarrhea for 3 - 8 days, and fever and abdominal pain occur frequently
- Immunity after infection is incomplete
- Vaccination possible but not widespread

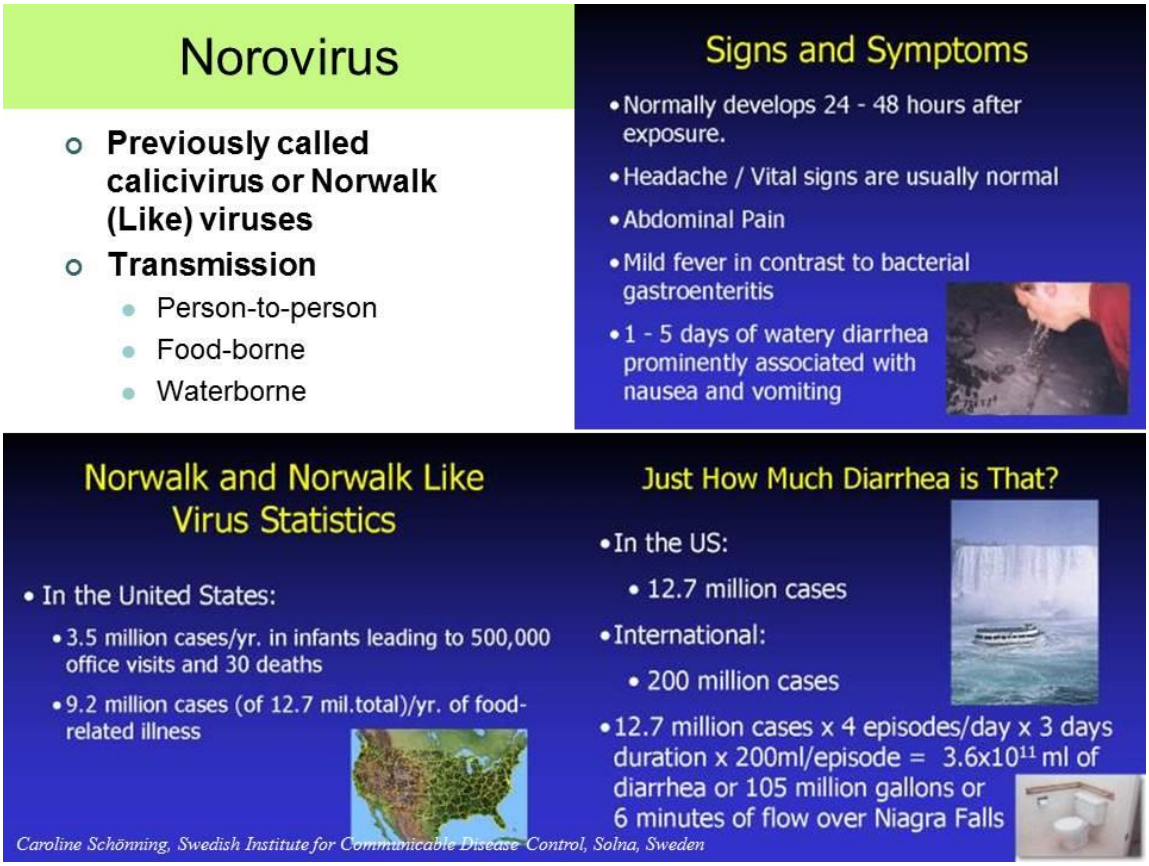


(http://www.cdc.gov/rotavirus)

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

Rotavirus is the most common cause of severe diarrhea among children. Prior the introduction of rotavirus vaccines in the United States in 2006, rotavirus resulted in the hospitalization of approximately 55,000 US children each year. Globally, rotavirus is estimated to cause 527,000 deaths in children annually. The incubation period for rotavirus disease is approximately two days. The disease is characterized by vomiting and watery diarrhea for 3–8 days, and fever and abdominal pain occur frequently. Immunity after infection is incomplete, but repeat infections tend to be less severe than the original infection. (http://www.cdc.gov/rotavirus/)

3.1 - 31



Noroviruses (genus *Norovirus*, family *Caliciviridae*) are a group of related, single-stranded RNA, non-enveloped viruses that cause acute gastroenteritis in humans. Norovirus is the official genus name for the group of viruses previously described as "Norwalk-like viruses" (NLV). http://www.cdc.gov/ncidod/dvrd/revb/gastro/norovirus.htm

The symptoms of norovirus illness usually include nausea, vomiting, diarrhea, and some stomach cramping. Sometimes people also have a low-grade fever, chills, headaches, muscle aches, and a general sense of tiredness. The illness often begins suddenly, and the infected person may feel very sick. In most people the illness is self-limiting, with symptoms lasting for about 1 or 2 days. In general, diarrhea is more common in children and vomiting is more common in adults. Noroviruses are found in the stool and vomit of infected people. People can become infected with the virus in several ways:

- by eating food or drinking liquids that are contaminated with norovirus,
- by touching surfaces or objects contaminated with norovirus, and then placing their hand in their mouth, and
- by having direct contact with another person who is infected (for example, when caring for someone with illness, or sharing foods or eating utensils with someone who is ill).

http://www.cdc.gov/ncidod/dvrd/revb/gastro/norovirus-qa.htm

In the United States, the CDC (Centers for Disease Control and Prevention) estimates that more than 21 million cases of acute gastroenteritis each year are due to norovirus infections, and more than 50% of all foodborne disease outbreaks can be attributed to noroviruses.

Among the 232 outbreaks of norovirus illness reported to CDC from July 1997 to June 2000, 57% were foodborne, 16% were due to person-to-person contact, 3% were waterborne, and in 23% of outbreaks, the cause of transmission was not determined. The infection is a major cause of diarrhea in the developed world but has been less discussed in relation to sanitation in developing countries.

Most foodborne outbreaks of norovirus illness are likely to arise though direct contamination of food by a food handler immediately before its consumption. Outbreaks have frequently been associated with consumption of cold foods, including various salads, sandwiches, and bakery products. Liquid items (e.g. salad dressing or cake icing) that allow the virus to mix evenly are often implicated as a cause of outbreaks. Food can also be contaminated at its source, and oysters from contaminated waters have been associated with widespread outbreaks of gastroenteritis. Other foods, including raspberries and salads, have been contaminated before widespread distribution and have subsequently caused extensive outbreaks.

Waterborne outbreaks of norovirus disease in community settings have often been caused by sewage contamination of wells and recreational waters (e.g. swimming areas).

http://www.cdc.gov/ncidod/dvrd/revb/gastro/norovirus-factsheet.htm

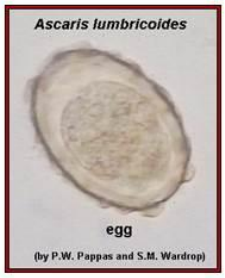
Transmission routes are further described in Module 3.2.

An exercise that may provide an understanding of the magnitude of the diarrhea problem is the calculation of the volume of loose stool (faeces) that norovirus causes in the US (see slide for numbers).

3.1 - 32

Ascaris

- *Ascaris lumbricoides* is one of the largest and most common parasites found in humans
- It is estimated that 10% of the world's population is infected with this nematode
- The adult worms live in the small intestine and eggs are passed in the feces - a single female can produce up to 200,000 eggs each day



Ascaris lumbricoides, fertilized egg. The egg is covered with a thick shell that appears lumpy approximate size = 65 µm in length.

The adult worm. Adult females of this species can measure up to 18 inches long (males are generally shorter).

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

Ascariasis is an infection of the small intestine caused by *Ascaris lumbricoides*, a large roundworm. The eggs of the worm are found in soil contaminated by human faeces or in uncooked food contaminated by soil containing eggs of the worm. A person becomes infected after accidentally swallowing the eggs. The eggs hatch into larvae within the person's intestine. The larvae penetrate the intestine wall and reach the lungs through the blood stream. They eventually get back to the throat and are swallowed. In the intestines, the larvae develop into adult worms. The female adult worm which can grow to over 30 cm in length, lays eggs that are then passed into the faeces. If soil is polluted with human or animal faeces containing eggs the cycle begins again. Eggs develop in the soil and become infectious after 2–3 weeks, but can remain infectious for several months or years.

Children are infected more often than adults, the most common age group being 3–8 years. The infection is likely to be more serious if nutrition is poor. Children often become infected after putting their hands to their mouths after playing in contaminated soil. Eating uncooked food grown in contaminated soil or irrigated with inadequately treated wastewater is another frequent source of infection.

The first sign of infection may be the passage of a live worm, usually in the faeces. In a severe infection, intestinal blockage may cause abdominal pain, particularly in children. People may also experience coughing, wheezing, difficulty in breathing, or fever.

Ascariasis is found worldwide. Infection occurs with greatest frequency in tropical and subtropical regions, and in any areas with inadequate sanitation. Ascariasis is one of the most common human parasitic infections. Up to 10% of the population of the developing world is infected with intestinal worms and a large percentage these infections are caused by *Ascaris*. Worldwide, severe *Ascaris* infections cause approximately 60,000 deaths per year, mainly in children.

Health education providing the following messages reduces the number of infected people:

- avoid contact with soil that may be contaminated with human faeces;
- wash hands with soap and water before handling food;
- wash, peel or cook all raw vegetables and fruits;
- protect food from soil and wash or reheat any food that falls on the floor.

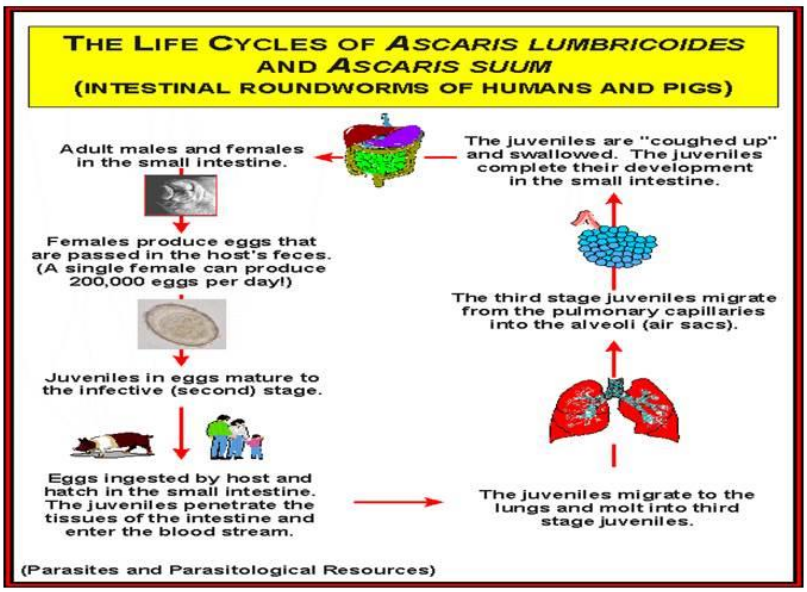
Barriers for disease transmission are further described in Modules 3.3 and 3.4.

The availability of water for use in personal hygiene as well as proper disposal of human faeces will also reduce the number of cases. Where wastewater is used for irrigation, waste stabilization ponds and some other technologies are effective for decreasing transmission due to food grown in contaminated soil.

http://www.who.int/water_sanitation_health/diseases/ascariasis/en/

Ascaris (con´t)

3.1 - 33



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Life Cycle of *Ascaris lumbricoides* and *Ascaris suum*

Ascaris lumbricoides eggs are found in human faeces. After faeces contaminate the soil, the eggs become infectious after a few weeks. Infection occurs when a person accidentally ingests (swallows) infectious *Ascaris* eggs. Once in the small intestines, immature worms hatch from the eggs. The larvae are carried through the lungs and then to the throat where they are swallowed. Once swallowed, they reach the intestines and develop into adult worms. Adult female worms lay eggs that are then passed in faeces; this cycle will take between 2-3 months.

Pigs can be infected with another species of *Ascaris* - *Ascaris suum.* Occasionally, a pig *Ascaris* infection can be spread to humans; this occurs when infectious eggs, found in the soil and manure, are ingested. Infection is more likely if pig feces are used as fertilizer in the garden; crops then become contaminated with *Ascaris* eggs.

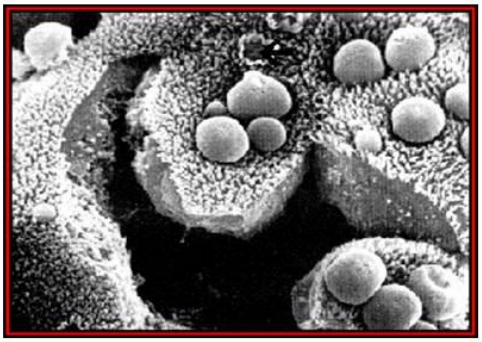
http://www.cdc.gov/ncidod/dpd/parasites/ascaris/factsht_ascaris.htm#what

In research studies, *Ascaris suum*, has been used more extensively than the human *Ascaris*.

Cryptosporidium

3.1 - 34

- *Cryptosporidium* is a small parasite, about 3-5 µm.
- It lives on the surface of the cells lining the small intestine and oocysts are passed in the feces.
- Transmission of the infection occurs via the oocysts.
- Many human infections have been traced to the contamination of drinking water with oocysts from agricultural "run-off" (i.e., drainage from pastures), so it is considered a zoonosis.



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Cryptosporidiosis is a diarrheal disease caused by microscopic parasites of the genus *Cryptosporidium*. Both the disease and the parasite are commonly known as "Crypto."

Many species of *Cryptosporidium* exist that infect humans and a wide range of animals. The parasite is protected by an outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine disinfection.

While this parasite can be transmitted in several different ways, water is a common method of transmission and *Cryptosporidium* is one of the most frequent causes of waterborne disease (via drinking water and recreational water) among humans in the United States.

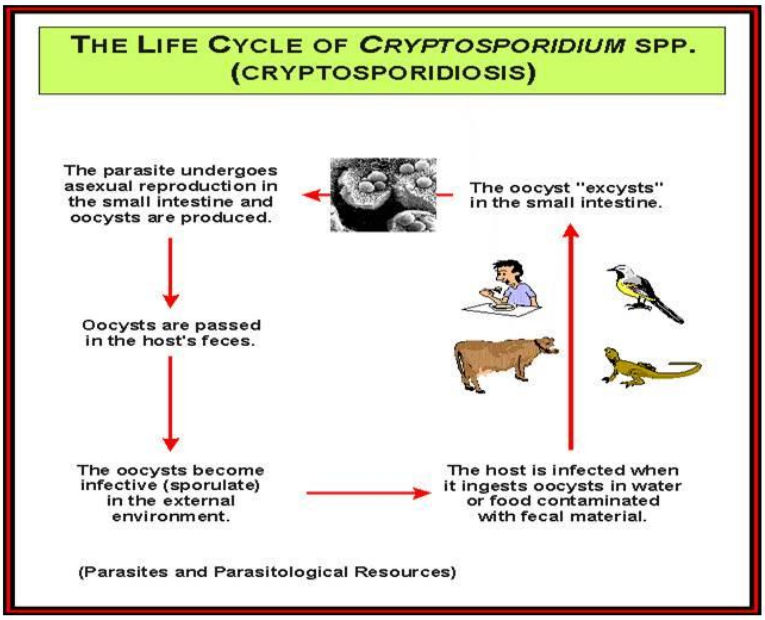
http://www.cdc.gov/crypto/

Since the first reports of human cases in 1976, *Cryptosporidium* has been found worldwide. Outbreaks of cryptosporidiosis have been reported in several countries, the most remarkable being a waterborne outbreak in Milwaukee (Wisconsin) in 1993, that affected more than 400,000 people.

http://www.dpd.cdc.gov/dpdx/HTML/Cryptosporidiosis.htm

Cryptosporidium (con´t)

3.1 - 35



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Life Cycle of *Cryptosporidium* spp

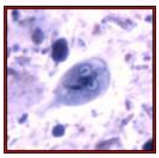
Sporulated oocysts, containing four sporozoites, are excreted by the infected host through feces and possibly other routes such as respiratory secretions. Transmission of *Cryptosporidium parvum* and *C. hominis* occurs mainly through contact with contaminated water (e.g. drinking or recreational water). Occasionally food sources, such as chicken salad, may serve as vehicles for transmission. Many outbreaks in the United States have occurred in waterparks, community swimming pools, and day care centres. Zoonotic and anthroponotic transmission of *C. parvum* and anthroponotic transmission of *C. hominis* occur through exposure to infected animals or exposure to water contaminated by feces of infected animals . Following ingestion (and possibly inhalation) by a suitable host , excystation occurs. The sporozoites are released and parasitize epithelial cells of the gastrointestinal tract or other tissues such as the respiratory tract. In these cells, the parasites undergo asexual multiplication (schizogony or merogony) and then sexual multiplication (gametogony) producing microgamonts (male) and macrogamonts (female) . Upon fertilization of the macrogamonts by the microgametes, oocysts develop that sporulate in the infected host. Two different types of oocysts are produced, the thick-walled variety, which is commonly excreted from the host, and the thin-walled oocyst , which is primarily involved in autoinfection. Oocysts are infectious upon excretion, thus permitting direct and immediate faecal-oral transmission.

Giardia

3.1 - 36

- *Giardia intestinalis* (also known as *Giardia lamblia* or *Giardia duodenalis*
- soil, food, or water that has been contaminated with feces
- Common in both developing and developed areas

- *Giardia lamblia* trophozoites live in the small intestine of the host. Cysts, which are resistant to adverse environmental conditions, are passed in the feces of an infected host, and the next host is infected when it ingests cysts in food or water contaminated with feces.



- The trophozoites adhere closely to the lining of the small intestine, and in heavy infections much of the lining can be covered with trophozoites. The giardiasis symptoms range from none (in light infections) to severe, chronic diarrhea (in heavy infections).

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Giardiasis is caused by a microscopic parasite *Giardia intestinalis* (also known as *Giardia lamblia* or *Giardia duodenalis*). The parasite is found on surfaces or in soil, food, or water that has been contaminated with faeces from infected humans or animals. People can become infected after accidentally swallowing the parasite. *Giardia* causes diarrheal illness, and giardiasis is a common cause of waterborne disease in humans in both developing and developed countries. There are several prescription medicines available to treat *Giardia* infection.
http://www.cdc.gov/ncidod/dpd/parasites/giardiasis/default.htm

3.1 - 37

Features of some gastrointestinal infections

	Morbidity (%)	Excretion (g^{-1} faeces)	Excretion time (days)	ID_{50}
Salmonella	6-80	10^{4-8}	26-51	23 600
Campylobacter	25	10^{6-9}	1-77	900
EHEC	76-89	10^{2-3}	5-12	1 120
Hepatitis A	70	10^{4-6}	13-30	30
Rotavirus	50	10^{7-11}	1-39	6
Norovirus	70	10^{5-9}	5-22	10?
Adenovirus	54	10^{11}	1-14	1.7
Cryptosporidium	39	10^{7-8}	2-30	165
Giardia	20-40	10^{5-8}	28-284	35
Ascaris	15	10^{4}	107-557	0.7

(Westrell, 2004)

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This table shows features of various pathogens that illustrate their differences. These characteristics are of importance when considering the risk the pathogens constitute in water and sanitation systems. “Morbidity” here means the percentage of infected individuals who have symptoms, and this figure can be used to calculate the probability of illness if the probability of infection is known (see Module 3.4). Excretion is a measure of the number of organisms per gram of faeces. These numbers vary substantially between pathogens and may also vary during the course of the infection. The excretion time is listed in days and also varies a lot as can be seen. All these values can be utilised when conducting quantitative microbial risk assessments (QMRA) as further described in Modules 3.4 and 3.5. ID50 is the estimated number of organisms required for 50% of the individuals exposed to this number to become infected (also see slide no 9).

http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-4880

Emerging pathogens

3.1 - 38

- Emerging diseases
  - Newly recognized or
  - Increasing importance
- Zoonoses
  - Many emerging pathogens of zoonotic origin
  - Animal faeces contaminate water
- Climate change
  - Increased risks related to water and sanitation
  - Affects food-production

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New diseases, including water-related diseases, periodically "emerge" or “re-emerge” either because they are newly recognized or because their importance increases. This may be due to the micro-organisms themselves evolving; to changes in the way we manage water resources and supplies; to changes in the tools and methods used to study the organisms and the health effects they cause; or to changes in the human population itself.

The WHO, the USEPA and other agencies collaborate to address some of these challenges through an initiative on Emerging Issues in Water and Infectious Disease. The initiative leads to the development and publication of state-of-the-art reviews based on wide consultation of international expert.

Zoonoses are diseases caused by microorganisms of animal origin that also infect humans. Zoonoses are of increasing concern for human health; next to pathogens with human-to-human transmission, they are pose the greatest challenges to ensuring the safety of drinking-water and ambient water, now and in the future. Up to 75% of emerging pathogens may be of zoonotic origin. A significant number of emerging and re-emerging waterborne pathogens have been recognized over recent decades. Examples include *E. coli* O157:H7, *Campylobacter*, and *Cryptosporidium*, all of which can be excreted in animal faeces.

It is now generally acknowledged that the global climate is changing, as the earth becomes warmer. Climate change is a significant and emerging threat to public health, and changes the way we must look at protecting vulnerable populations. This change has the potential to affect human health in a number of ways, for instance by altering the geographic range and seasonality of certain infectious diseases. These changes disturb food-producing ecosystems and increase the frequency of extreme weather events such as hurricanes. Thus, these changes may have a large impact on health risks related to water and sanitation systems as well as on food production. How to respond to additional vulnerability is not specifically addressed in this training material. Food and water security will be a major issue as climate change progresses. Water scarcity in itself is a health problem, and water is crucial in food production.

http://www.who.int/water_sanitation_health/emerging/emergingissues/en/

Protozoa and helminths in faecal material

3.1 - 39

- Faecal samples from 120 urine-diverting latrines in KwaZulu-Natal, South Africa
- Varying features – water-filled to dry (normal)
- Analysing for presence of:
  - parasitic protozoa *Giardia* and *Cryptosporidium*
  - helminths *Ascaris lumbricoides, Trichuris trichiura* and *Taenia* spp

Picture provided by Teddy Gounden

(Trönnberg et al., 2010)

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

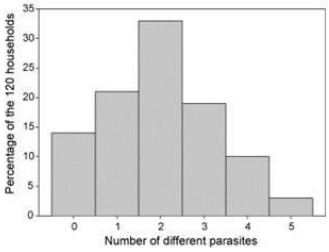
As an example of the prevalence of infectious diseases and risks related to human excreta the following study by Trönnberg et al. (2010) is described (http://dx.doi.org/10.1016/j.trstmh.2010.06.009).

In KwaZulu-Natal outside Durban in South Africa, a large number of urine diverting latrines have been built. In this study samples were collected from the faecal heap collected underneath the diverting toilet. The purpose was to analyse for parasitic protozoa and helminths. In total, 120 household latrines were sampled. The faecal material had varying features, from dry to water-filled.

Protozoa and helminths in faecal material

3.1 - 40

- Parasites
  - 54% positive for Giardia
  - 21% positive for Cryptosporidium
- Helminths
  - 59% *Ascaris lumbricoides*
  - 48% *Trichuris trichiura*
  - 18% *Taenia* spp
- In 73% of the 120 household toilets, one or several types of helminths were found
- Prevalence by family (at least one member infected)
- Supports theory of high prevalence in certain areas
- Treatment needed before use of faeces



(Trönnberg et al., 2010)

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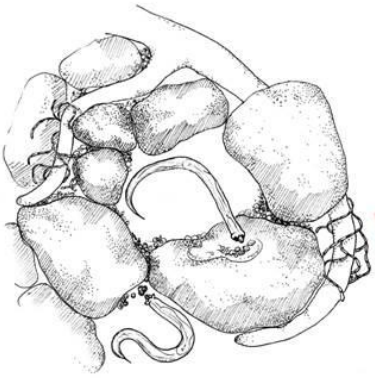
The 120 samples of fresh faecal deposits resulted in the following occurrence of parasites in the family toilets: *A. lumbricoides* (59%), *G. intestinalis* (54%), *T. trichiura* (48%), *Cryptosporidium* spp. (21%) and *Taenia* spp. (18%). In 73% of the 120 household toilets, one or several types of helminths were found. Analysis showed that in 34% of toilets, there was one type of helminth infection A single helminth infection occurred in 34% of the household toilets. Only 14% of the samples were completely negative for parasites. The prevalence can be said to be family-based, meaning that at least one member of the family (the household) was infected at the time of sampling (fresh faeces). The presence of children aged five years or less in the families was found to positively correlate with a higher prevalence of all parasites except *A. lumbricoides*, which showed the opposite. A significant correlation was however only found with respect to the occurrence of *G. intestinalis*.

The occurrence of parasites in 86% of the families implies a risk for further transmission of the pathogens if proper hygiene behaviour is lacking and the toilets are not properly used. The high prevalence of the helminths and parasitic protozoa in the family toilets demonstrates an endemic state of infection in the communities. Other studies report high prevalence in communities lacking municipal sewers and a higher prevalence of *Cryptosporidium* spp. has been reported for communities with unsafe drinking water sources, which supports the potential link between parasite endemicity and poor water and sanitation. The findings of the present study highlight the need for proper containment of excreta to reduce the likelihood of further transmission of parasites when hygiene resources are limited and socioeconomic standards are low.

The numbers for excretion (densities in faeces) found in literature are higher than the quantities of ova and (oo)cysts found in the sampled excreta from the vaults in this study. This implies that an overestimation of the risk will be made if values, as reported in the literature, are used as input parameters in a risk assessment, and thus shows the value of using local data in quantitative risk assessments. The families in these areas are currently not reusing the faecal material after storage, but health protection measures still need to be applied in the system. These measures are needed regardless of whether the faeces are used or buried (e.g. treatment and personal protective equipment, see Module 3.4).

3.2 Environmental transmission of pathogens



Where do the pathogens come from?

How do pathogens in excreta contaminate the environment?

Learning objective: to become familiar with environmental transmission routes for pathogens, especially in relation to water and sanitation.

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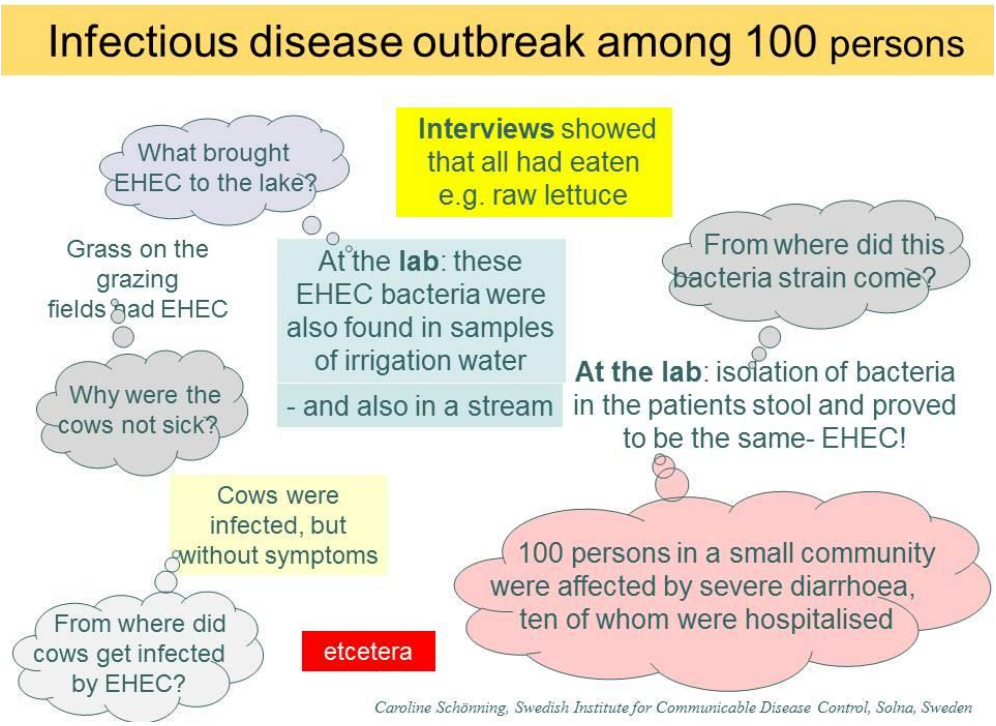
The environment around us is full of bacteria and other microorganisms. However, most of them are harmless to us. However, some cause disease – pathogens - and have to be kept under control. This is partly challenging partly easy. Societies have had hygienic rules for thousands of years, and some of these are encoded in religious scriptures.

In this module we deal with pathogens in different waste fractions and how they can be transmitted in the environment, resulting in potential exposure of humans and animals.

Chemicals in excreta and other waste fractions may also constitute a health problem, for example if they end up in our drinking water or on crops that we consume. This is mainly considered an issue for greywater in sanitation systems with diverted flows (see Chapter 4). Chemical aspects are partly covered in Module 4.8 (agricultural use). For wastewater, and especially for extracted sludge, there has been an intense debate regarding environmental pollution that is not within the scope of this module.

The module is essentially following the approach of (1) number of pathogens (2) exposure (3) diseases-response (4) vulnerability, and (5) barriers (see slide 4.5-7).

3.2–2



To trace disease-causing microorganisms is often like a detective narrative, and done by professional epidemiologists as well as individuals who wonder why they or others got ill. We use a real example of searching for a pathogen to highlight the main points when considering transmission of microorganisms in the environment.

An outbreak of severe diarrhoea occurred in a small community is Sweden. One hundred persons were affected and ten hospitalized. The national institute of infectious disease control was engaged to trace the cause and source of the outbreak. Lab tests of the sick persons found EHEC bacteria in their stool. This pathogen was the direct cause of the disease. But where did they come from? Interviews revealed that the sick persons all had eaten fresh lettuce, among a number of other food items. So, the team looked for EHEC bacteria in shops and food joints, and lab tests found the same strain of EHEC on lettuce leaves. A likely source of the disease was the water-washed lettuce. The water sources were tested, and the team found that a river carried the EHEC bacteria. Fine, but from where did the bacteria originate?

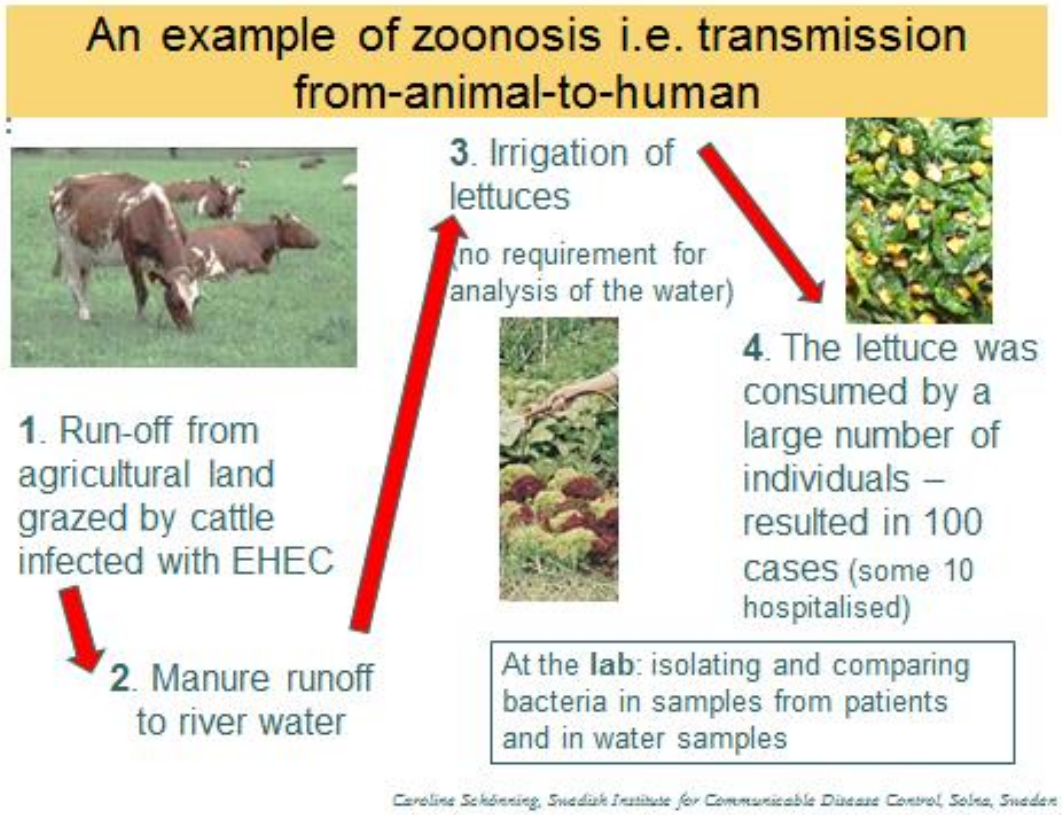
The team started to suspect a source in the environment. They checked the cow dung from cows grazing along the river, and found the same EHEC strain in the dung. So, when the rain washes away dung some of it ends up in the nearby river, and the amount was enough to infect persons eating the washed lettuce.

An epidemiologist would like to continue their search. Why do the cows not show symptom? From which source were the cows getting the EHEC etc. The chain can be traced further and further away.

The first step in the analysis is a narrow system boundary – the eaten food. In order to find the source of disease, the system boundary is widened to include the environment the food comes from. When that link is established, one could stop further work. But in order to make sure that the transmission is under control, the system boundary is widened even more to include animals.

When we talk about the source of pathogens or the origin of the disease, we must remember that the answer is not always final, but depends on at what system boundary you have decided is satisfactory and that you can contain further spread of the disease.

3.2–3



This example of a foodborne outbreak is easy to follow once the route of transmission has been discovered. The case illustrates several of the sanitation and health issues covered in this module.

A larger than usual number of EHEC infections was reported to the surveillance system and the health authorities realised that there was an outbreak. Great efforts were made to find the source, and nearly 60 people were involved in the investigation. Lettuce was found to be a risk factor in the epidemiological assessment, and finally one lettuce producer was identified as a source. It was noted that the producer irrigated their fields with river water. Water samples were collected and EHEC was found in the water. Bacteria isolated from stool (faecal) samples from patients were compared to the water samples and it was concluded that it was the same strain of the bacteria. Eventually run-off from agricultural land upstream of the producer's water source was identified as the cause of the outbreak. On this land, cattle were infected with EHEC and the bacteria were transported from the cow dung by surface run-off to the river water that was used for irrigation.

Transmission by animals

3.2–4

- **Zoonoses**
  - Transmission humans ⟷ animals
  - May cause symptoms or not in animal
- **Vectors**
  - Insects, rodents, birds – mechanical transport
  - Birds, wild and domestic animals infected without symptoms
- **Intermediate host**
  - Animal necessary for lifecycle of pathogen, e.g. malaria, schistosomiasis

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

Infectious diseases that can be transmitted from animals to humans are called zoonosis. This possibility makes the environmental transmission routes of diseases more complex. The infections may or may not cause symptoms in animals.

Animals can also be vectors – animals that transmit diseases. Vector-borne transmission may occur by the mechanical transport of pathogens. Infected animals may move the pathogens to another location exposing humans (or other animals). Vectors are usually insects, rodents or birds. Examples of vectors are mosquitoes which transmit malaria, dengue fever and other diseases.

Some infections also require an animal host for further transmission. This is the case for schistosomiasis where eggs are excreted in urine or faeces and a specific freshwater snail is infected by the larvae after hatching (one of the life stages of the parasite). The aquatic larvae are then excreted in the water by the snail and have the potential to infect new human hosts.

Microorganisms in excreta

3.2–5

- **Urine**
  - Sterile in body
  - Naturally containing some bacteria after excretion
  - Few diseases transmitted by urine
  - Low risk to handle
- **Faeces**
  - Naturally containing high amounts of bacteria
  - Many diseases transmitted by faeces (faecal-oral)
  - May contain pathogenic bacteria, viruses, protozoa or helminths
  - Significant risk to handle

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

The picture above summarizes the health risks from urine and faecal matter. Urine poses low risks compared to faeces. It is sterile in the body of a healthy person. Only a few diseases are transmitted through urine. Faeces are different. They contain large amounts of naturally occurring, non-harmful bacteria, but many diseases are transmitted via the faecal-oral route and faeces commonly contain pathogens. Faeces should therefore be handled with caution.

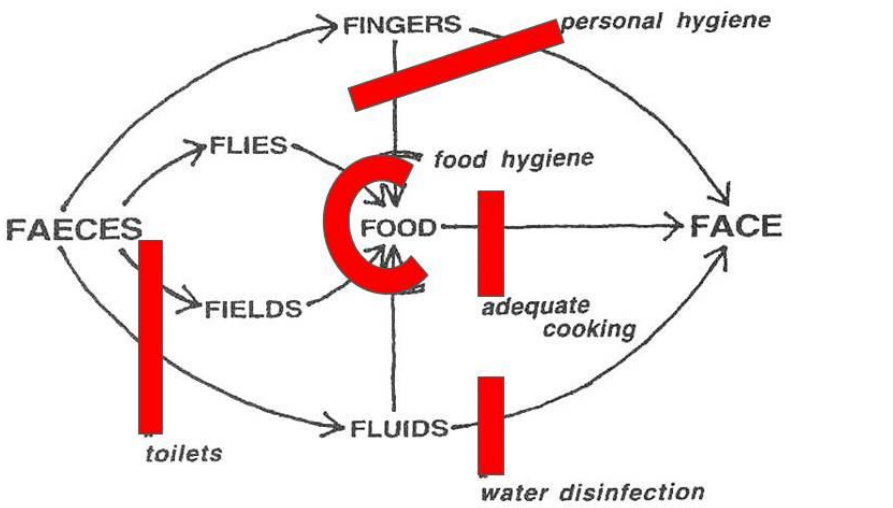
Using urine as a fertiliser carries little health risks compared to untreated faecal matter. This is an important message since urine contains most of plant nutrients excreted by humans, and, therefore, is the most valuable fraction for reuse (see Chapter 4 about agricultural use).

If faeces are kept separate from other waste fractions, as is done in urine-diverting toilets, the other fractions can be used as fertilizers after some treatment, and the treatment and handling of the faecal fraction can be conducted in a safer and more optimized way. This is generally true both in high-tech systems and low-tech systems, and can result in the creation of sustainable systems regardless of whether financial resources for sanitation are scarce or plentiful.

A more detailed account of pathogens in faeces, urine, wastewater and sludge is now given.

The "F-diagram" - main routes for the spread of diarrhoea

3.2–6



(Esrey et al. 1998)

Extensive experiences of disease transmission gradually adds up to a situation where one can give hints on where to look for pathogen transmission routes and ways to block such routes, often by simple measures or barriers.

Faecal-oral transmission is the main route when it comes to sanitation, and therefore we focus on that here. Disease and various symptoms are dealt with in Module 3.1, and here the main/concern is diarrhoeal disease caused by gastrointestinal (enteric) infections via faeces or toilet wastewater. The F-diagram above is often used to describe the spread of diarrhoea in society. It shows how pathogens in faeces can reach the face and be ingested via fluids, food, flies and fingers. Fingers may carry pathogens if faecal material has been touched, e.g. when defecating, changing diapers or touching a contaminated surface like door handle or toilet knob.

The diagram is simple and instructive, and instead of requiring deep knowledge of pathogens it recommends simple actions to protect oneself from disease. The principle of barriers is valid for all sanitation systems – while the faecal material may be present in different forms.

In some societies child faeces are considered harmless, but many infections (like rotavirus) are more common among children so it is important to see everybody's faeces as potentially harmful. It is also possible for an infected person to contaminate food that is then served to others. Proper hand washing after defecation and before eating is an effective barrier. Flies can physically transport microorganisms on their legs from faeces to food. By covering the food this route is blocked. The arrow from FIELDS → FOOD illustrates the risk of transmission if faeces from humans (or animals) are used as a fertilizer without proper pre-treatment before use, or if open defecation in fields is practised. The barrier is to end open defecation and to pre-treat organic fertilisers. Transmissions via fluids are illustrated by contaminated drinking water.

Urine may also contain pathogens, but to a much lesser extent (See slide 3.2-5).

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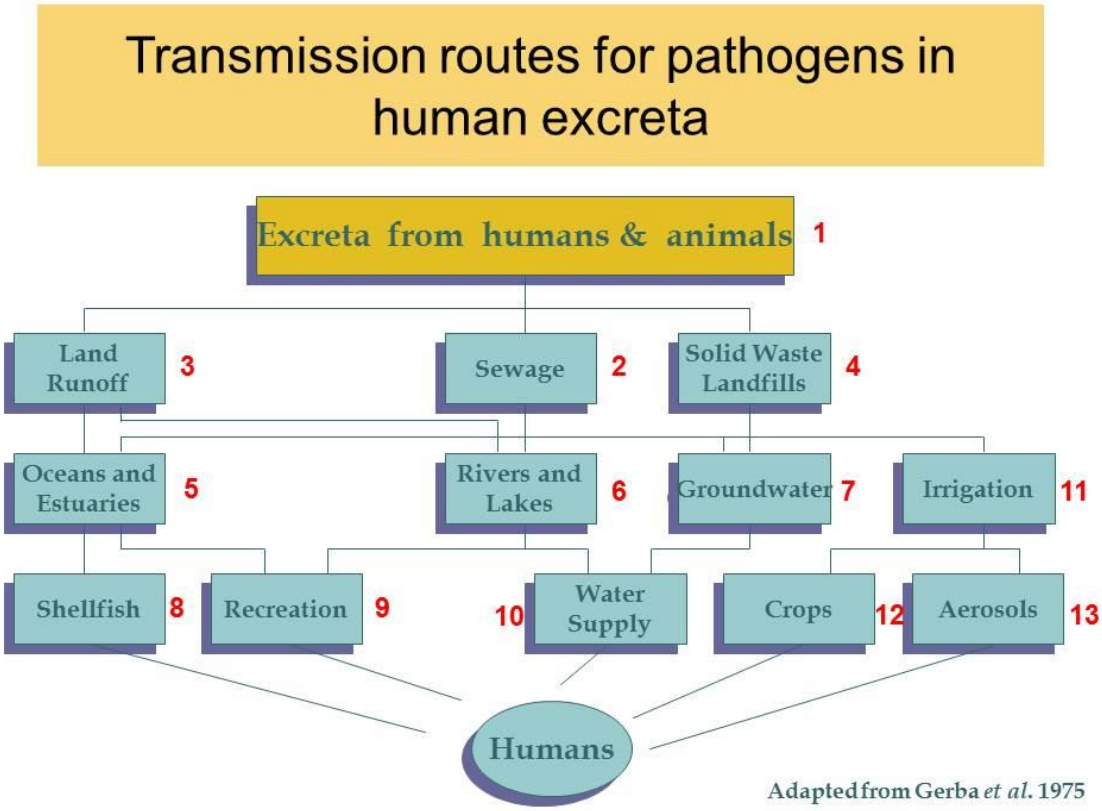
3.2–7



Another systematic way of describing the transmission routes for pathogens in water and sanitation systems is by schedules/pictures such as the one above.

The enteric (meaning from the intestine) pathogens are excreted in human or animal faeces (1). The faeces either end up in sewage (wastewater) (2), on land (3) or in solid waste landfills (4). From all these sources pathogens can be transported to oceans and estuaries (5), rivers and lakes (6) or to groundwater (7). This water may then be used for growing of shellfish (8), for recreation (swimming) (9), as a water supply (for drinking water) (10) or for irrigation of crops (11, 12). It is possible for humans to ingest pathogens.by consuming crops, shellfish and drinking water. When swimming or performing other water-related activities water may unintentionally be swallowed. Sewage/wastewater may directly, or after some treatment, be used for irrigation of crops and apart from contaminating crops, pathogens may also be ingested by exposure to aerosols formed when irrigating the crops (13).

How such exposure and risks can be managed is further described in Modules 3.3 and 3.4.

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Pathogens in faeces

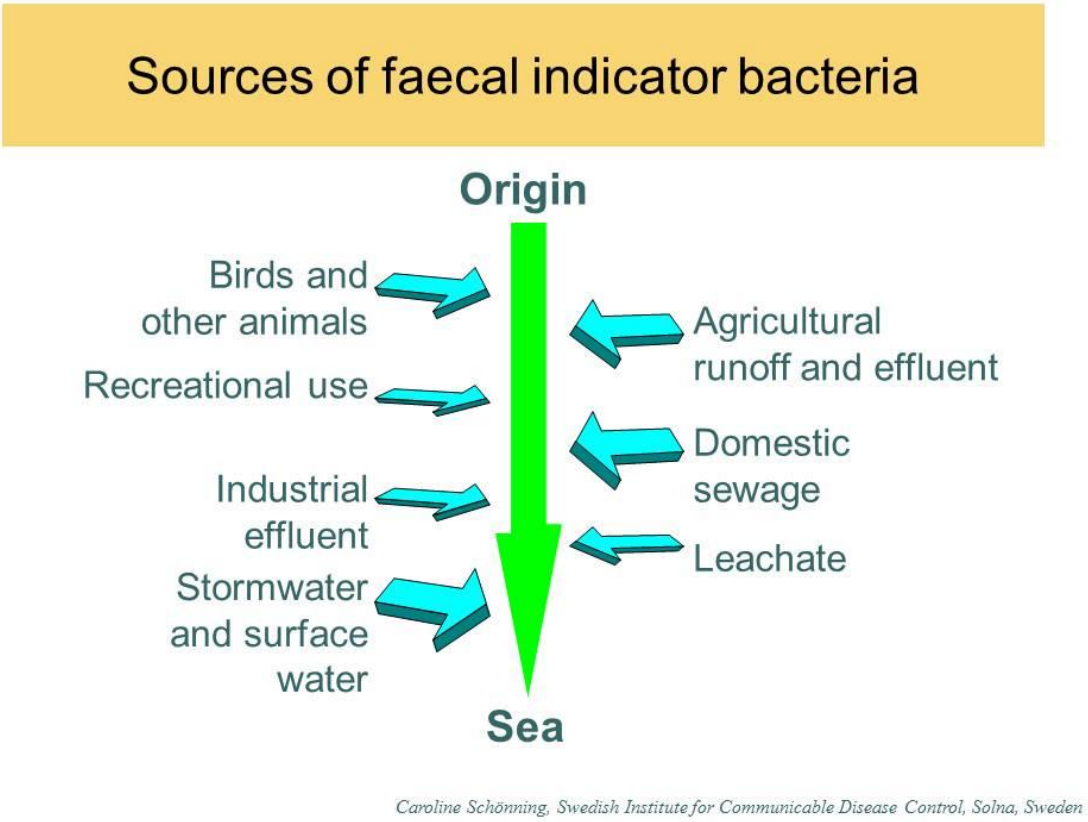
3.2–8

- May contain bacteria, viruses, parasitic protozoa and helminths that cause infections
- Diarrhoeal disease is the main concern
- Faeces should be considered a health hazard
- Need to be treated before use as a fertiliser
- Easier to handle and treat if diverted from other waste fractions

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

Infectious diseases can be caused by bacteria, viruses, parasitic protozoa and helminths and the main health risk in relation to sanitation systems is exposure to pathogens causing diarrhoeal disease. The majority of these pathogens are excreted in faeces and an infected person can excrete large numbers of pathogenic organisms. The prevalence of infectious diseases varies greatly between societies and populations. However, despite these variations, faeces should always be considered as harmful to health. Faeces should be handled with care and need to be treated before being used as fertilizer as discussed in Modules 3.3 and 3.4 and in Chapter 4. Exceptions exist where treatment of faecal matter is not necessary e.g. for growing of trees in shallow pits (like the Arbour Loo, see Chapter 5). A basic problem in waterborne sewage systems is the production of large volumes of contaminated wastewater that need to be treated, which for various reasons is not feasible everywhere (see Chapters 1 and 2).

3.2–9



Faecal bacteria may originate from a variety of sources. As can be seen in the picture above, domestic (household) sewage is a major source of faecal bacteria together with agricultural, stormwater and surface water. Leachate is the liquid of contaminated water leaked from landfills. This is a general picture, and the local variations may differ a lot. Suffice it to know that pathogens are present in many flows, not only in domestic sewage.

Pathogens found in domestic sewage or faecal matter indicates the health conditions in a community. The presence of pathogens depends on what type of infections people have and how common these are – that is, they indicate the prevalence of an infectious disease in the population. Faecal indicators are further discussed in Module 3.4.

Microorganisms in urine

3.2–10

- Urine is sterile in the bladder
- Freshly excreted urine contains <10 000 bacteria/ml
- Urinary tract infections - not transmitted through the environment
- *Leptospira interrogans* - low prevalence
- *Salmonella typhi*, *Salmonella paratyphi* - developing countries, faecal-oral transmission more common
- *Schistosoma haematobium* - fresh water snail needed for development

→ low risk for transmission of infectious diseases through urine

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

Does urine contain pathogens that could cause problems in relation to sanitation systems? Urine is a sterile liquid in the bladder, but when excreted it contains up to 10,000 bacteria per ml. urine. A person with urinary tract infection may have a much higher concentration, but these are not known to be transmitted through the environment.

There are a few other pathogenic bacteria and viruses that have been isolated from urine but the pathogens commonly known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and the parasite *Schistosoma haematobium*. *Leptospira* is uncommon and the *Salmonellas* are only excreted in urine from individuals with typhoid and paratyphoid fever, which are rare diseases in developed countries. In developing countries, however, these infections are endemic but still faecal-oral transmission is the most common route of transmission.

This parasite requires an aquatic snail living in fresh water for its life-cycle. Also, the parasite is not infectious when excreted. It can thus be concluded that the risk for transmission of infectious diseases through urine is low.

3.2–11

Origin of pathogens in wastewater
- contribution from different waste fractions

- **Faeces**
  - the main source of pathogens that cause enteric infections
- **Urine**
  - only a few diseases transmitted through urine
- **Greywater**
  - e.g. laundry, washing diapers, from food stuffs
- **Industry**
  - abattoir, food industry (plant pathogens)
- **Storm water**
  - e.g. surface run-off – animal faeces

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A closer look at wastewater gives us an idea of the contribution of pathogens from different waste fractions. A healthy individual does not excrete pathogens in urine or faeces. However, symptom-free persons may well excrete pathogens. If an individual has an enteric (gastro-intestinal) infection, large amounts of pathogens may be excreted in their faeces and end up in the sewage. Only a few diseases are known to be transmitted through urine, while bacteria that cause urinary tract infections are not further transmitted in the environment.

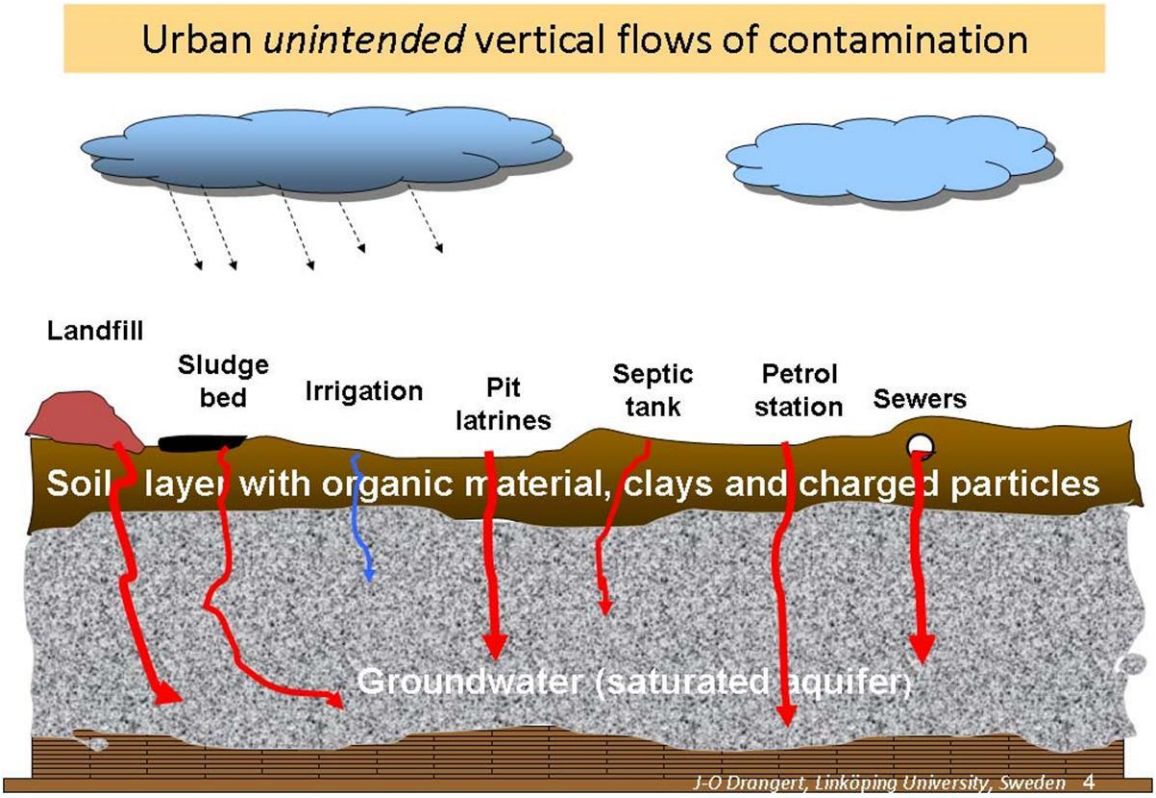
Greywater may also contain enteric (intestinal) pathogens, for example from laundry of soiled cloths, from showering and from washed foodstuffs in the kitchen sink. Symptom-less individuals and ill persons being treated at home also contribute pathogens to household (domestic) wastewater.

The contents of industrial wastewater depend on the type of industry. Regarding disease transmission, abattoirs and food industries are of concern, because they may contribute pathogens originating from plants.

Stormwater may contain pathogens e.g. from animal faeces that are transported by surface run-off. More details on the pathogens that can be present in different waste fractions are given both later on in this module and in Module 3.1.

Wastewater from hospitals is of special concern, but hazardous waste and hospital waste are outside the scope of this training material.

3.2–12



Drinking water is of particular concern since it is a necessity. It is estimated that 1 billion people do not have access to adequate drinking water. Preventing drinking water from being contaminated should be of utmost concern. Drinking water quality is affected by several factors, one of which is the presence of pathogenic microorganisms. Other health risks include the presence of chemical compounds such as nitrates, organic compounds and metals. In addition, some substances cause problems with bad smell or colour.

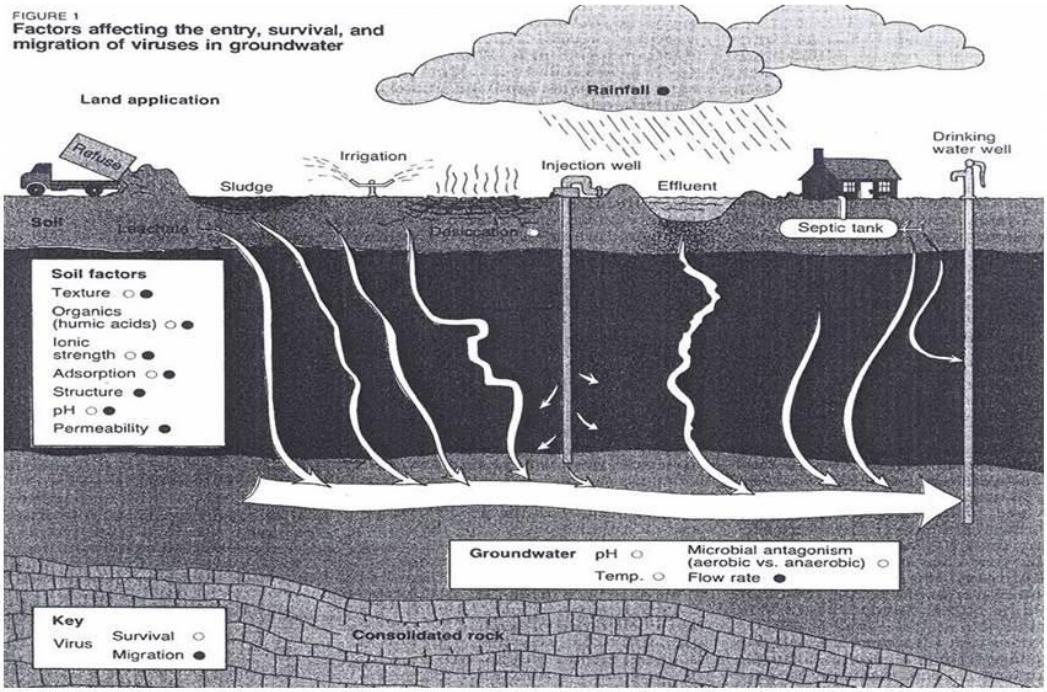
Drinking water is usually obtained from surface water or groundwater. Contamination of these sources may occur through run-off from latrines and land surface and from outlets of wastewater, both untreated and treated. Treatment of surface water is necessary in order to produce drinking water of acceptable quality.

The quality of groundwater is paramount when that is the main source of drinking water. This source is usually polluted in urban areas, often from unintentional events. The picture shows a number of ways that groundwater is being contaminated. Various contaminants are percolating with water down to groundwater (See Module 4.5). One often forgotten leachate is that from leaking wastewater pipes due to their poor state.

The goal of water treatment, usually of surface sources such as lakes, reservoirs or rivers, is to remove contaminants and organisms through a combination of biological, chemical, and physical processes to make it safe for drinking. Some of these processes occur naturally in the environment, whereas others occur in engineered and constructed water treatment plants. The engineered processes usually mimic or build on natural processes. Groundwater (e.g. from wells), on the other hand, is generally of better quality and is often used without treatment. This means that if groundwater sources are vulnerable to contamination, they become a serious health risk. There are no simple ways to treat groundwater in situ, and all treatment is done when it is available on the ground.

Contamination of groundwater

3.2–13



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The above picture shows a peri-urban situation without piped water, with possible contamination from sources similar to those shown in the previous slide. Septic tanks often results in infiltration of wastewater that can contribute pathogens in groundwater. The risk of exposure to pathogens (and the risk of infection) from drinking well water will depend on the quantity of pathogens that reaches the groundwater and the bore hole or dug well. These factors will in turn depend on the types of organisms and soil type such as pH, structure, ionic strength and texture. Some of the organisms will be adsorbed to soil particles and some will reach the groundwater. Some of the organisms may also be inactivated (die) during the time of transportation through the soil to reach the groundwater. The survival of pathogens in the groundwater will also depend on conditions such as the pH and the temperature of the water.

One example is given of transport of microorganisms from latrines to wells in Eldoret town in Kenya where a study of groundwater was conducted. The wells were situated up to 40 metres from the pit latrines on level ground and were considered safe. The possible occurrence of contamination was tested by adding bacteriophages in the latrines as a tracer. Bacteriophages are viruses that infect bacteria, and in this case a type of phage was used that infects Salmonella and the phage does not exist naturally in the environment. Daily samples were collected from the wells and tested. After a few days phages were detected. This shows that pathogens, especially viruses, can be transported long distances in the soil – even in a flat landscape. The study concluded that not only the distance, but also the flow direction of groundwater and topography need to be considered when choosing places for wells and latrines (Drangert et al., 1996).

3.2–14

Contamination of drinking water

- Drinking water quality
  - Heterotrophic bacteria, *E. coli*, metals, nitrate (other aspects are smell, colour)
- Contaminated surface- or groundwater
  - Wastewater outlet, latrines, run-off
- Contamination during distribution
  - Growth in pipes, intrusion of wastewater
- Contamination of finished water
  - During storage and handling, e.g. reservoirs, vendors

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Microbiological quality of drinking water is often assessed by the presence of so-called indicator bacteria which include coliforms and E. coli. Guidelines from Ministries of Health issue values for maximum acceptable levels of indicator bacteria (Module 3.4). The main message when choosing a sanitation system is to select one that is likely NOT to reduce the quality of drinking water sources (as discussed in Chapter 2). For example, proper siting and depth of latrines (pits) and infiltration units is crucial for protecting the groundwater quality. Containment of faeces above ground is preferred. Surface water used for drinking water or recreation should be protected from wastewater discharge (outlets) and run-off from land where human or animal faeces can contribute pathogens. It is also necessary to avoid pollution of waterways (e.g. rivers) upstream of locations where they are used as water sources.

Contamination may occur both from transport of pathogens through the soil as described above and from poorly maintained hand pumps e.g. due to loose lids allowing intrusion of contaminated water.

Contamination may further occur during distribution of the drinking water in pipes. One important consideration is the need to keep pipes as intact as possible and with constant water pressure to prevent intrusion of wastewater during low pressure. Microbial growth on inner surfaces of pipes is inevitable, but should be controlled, ideally by distributing water with a low organic content and by the appropriate use of disinfecting chemicals.

Even if safe water is delivered to the household, contamination may occur during storage and handling, e.g. if the storage container is not clean, or if unclean hands touch the water, or if insects, birds or their droppings enter the container (e.g. if a proper lid is not attached). For drinking water (as well as for food) it is important that the whole chain from production to consumption is kept clean and safe.

3.2–15

Health risks related to untreated wastewater

- Local environmental pollution
  - Accidental exposure
- High risk of down-stream pollution
  - Exposure from e.g. swimming and intended household use
- Pollution of drinking water sources
  - Surface run-off and ground water infiltration
- Contamination of irrigated crops
  - Exposure during irrigation and at consumption

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The two previous slides show how contaminated water can percolate and negatively affect the groundwater quality. Also, surface water is contaminated.

The lack of proper waste and wastewater management, in addition to the lack of sanitation per se, results in health risks due to exposure to untreated or insufficiently treated wastewater. In poor peri-urban areas the most obvious sanitation problem is wastewater flowing on the ground or in so-called wastewater ditches (see picture). Direct contact with this water, especially for children, poses a significant risk for infection as a result of unintentional ingestion. Use of this water, or of streams polluted with such water, is often necessary and results in health risks through direct contact for people performing tasks such as washing clothes and cleaning or preparing food. In such areas the drinking water sources are often unprotected, e.g. an open shallow dug well may be used, and well water is easily polluted by surface run-off or by infiltration of wastewater.

The risk of crops being contaminated is high, and constitutes a health risk especially if the crops are consumed raw. The use of insufficiently treated faeces, and of other waste fractions, results in similar risks. There is also a risk of agricultural workers ingesting pathogens during irrigation and fertilization of the crops.

After this general description of transmission routes of various kinds, we take a closer look at the pathogens involved. Since there is a need to explain why certain barriers should be maintained, the following slides deal with more science-based information.

3.2–16

Excretion of pathogens in faeces

	Incidence (per 100.000)		Excretion (per g wet weight)		Duration (days)	
	Typically	Variation	Typically	Variation	Typically	Variation
Bacteria						
Salmonella	500	300-700	$10^{8,0}$	10^{4} - 10^{8}	37	25 - 55
EHEC	30	20-40	$10^{2,5}$	$10^{1,5}$ - $10^{3,5}$	8	5 - 13
Viruses						
Rotavirus	1200	800-1600	$10^{9,0}$	10^{7} - 10^{11}	5	0,5 - 60
Hepatitis A	6	(4-8)	$10^{5,0}$	10^{4} - 10^{6}	20	12 - 33
Parasites						
Giardia	1100	900-1300	$10^{6,5}$	10^{5} - 10^{8}	90	22 - 365
Cryptosporidium	200	150-250	$10^{7,5}$	10^{7} - 10^{8}	7	1 - 40
Ascaris	20	14-26	$10^{4,0}$	$10^{3,5}$ - $10^{4,5}$	245	90 - 665

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Depending on the kind of infection a person has, varying amounts of pathogens are excreted in the faeces. The examples listed in the above table illustrate the variations between different pathogens, but also between infected individuals.

The incidence of pathogens found in faecal matter excreted among 100 000 person or stool samples, varies from a few (Hepatitis A) to over a thousand (Rotavirus and Giardia). This represents the prevalence of sick people in an average population.

The variation in the number of pathogens in a gram of wet faecal matter in infected persons is very large in most cases. For example, there are up to 10 000 000 000 rotaviruses (ten billions or equal to the number people on the globe in the year 2050) and 10 000 Ascaris eggs. The infectious doses, i.e. how many microorganisms that is required to cause infection also varies depending on infection, and on the individual who is exposed.

The number of days (duration) an infected individual excretes a certain pathogen varies considerably: from a few days to years. Some infections may even be chronic, in which case excretion of the pathogen is life-long. Numbers can also vary during the course of an infection with higher numbers in the first (acute) phase of the illness. And in many locations with bad sanitary conditions it is not uncommon for most people to be infected with one or more gastrointestinal infection. Exposure is imminent in such areas.

Pathogens in urine and importance of urine as a transmission route

3.2–17

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

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A summary of pathogens possibly transmitted in urine and the importance of urine as a transmission route for each of these pathogens is presented in the table above.

As stated in a previous slide *Leptospira interrogans* is known to be excreted in urine. There are, to the authors' knowledge, no reports of this disease being contracted from human urine. It is more common to refer to it as a potential risk from animal urine (e.g. from rats). Typhoid fever is a large problem in developing regions and the bacteria can be excreted in urine, but we consider the importance of it as a transmission route as low. Mycobacteria can be found in urine but this infection is usually airborne.

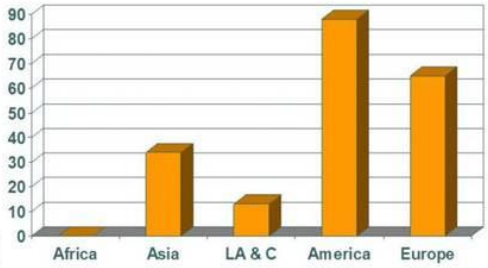
It has been suggested that the parasitic protozoa *Microsporidia* is transmitted via urine but it is (so far) not a recognized route. Venereal diseases may be thought of as a concern related to sanitation, but the organisms causing such diseases are not relevant since they are not adapted to environmental conditions outside the body and their transmission occurs from person to person when they are "exchanging" bodily fluids. Urinary tract infections (UTIs or urethritis) are common but are not caused by environmental transmission. Urethritis occurs when bacteria, usually from your rectum, travel into your urethra and grow there. Bladder infection, or cystitis, occurs when bacteria travel up past the urethra and lodge in the bladder. Bladder infections are the most common form of urinary tract infection, and can often occur at the same time as urethritis. *E. coli* is the most common cause of urinary tract infections.

The risk of disease transmission from urine itself is negligible. However, possible faecal cross-contamination – that is, faecal matter that is misplaced in a urine-diverting toilet – can be a route of contamination. Quantification of this faecal contamination is further discussed in Module 3.5.

3.2–18

Pathogens in mixed wastewater

- Small volumes of faeces contaminates large volumes of clean water
- Collection from a large number of persons – pathogens continuously present
- Smaller systems – higher concentration of a specific pathogen
- Treatment not optimized for killing pathogens
- 10% of wastewater is treated (developing countries)
- 20 million ha (?) irrigated with wastewater



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When water-flush toilets are used, small amounts of faeces contaminate large volumes of more or less clean water. In large sanitation systems (in which many people are connected to the same system) a large variety of pathogens will be continuously present since it is likely that someone connected to the system has the infection in question. In smaller systems it is less likely that a specific pathogen will be present at any given time but during events of infection, or during outbreak situations, the concentration of a pathogen may be higher than in a large sanitation system, resulting in a significant risk if people are exposed to the wastewater or sludge.

Where wastewater treatment plants are in place, the sewage/wastewater is treated in various processes that are categorized either as mechanical, biological or physical.

However, the treatment plants are not optimized for reducing (killing) pathogens. The concentration of pathogens in outgoing wastewater varies a lot and is dependent on the type of pathogen and the type of treatment process(es). It is only a final disinfection step that can effectively remove pathogens by killing them. It is therefore very important that the outlets from treatment plants are located in places where the harm to recipients and exposure to humans are minimized.

Treatment and barriers to hinder disease transmission is further discussed in Module 3.3. For details regarding the treatment of mixed wastewater, further reading of specialized text books is recommended (examples are given at the end of Chapter 3).

It is also important to remember that worldwide, only a small fraction of sanitation systems producing wastewater are connected to wastewater treatment plants. In many developing countries, the bulk of domestic and industrial wastewater is discharged without treatment or after primary treatment only and it is estimated that only 10% is treated effectively. The graph above shows estimates for the percentage of wastewater that is treated in various parts of the world.

Pathogens in greywater

3.2–19

- Lower concentrations of pathogens here than in faeces
- Faecal origin of pathogens (bathroom and laundry)
  - Shower and bath, washing clothes, washing diapers
- Pathogens from food stuffs (kitchen sink)
  - Faecally contaminated vegetables (e.g. from irrigation with wastewater or application of animal manure), soil
  - Contaminated meat (e.g. chicken)
- Health risk from disposal or reuse
  - Contamination of nearby surroundings
  - Contamination of drinking and recreational water
  - Irrigation of crops

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In addition to urine and faeces, households produce greywater. Greywater systems, from collection to treatment and possible reuse, may vary a lot in design and management. Greywater is dealt with in detail in Chapter 4. The content of greywater depends on what flows are collected from the household and what products (chemicals etc.) are used. Pathogens are generally present in greywater, but the concentrations are much lower than in faeces or in mixed wastewater containing faeces. Greywater may however be high in nutrients that bacteria can thrive on, resulting in possible growth of bacteria. This has proved to be the case for indicator bacteria (see Module 3.3).

Faecal pathogens in greywater can come from dirty laundry (underwear), washing of diapers or showering/bathing. Different foodstuffs can also contain pathogens, due either to faecal contamination (e.g. from wastewater irrigation or animal manure) or to “internal” contamination that occurs during production. For example, Campylobacter are present in 30% of chicken retail products in the Netherlands.

Health risks from greywater are similar to those associated with mixed wastewater – that is, potential pollution of nearby surroundings, pollution of recreational waters and drinking water sources. Greywater is used for irrigation of crops mainly as a water source, not for its nutrient content. Health risks have been recognized and are further described in Module 3.4 and in Chapter 4.

3.2–20

Typical concentrations of microorganisms in sludge (EC, 2001)

[per g wet weight]

Bacteria	*E coli*	10^6
	Salmonella	10^2-10^3
Virus	Enterovirus	10^2-10^4
Protozoa	*Giardia*	10^2-10^3
Helminths	*Ascaris*	10^2-10^3
	Toxocara	10-10^2
	Taenia	5

When treating wastewater, pathogens are being concentrated in the sludge – not in the effluent

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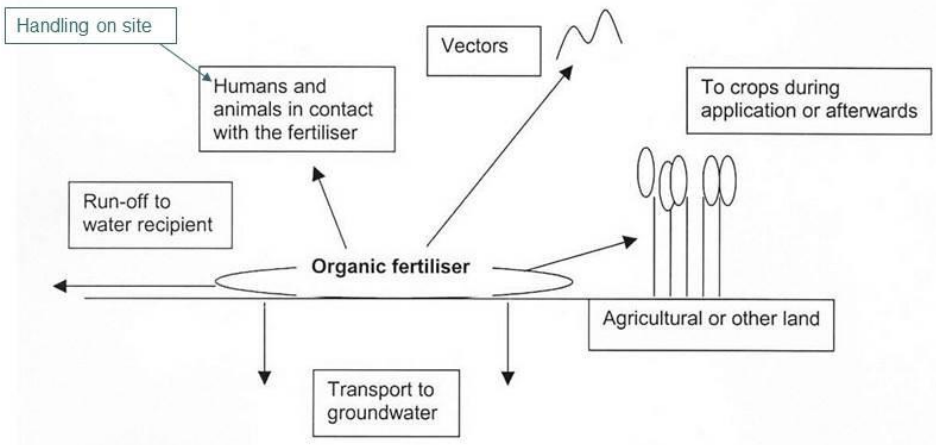
In any wastewater treatment, sludge is produced. Since pathogens in wastewater are attached to particles, pathogens will be concentrated in sludge and not in the effluent. The table above shows typical concentrations of the indicator *E. coli* and some other pathogens that can affect human and animal health. Since sludge also contains nutrients it is used as a fertilizer in agriculture. In many countries sludge is treated before use (hygienization) in order to decrease the risk of disease transmission. But regulations vary and other barriers may be introduced to decrease exposure (see Module 3.3).

Sludge is also formed in single-household systems e.g. septic tanks. A concentration of pathogens occurs, and the material can, in terms of some of the associated risks, be comparable to faeces. However chemical pollution of both wastewater and sludge is of greater concern.

3.2–21

Possible transmission routes for pathogens from organic fertilisers (e.g. faeces)



- The handling and reuse of all types of waste products with human or animal origin involve hygienic risks

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Reuse of "waste products" containing plant nutrients is encouraged in Chapter 1. Fertilizer products such as wastewater, sewage sludge, animal manure, human urine, treated faeces or organic household waste (food waste) may be used.

The use of organic waste fertilizers will always involve some risk of humans and animals being exposed to pathogens. Exposure can occur during the handling of the material, since there is a risk of accidental ingestion for a person coming into direct contact with pathogens. Direct contact is also possible after application. Further spread of pathogens to the surrounding environment and waters and to crops may result from exposure by ingestion, e.g. when drinking the water, during swimming or when consuming food crops.

Contamination of food

3.2–22

- Contaminated seeds, uptake of pathogens?
- Organic fertilisers – human excreta, wastewater, animal manure
- Irrigation – wastewater, contaminated surface water
- Handling and storage
- Cooking
- Storing of cooked food, growth of pathogens

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As is the case with drinking water, food may be a potential source of pathogens. Pathogens may be present from the beginning and in the crop if seeds are contaminated, but this risk is considered quite low. Fertilizer products from human (and animal) waste could add pathogens to the crop, as could wastewater or contaminated surface water that is used for irrigation. Later in the food chain it is possible that food may become contaminated by improper handling and storage, for example if hand hygiene is insufficient or if animals or insects come in contact with the food.

It is also common that raw food is contaminated in other ways. For example, meat or eggs can become contaminated in the production process. Some bacteria can grow on food, resulting in their presence in high numbers and potential infection by eating. Others produce toxins that are not removed by normal cooking procedures. Gastrointestinal disease caused by infection or a toxic reaction after food consumption is generally referred to as food poisoning. In general, pathogen risks are possible to manage, as described in subsequent modules, whereas chemicals cannot be removed from food or water as easily (in analogy with the example of bacterial toxin).

When discussing the reuse of waste products as fertilizers we are dealing with cereal, vegetable and fruit crops. Animal products like fish and meat may also contain pathogens that infect humans when they are consumed. Appropriate handling and proper cooking is essential to minimize these risks.

Health aspects related to aquaculture are not specifically included in this training material but further information on guidelines for irrigation and fertilization of crops is given in Module 3.4.

3. 2–23

Waterborne diseases and sanitation

Waterborne diseases are caused by:

- ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria or viruses.

- they include cholera, typhoid, amoebic and bacillary dysentery and other diarrhoeal diseases.

Sanitation system that involve reuse:
need to avoid disease transmission, mainly by:

- protecting ground- and surface water

- safe handling and use of the waste products in agriculture

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As described in Module 3.1 water-related diseases can be divided into several categories. As stated, in this training material we deal mainly with the first group – waterborne diseases. The origin of the pathogens causing disease is human or animal faeces or urine. Waterborne diseases are of concern in relation to sanitation in all regions, whereas many of the other water-related diseases mainly are related to tropical areas around the world. But, the risk in a sanitation system is also related to other waste fractions. This training material covers the reuse of various waste fractions in agriculture, and so it deals not only with the potential exposure to pathogens in water, but also with possible exposure through the ingestion of crops that have been in contact with contaminated water or waste products.

According to the International Water Management Institute (IWMI) and the International Development Research Centre (IDRC) untreated wastewater is increasingly being used for irrigation in urban and peri-urban agriculture, and even in distant rural areas downstream of the very large cities, as a result of both increased amounts of wastewater and of water scarcity. The current knowledge about the amounts of wastewater used in various countries (Scott, Faruqui and Raschid-Sally, 2008) . This book also discusses the accuracy of the estimate that 20 million ha of the world's agricultural land is being irrigated with wastewater.

Further reading:

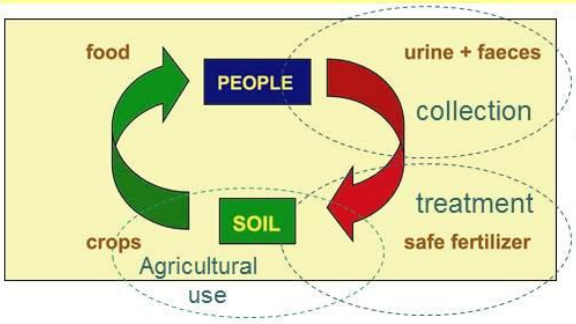
For more information on drinking water quality guidelines we refer to the WHO (www.who.org). The new edition of the guidelines can be found at:

http://www.who.int/water_sanitation_health/dwq/GDW7rev1and2.pdf

Scott, C., Faruqui, N., and Raschid-Sally (2008). *Wastewater use in irrigated agriculture*. Confronting the Livelihood and Environmental Realities.

http://www.cabi.org/bookshop/book/9780851998237

3.3 Pathogen reduction



How persistent are pathogens in the environment?

How can we prevent exposure and disease transmission in sanitation systems?

Learning objective: to become familiar with:

- the behaviour of pathogens in the environment
- the effects of treatment
- strategies for minimizing the transmission of disease, especially in relation to agricultural use of excreta

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Pathogens are present in all flows in sanitation systems (Module 3.2). Collection and treatment of the various waste streams like greywater, urine and faeces is necessary in order to protect water sources and our immediate environment. When waste fractions are recycled – or "reused" – as a resource in agriculture, new transmission routes for pathogens may be introduced. The management of the new system must minimize the risk of disease transmission through treatments and other barriers that prevent humans and animals from being exposed to pathogens.

This module examines conditions under which pathogens will survive or perish in systems and in the environment. It discusses the types of barriers that can be used to reduce pathogens and decrease health risks in sanitation systems where the waste fractions are intended for agricultural use. The module builds on recent research with the purpose to provide an understanding of the possibilities to employ various barriers to reduce health risks.

The Module has a focus on excreta. By closing the so called nutrient loop, that is ensuring the return of nutrients in urine and faeces to agriculture, we can further improve health by increasing food production. When people´s nutritional status is improved it makes them less susceptible to infectious diseases. However, this recycling of nutrients needs to be done in a safe way and this involves the safe collection of the excreta, safe treatment (before use), and the safe use of the products.

In Modules 3.4 and 3.5 there are further descriptions of how barriers are used in a systematic way and guidelines are developed for safe reuse of excreta. More practical information on how to treat excreta is included in Chapter 4.

Transmission of infectious disease during reuse

3.3–2

- Mexico, untreated wastewater: 33% higher risk of diarrhoeal diseases (Cifuentes et al. 1998)
- Israel (kibbutz), partially treated stabilization pond effluent: two-fold excess risk of enteric disease in 0-4 year-old age group (Fattal et al. 1986)
- No recorded incidents associated with "appropriately treated" wastewater (Cooper & Olivieri 1998)
- National Research Council (NRC, USA, 2000) evaluated 23 studies: no proof for either risk or non-risk for reuse of sewage sludge
- Risk assessment a valuable tool

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Excreta and other waste products always contain pathogens. The cited studies above prove that there are potential increased health risks when using treated excreta or other waste products in agriculture. These risks can be managed by limiting the exposure to pathogens and to reduce the numbers of pathogens by introducing barriers such as treatment of waste. The relationship between the use of waste products and possible enteric disease is difficult to establish by epidemiological methods, but some studies have been carried out. The examples listed here lead to the following conclusions:

In Mexico, children from households that irrigated gardens with untreated wastewater had a higher prevalence of diarrhoeal disease compared to children living in areas where untreated wastewater was not utilised ("rainfall villages"). The risk for diarrhoeal disease was 33% higher.

According to a 1986 study the use of partially treated wastewater in Israel resulted in a doubling of the rate of enteric disease among children. However, a summary of research involving more advanced wastewater treatments found no evidence of increased enteric disease. Regarding the use of sewage sludge, the National Research Council (NRC) in the USA evaluated a number of studies where individuals were exposed to sludge and concluded that there was no proof that the health risk increased or decreased. The NRC further stated the risks need to be further evaluated.

Epidemiological studies are expensive and often complemented with the valuable cost-effective tool of risk assessment. Risk assessments are discussed further in Modules 3.4 and 3.5. An aligned issue touched upon is how risks are perceived in varies regions of the world and between individuals. This module focuses on survival and inactivation of pathogens.

3.3–3

Estimated survival times for microorganisms in faeces, sludge, soil and on crop

Times given in days if not otherwise stated

Microorganism	Faeces and sludge[a] 20-30°C	Soil[a] 20-30°C	Soil[b] absolute max[c]/ normal max	Crop[a] 20-30°C	Crop[b] absolute max[c]/ normal max
Bacteria			1 year/ 2 months		6 months /1 month
Faecal coliforms	<90 normally <50	<70 normally <20		<30 normally <15	
Salmonella	<60 normally <30	<70 normally <20		<30 normally <15	
Virus	<100 normally <20	<100 normally <20	1 year/3 months	<60 normally <15	2 months /1 month
Protozoa[d] (Amoeba)	<30 normally <15	<20 normally <10	10/2	<10 normally <2	5/2
Helminths (egg)	several months	several months	7 year/2 year	<60 normally <30	5 months /1 month

[c] Absolute maximum times for survival are possible during unusaual conditions, such as at constant low temperature or at extermely protected conditions.

[d] Data is missing for Giardia and Cryptosporidium. Their cysts and oocysts, respectively, probably survive longer than the times stated here for protozoa.

(*Faechem[a] 1983 and Kowan[b] 1985, in EPA 1999*)

Microorganisms cannot live forever, but perish for various 'natural' reasons – just like human beings. Earlier, the literature often defined survival times of indicator bacteria and pathogens as the time it takes for "total inactivation". However, a total inactivation cannot be achieved in practice, only in theory. Only sterilization can kill all microorganisms, but this is only economically possible to achieve in a laboratory. Therefore, a zero risk cannot be the aim for any sanitary system which converts organic waste to fertilizers.

The above table summarizes some commonly used references and illustrates the variations in survival between different groups of organisms. The general impression is that bacteria, viruses and protozoa have strikingly similar survival times in faeces, soil and on crops in the temperature range of 20-30°C. Helminths, on the other hand, often survive for longer periods than other microorganisms. Yet, some studies have found bacteria like Salmonella alive in the soil after a number of years, despite a stated survival time of just days!

It should be noted that in commonly used laboratory procedures for detecting microorganisms, it is not possible to determine whether inactivation is total. For each type of organism there is a minimum concentration below which it is not possible to specify the number present. That is, results will not state "there are no organisms" but rather, that there are less than 1 or 10 per ml or per gram (numbers are given here as examples). Thus, 'total inactivation' is too crude a concept and therefore complemented with the time it takes for a, say, 90% reduction, called T_{90}.

Keeping these circumstances in mind, the table on survival time still gives guiding information that is helpful in practice. For instance, if faecal matter or sludge is stored for more than a year, most pathogens are expected to have died off. Even if a 100% inactivation is not expected or necessary, treatment methods can be introduced to manipulate or speed up the inactivation of pathogens.

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3.3–4

Inactivation of microorganisms in faeces

Organism to be modelled	4°C/low temp range	20°C/high temp range
E.coli*	T_{90} = 70-100 days	T_{90} = 15-35 days
Enterococci*	T_{90} = 100-200 days	Same as 4°C
Bacteriophages	T_{90} = 20-200 days	T_{90} = 10-100 days
Salmonella*	T_{90} = 10-50 days	
EHEC*	T_{90} = 10-30 days	Same as 4°C
Rotavirus	conservative model – no reduction T_{90} = 100-300 days	T_{90} = 20-100 days
Giardia	T_{90} = 15-100 days	T_{90} = 5-50 days
Cryptosporidium	T_{90} = 30-200 days	T_{90} = 20-120 days
Ascaris	T_{90} = 100-400 days	T_{90} = 50-200 days

*Possible growth not taken into consideration

(Arnbjerg-Nielsen et al., 2005)

The ‘natural’ die-off times for specific microorganisms in faecal matter is given in the table for two temperature ranges.

Since “full inactivation” of pathogens cannot be attained for a long time (years) in soil, sludge or faeces, instead so-called T_{90}-values are often used. The T_{90}-value is the time required to inactivate 90% (or 1 $\log_{10}$) of the microorganisms. The survival times given in this table are based on a literature survey of survival experiments performed using faeces and other similar material such as manure and sludge. Studies of inactivation in faeces are few and other studies had to be considered in order to estimate the T_{90}-values. These figures are later used in a risk assessment – see Module 3.5.

As can be seen, the results for different organisms vary considerably both between species and between temperature ranges. However, two observations on slide 3.3-3 seems to hold; for the higher temperature range the variation between species is rather small, and the survival time in a colder environment is substantially longer than in warmer environment.

The WHO guideline (2006) to store faecal matter for more than a year seems to be reasonably safe at the T_{90} inactivation level. More recent results from inactivation studies are presented in Chapter 4 to give practical advice and rules of thumb about how to treat excreta. In this chapter you can also find explanations of how inactivation can be calculated and expressed, especially in relation to temperature.

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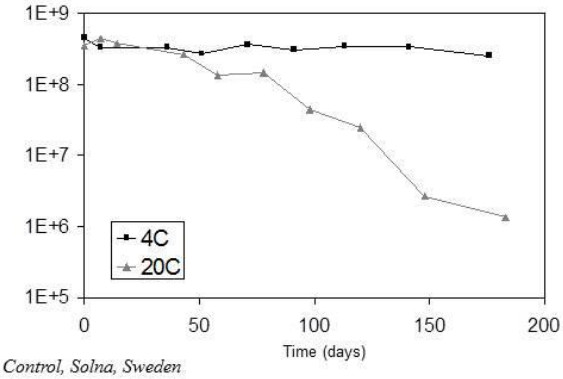
3.3–5

Survival of microorganisms in human urine

Organism group (ex.)		Survival time
Bacteria (*Salmonella*, *E. coli*)	-	**Short** (T_{90} = days)
Protozoa (*Cryptosporidium*)	-	**Average** (T_{90} = ~1 month)
Virus (rotavirus, bacteriophage)	-	**Long** (no reduction at 4°C, T_{90} = ~ 1-2 months at 20°C)

Factors that speed up die-off

- elevated **pH** (7 → 9, urea → ammonia)
- higher **temperature**
- lower **dilution**



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Urine is largely sterile in the body (see 3.2-17). Sill, urine in a urine-diverting toilet may be mixed with faecal matter through cross-contamination. What happens if enteric pathogens end up in the urine? Research on the survival of pathogens in urine during storage provides the following answers (http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-3090):

Bacteria are inactivated within days. Protozoa, represented by *Cryptosporidium* had a T_{90} of one month, whereas viruses were the most persistent organisms with no reduction at 4°C, and a T_{90} of 1–2 months at 20°C (see graph above).

The temperatures investigated here correspond to minimum and maximum temperatures in a Northern European climate. Since a higher temperature generally results in a faster inactivation it is likely that T_{90}-values will be lower in tropical climate, which is to say that a shorter time is needed for the same level of treatment.

There are other factors that promote inactivation (next slide). For instance, pH in urine increases from 7 to around 9 even after a short transport through a pipe. The reason is that urea is transformed to ammonia. This gas can kill pathogens.

3.3–6

Parameters affecting microbial survival in the environment

Temperature	Low temperature prolongs survival. Inactivation if >40°C, treatment processes 55-65°C.
pH	Neutral pH (7) beneficial for survival. Inactivation – if highly acidic or alkaline conditions.
Moisture	Moisture (e.g. in soil) favours the survival. Inactivation – if drying condition.
Solar radiation/ UV-light	Inactivation – by natural solar radiation or UV-lamps.
Other microorganisms	Longer survival in sterile material. Inactivation – competition and predation.
Ammonia	Often affects microorganisms negatively. Inactivation – by ammonia produced at high pH.
Nutrients	Needed for growth of bacteria. Inactivation – if lack of nutrients.
Other factors	Oxygen availability, chemical compounds.

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Understanding why pathogens survive and perish in the environment is crucial for developing measures to reduce pathogens. The above table lists important parameters for the survival and inactivation of microorganisms.

Temperature – even if human pathogens are adapted to the body temperature of 37°C, they may favour other temperatures in the environment. A lower temperature (but above 0°C) generally prolongs survival. The higher the temperature is, the quicker the inactivation. For effective treatment in compost heaps, temperatures above 55°C are preferable, and sometimes required in legislation. Temperatures of at least 120°C are needed to kill bacterial spores.

pH – most pathogenic microorganisms are adapted to a neutral pH (7) and can potentially be killed by a (significantly) higher (alkaline) or lower (acidic) pH-level.

Moisture – living organisms require moisture for their survival so drying material (like soil or faeces) has a negative effect on pathogens. However, some life stages of parasitic protozoa and helminths can be quite resistant to drying, e.g. Ascaris requires <5% humidity.

Solar radiation and UV-light - is a natural factor that can kill pathogens. It is therefore used in water treatment systems to reduce the number of pathogens.

Microorganisms will affect each other by predation and competition, and pathogens survive longer in sterile water than in water in which there are other organisms.

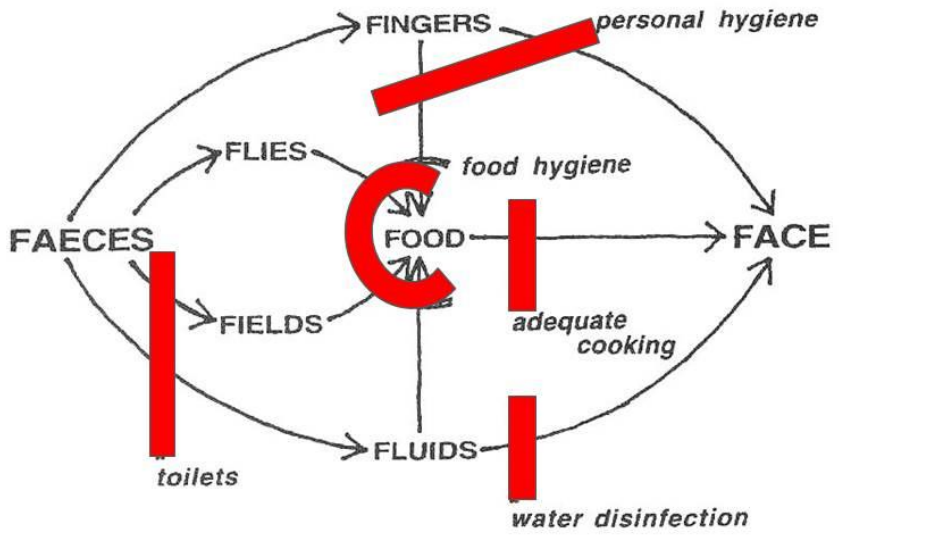
Ammonia is a compound that plays an important role in treating waste such as sewage sludge and faeces. Ammonia kills pathogens and can be generated at high pH-level by treatment with lime or urea (see Chapter 4).

Nutrients – presence of nutrients can affect the survival of bacteria, since they can both grow and multiply in such environment. Bacteria can also starve and die or become inactive for lack of nutrients.

Other factors such as oxygen or some chemical compounds can affect pathogens negatively.

3.3–7

Barriers required to prevent the spread of pathogens



(Esrey et al. 1998)

Barriers refer to measures to limit people's exposure to pathogens either by an actual reduction of pathogens in the material (human waste, organic fertilizer or crop) or by actually preventing people (and animals) from coming into contact with the material. Returning to the F-diagram presented in Module 3.2, barriers to prevent the spread of pathogens from faeces include the following:

Toilets – the use of **toilets** to collect **faeces** reduces exposure compared to the practice of open defecation. Defecation in **fields** where **food** is produced, introduce pathogens on crops and runoff may contaminate the water in nearby streams (**fluids**).

Water disinfection – is practised on all large-scale water production facilities, but can also be applied on a small scale. However, it is not easy to find a chemical or a filter that removes all pathogens. To boil unclean water, before drinking it, is therefore a common practice. It is important that water is stored in a safe way so that further contamination is avoided.

Personal hygiene – to wash hands is a simple measure to improve the health situation if water is available. It prevents the transfer of pathogens from **faeces** or the environment to the **food** or directly to your **face** (mouth, nose, and eyes). Some pathogens are sensitive to alcohol gel whereas others are not and general hand washing, preferably with soap, is more effective.

Adequate cooking – microorganisms thrive on stored food but by heating food it is possible to kill the pathogens. If a toxin has been produced by bacteria, it is however not possible to remove it by heating the food. Diseases caused either by infection or toxic reactions are generally referred to as food poisoning. Cooking also has little or no impact on the concentrations of toxic chemicals that might be present.

In practice, some communities rely on a barrier late in the food chain. For example, the old Chinese tradition to use faecal material in crop production is accompanied by household practice to heat all vegetables i.e. they are not consumed raw as in many other countries. Nevertheless, there is/has been a high prevalence of helminth infections in parts of the population. The ideal situation is to apply a set of barriers, since no single barrier is completely effective on its own, and relying on more than one barrier will increase safety (see also Module 3.4).

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3.3–8

How can we kill pathogens?

- We cannot only wait for the pathogens to be inactivated (eventual pathogen die-off)
- Measures can be taken to introduce conditions that are hostile to pathogen survival, such as
  - High temperature,
  - Low moisture,
  - Competing microflora,
  - High or low pH
  - Ammonia gas
  - etc.

But, difficult to establish T_{90} for reduction of each and every pathogen

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It is now known what species of pathogens are present and to have a fair idea of how many there are (Module 3.2). In this module, information is given about how long they survive in various environments, and the rate at which they are inactivated. We also know some simple measures as to how humans avoid exposure to pathogens (slide 3.3-7). The next issue is to see how pathogens can be manipulated or killed in order to reduce health risks.

Inactivation depends on the microorganism´s sensitivity to environmental factors such as temperature and moisture (see previous slide). It is possible to alter these conditions to increase the inactivation rate, but it is difficult to state the approximate time it will take to achieve a “total” inactivation in a specific environment. Inactivation is crucial in managing the treatment of excreta and other organic wastes. Bacteria can multiply under favourable conditions, but that is not the case for the other groups of microorganisms e.g. viruses.

We utilise the information on positive influences on survival and try to introduce the opposite conditions. For instance, to raise pH or temperature, or to reduce oxygen levels. The next set of barriers relates to treatment of wastewater, sludge, faecal material, and urine.

3.3–9

Expected removal (log_{10}) of micro-organisms by wastewater treatment barrier

Process	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemically assisted	1-2	1-3	0-1	0-1
Activated sludge	0-2	0-2	0-1	0-1
Bio filtration	0-2	0-2	0-1	0-1
Aerated lagoon	1-2	1-3	1-2	0-1
Oxidation ditch	1-2	0-2	1-2	0-1
Disinfection	2-6	0-1	0-4	0-3
Waste stabilization ponds	1-6	1-3	1-4	1-4
Effluent storage reservoirs	1-6	1-3	1-4	1-4

Large variations depend on organism and difficult to predict

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We start with wastewater and sludge treatment (see also Module 4.6) before expanding on treatment of faeces and urine.

A wastewater treatment plant is not optimized for pathogen inactivation/removal but has other primary functions, mainly reducing nutrients and solids. Each step in a treatment plant constitutes a barrier to transmission of disease. However, new routes are established via air, seepage and sludge, and have to be kept under control. The table above shows approximate log_{10} removal rates of various types of microorganisms in the effluent by different wastewater treatment steps. Such removal is due to both die-off and actual removal, for example by sedimentation processes or adhesion to particles.

As can be seen in the table, low-tech systems such as waste stabilization ponds can result in high rates of removal of pathogens. Treatment systems like this are further described in Module 4.6. Even disinfection by chlorination fails to reduce cysts (or oocysts) like Cryptosporidium which is very resistant to chlorine. Therefore, it remains important to include barriers preventing people and animals from coming in contact with the outgoing wastewater.

The greywater contains much fewer pathogens than household wastewater (see 3.2-18/19), but even treated greywater contains a range of contaminants, among them pathogens. Treatment is required, but what kind of treatment is appropriate depends on the constitution of the greywater and its subsequent use. For instance, specific risks are related to irrigation such as aerosol and cultivation. Irrigation methods can themselves be important barriers e.g. sub-surface irrigation. Ponds represent a case where the treatment facility itself constitutes a risk both from a hygienic perspective and due to accidents e.g. falling into the pond. If the treated greywater is used for groundwater recharge and subsequent drinking water production, the infiltration process needs to reduce the pathogen population sufficiently. Greywater systems and treatment are elaborate on in Chapter 4.

Greywater treatment

3.3–10

- Treatment to remove grease, N, P, chemicals….and pathogens (see chapter 4)
- Choice of treatment method dependent on the intended use
- Specific risks of use:
  - Irrigation, subsurface
  - Treatment in ponds – limit exposure
  - Infiltration, drinking water
- Handling to avoid smell

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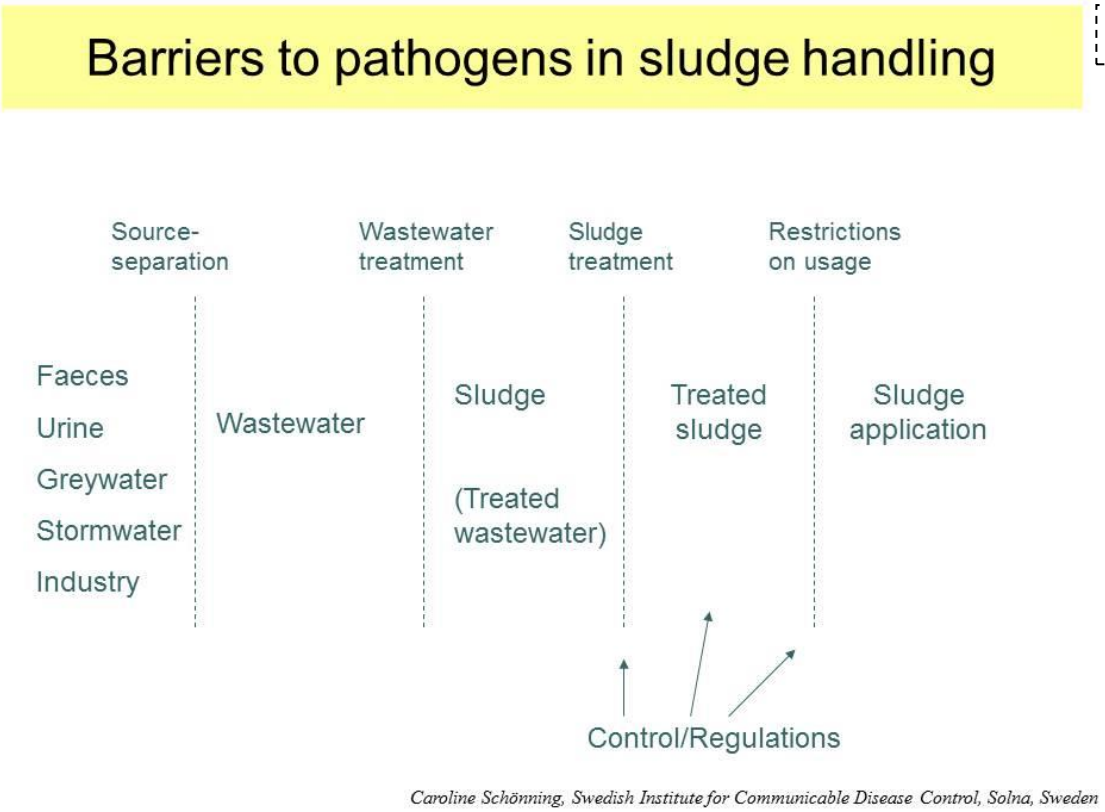
The greywater flow contains much fewer pathogens than household wastewater (see 3.2-18/19), but even treated greywater contains a range of contaminants, among them pathogens. Treatment is required, but what kind of treatment is appropriate depends on the constitution of the greywater and its subsequent use.

Initially, greywater must be treated in order to avoid smell, which is likely to be caused by anaerobic conditions. Studies of greywater treatment show large variations in the effectiveness and efficiency (see Module 4.7). Additional barriers may be needed to prevent exposure.

3.3–11



Another example of barriers is in relation to managing sludge, where sewage sludge can be compared to other types of organic wastes. A kind of '*liquid waste hierarchy*' can be applied, starting from reducing the volume and hazardous content of the sludge (see 1.3-8). Keeping waste flows separate, makes it is easier to treat each flow separately e.g. greywater with or little pathogen load. Also, each flow has less varied composition and some streams have few hazardous compounds.

After treatment the bulk of pathogens are found in the sludge (see 3.4-6), while some remain in the treated effluent and some are found in sediments in the treatment plant. Sludge can be treated further (see 4.7-28) by drying or storage, while incineration should be avoided since this process makes plant nutrients inaccessible in the ashes.

Restricting the use in agriculture constitutes a major barrier and limits exposure of humans and animals to pathogens. The European Union has issued detailed quality requirements for substances in sludge and allowed application rates on different soils (http://ec.eurpoa.eu/environment/waste/sludge/).

In addition to content of the sludge, behavioural restrictions make up important barriers for transmission of pathogens and disease (further discussed in Module 3.4).

Urine diversion in dry sanitation systems

3.3–12

- Will result in (compared to mixing of faeces and urine):
  - Less smell
  - Less volume (slower filling up, less to handle)
  - Prevention of dispersal of pathogen-containing material (spilling, leaching)
  - Safer and easier handling and use of excreta (volume, treatment)

→ **Less risk for disease transmission**

- Urine diversion is therefore recommended

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By separating urine from faeces in dry toilets several benefits can be obtained. There will generally be less smell, there will be smaller volumes to handle and the collection chamber will not fill up as quickly. Since the remaining material will be drier there will be less risk of spilling and leaching to groundwater and this can facilitate further treatment. All these factors can contribute to a reduction of the risk of disease transmission. It is therefore possible to advocate the implementation of urine diversion, and that is even if the urine is not reused.

Diversion of urine can also have large benefits in pipe-bound and water-flush systems.

Treatment of faeces as barrier

3.3–13

- **Primary treatment in dry toilet**
  - Adding drying material reduces pathogen load
- **Storage**
  - Ambient conditions
- **Biological methods**
  - Composting (heat, microbial competition, pH-changes)
  - Anaerobic digestion (competition, pH-changes)
- **Chemical treatment**
  - Alkaline treatment
    - Ash, lime (pH-elevation and desiccation)
    - Urea (ammonia)
- **Incineration**

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Excreta may be flushed with water and often together with toilet paper. This so called black water is commonly mixed with greywater in a sewer. In this Module, however, exposure is related to the singular flow of faecal matter.

A **primary treatment** occurs in dry toilet collection vaults and is influenced by the toilet construction and the habits of the users. For instance, if users add some material (lime, ash, sand, dried compost matter, etc.) to cover the faeces biological and chemical processes are initiated. If desiccation or a pH-increase occurs, this “treatment” can reduce bad odour as well as lower the health risks involved in subsequent handling of the faecal material.

Storage is a simple and effective treatment method both on-site and off-site. The storage place should be odour-free and faeces should be covered and seepage should be controlled. Since storage is done at ambient conditions, the reduction of pathogens will vary tremendously. However, further measures can be taken to improve the reduction while storing faecal matter.

Biological treatment is composting with organic matter in high temperature or anaerobic digestion producing biogas at ambient temperature (see Module 4.4 and 4.6).

Chemical treatment involves the addition of a chemical, either from a “natural” source such as wood ash or pure urea. The increase in pH and the production of ammonia that occurs in the controlled type of urea treatment (ammonia treatment) is effective in reducing pathogens. pH can be raised up to 12 by adding lime and effectively kill micro-organisms. Adding ash also raises pH level and desiccates the faeces, both of which inactivate pathogens. The latter is often used in small–scale treatment. Thorough mixing of chemicals with the faecal material is a crucial point.

Incineration of faeces is not advisable since the material is too moist and requires energy. Also, incineration tends to make N to disappear and P and K non-available to plants (see 1.3-8).

Storage of urine as a barrier

3.3–14

- The most appropriate treatment method
- Other methods tried out in order to reduce the volume
  - Easier handling for agricultural use
- Storage with low air exchange (tight containers) best method to keep the nutrients in urine
- Only necessary in large-scale systems
- Existing guidelines in module 3.4

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Storage is at present seen as the most viable method for the treatment of urine. Other methods have been tried, but more for the purpose of producing a fertilizer product that is easier to handle. However, a lot of energy is required to dry urine and most of the nitrogen is lost in the process. Urine is a well balanced fertilizer and it is considered most resource efficient to keep the urine as it is. Still, storage has to be in airtight containers to minimize nitrogen losses (about 1% lost instead of more than half in aerated storage). Storage for hygienic reasons is only considered necessary in large-scale systems. At household level the urine may be used directly, since the risk for disease transmission is considered low (WHO, 2006). If and when the volume of urine could be reduced without losing its nutrient content, transport and storage costs will go down and make the product competitive with chemical fertilizers.

An example of a risk assessment for reusing urine and existing guidelines is presented in Module 3.4. The agricultural use of urine is discussed in Module 4.8.

3.3–15

Survival study – double-vault latrines in Vietnam

Design of study:

- Ascaris and bacteriophage (mimicks virus) added to the vault material
- Study the effect of changes in pH, temperature and moisture content
- 12 double-vault latrines were studied (of different design)

(Carlander & Westrell 1999)

Results:

A total inactivation within 6 months of *Ascaris* and the model virus (bacteriophage)

pH played a significant role for the inactivation of the bacteriophages in the faecal material

The inactivation of bacteriophages and *Ascaris* was achieved through a combination of high pH (8.5-10.3), high temperature (31-37°C) and low moisture level (24-55%)

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A double-vault dry latrine placed above ground was developed in Vietnam in the 1950s. It is mainly being used in rural areas. The long use made it interesting to study its pathogen reduction capability. Ascaris eggs and Salmonella bacteriophages (viruses that infect bacteria, in this case the Salmonella strain *salmonella typhimurium* 28B) was added to the faeces in twelve vaults and studied over a period of six months. Three environmental parameters were measured – pH, temperature and moisture.

By statistical analysis it could be concluded that:

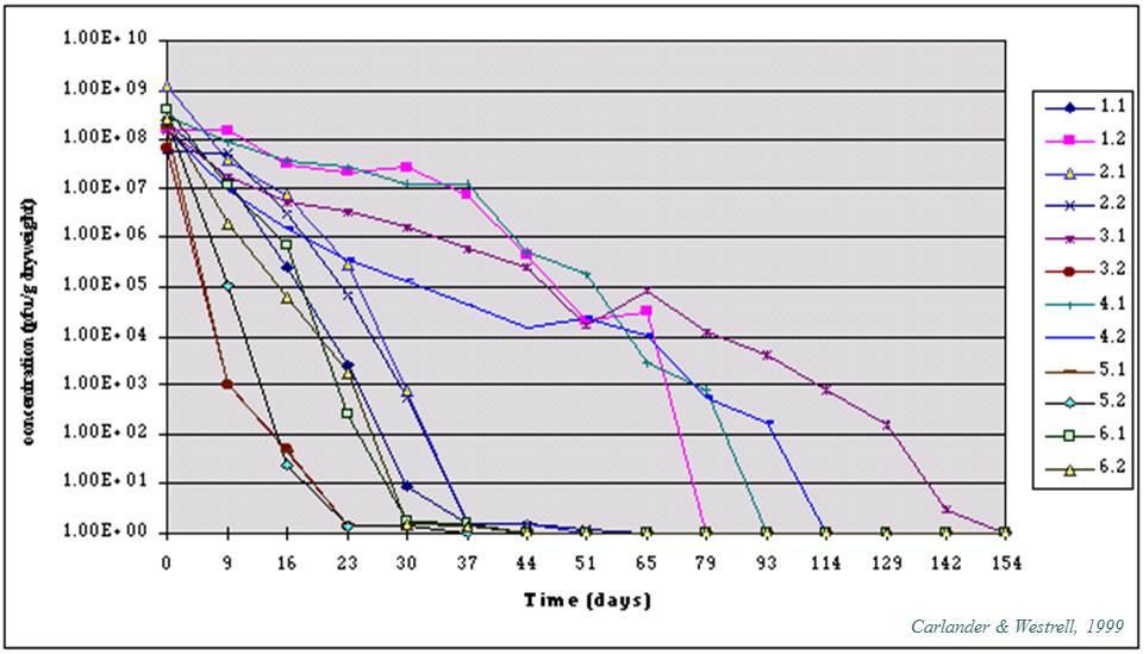
- A total inactivation of the sturdy *Ascaris* ova (possible to count due to their big size) and the model virus (bacteriophage) was achieved within 6 months.
- pH played a significant role in the inactivation of the bacteriophage in the faecal material
- The inactivation of the bacteriophage and *Ascaris* was achieved through a combination of high pH (8.5–10.3), high temperature (31–37°C) and low moisture content (24–55%).

It was not possible to determine the relative importance of the different factors on pathogen inactivation.

The detailed measurements are given in the following two slides.

Reduction of *Salmonella typhimurium* phage 28B in latrines over time for different measures

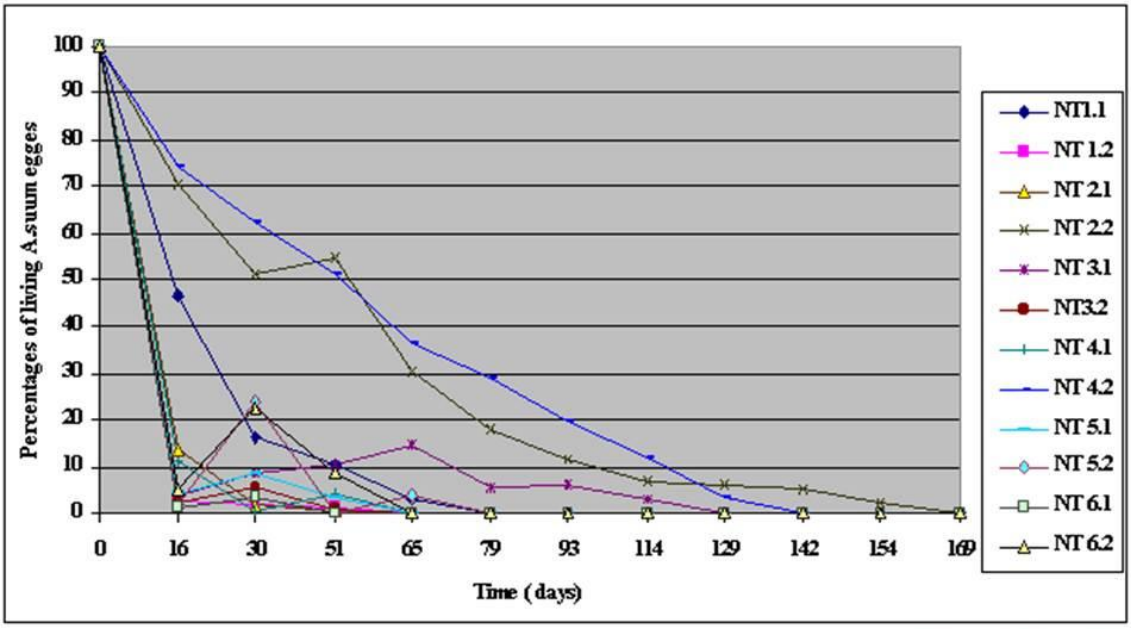
3.3–16



As can be seen, the phages were reduced to below the detection level in about 1–2 months in eight toilets, whereas they survived for up to 6 months in one.

Reduction of *Ascaris suum* eggs

3.3–17



(Carlander & Westrell 1999)

Looking at Ascaris eggs in the same toilets, the situation was somewhat similar with more rapid inactivation in most of the toilet vaults, and prolonged survival in a few vaults.

Interestingly, a comparison between Ascaris and Salmonella (previous graph) shows that the reduction in toilets NT 4.2, NT 3.1 and NT 2.2 is very slow for both, and one can only speculate about the reason for this.

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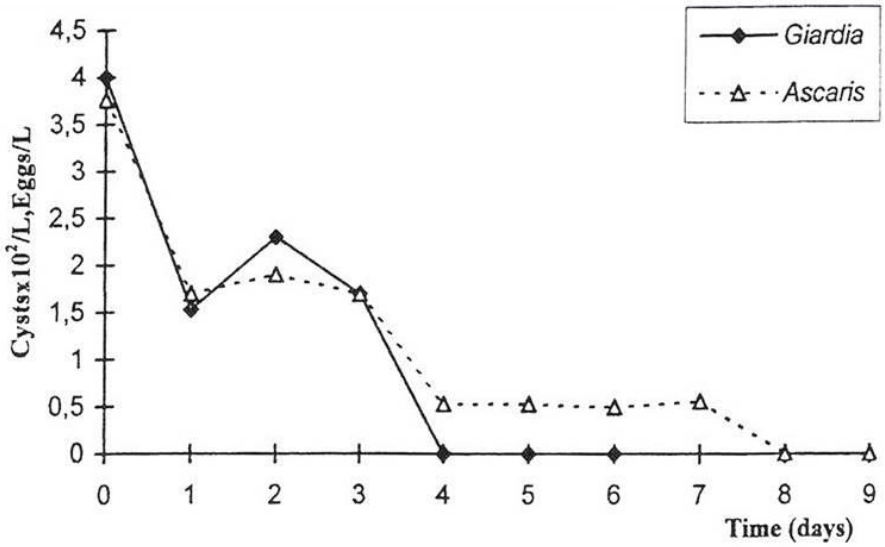
Inactivation on crops

3.3–18



Inactivation of Giardia and Ascaris on coriander leaves

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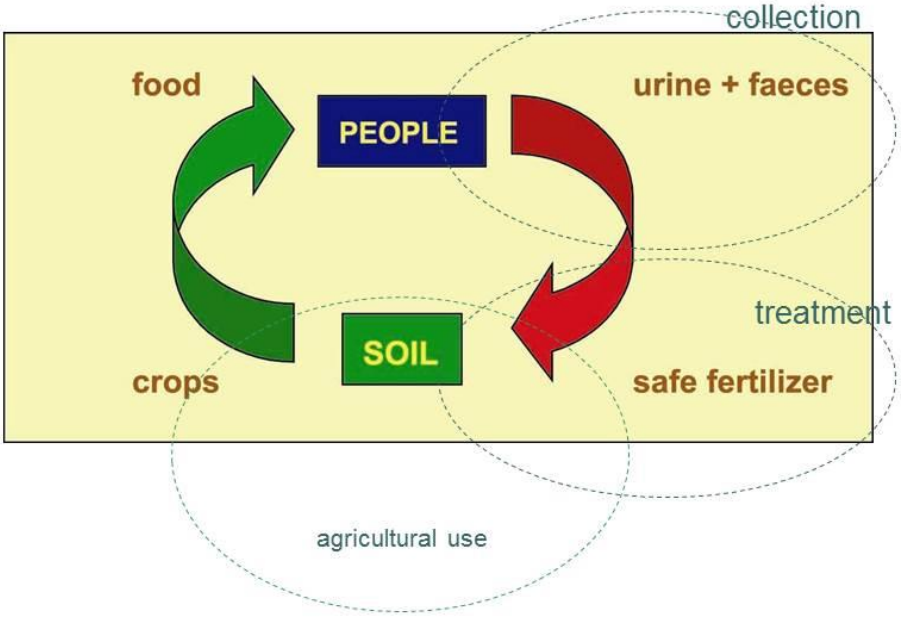
Pathogens can be transmitted via food (see 3.3-5) and they may originate from pathogens on crops. The spice coriander is made of grounded leaves and used as a condiment directly added to food. Therefore, pathogens have direct route from the crop to mouth. The graph displays a 'natural' reduction of Giardia and Ascaris on coriander leaves. This example shows a quite rapid inactivation of *Giardia* (4 log reduction in 4 days) and of Ascaris (4 log reduction in 8 days).

Inactivation of pathogens on crops is an important barrier for transmission of disease by food consumption. The above result supports the rule of thumb to do the last watering of leafy crops days before harvest.

Module 3.4 deals with risks of transmission in agriculture.

Closing the nutrient loop safely

3.3–19



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By closing the so called nutrient loop, that is ensuring the use of nutrients in urine and faeces in agriculture, we can further improve health by increasing food production. Thus, people´s nutritional status is improved which makes people less susceptible to infectious diseases. However, this recycling of nutrients needs to be done in a safe way and this involves the safe collection of the excreta, safe treatment (before use), and the safe use of the products. The purpose is to close the nutrient loop – but when it comes to pathogenic microorganisms the transmission routes need to be broken!

Other aspects of proper and optimal use of excreta and greywater, such as utilization of nutrients and choice of crops, are dealt with in Chapter 4.

3.3–20

Treatment as a barrier

Treatment as a barrier

A combination of barriers to decrease exposure of humans to excreta should be applied in order to reduce risks for disease transmission in ecological sanitation systems. Treatment of the excreta is considered as a necessary step for the subsequent use as fertiliser on (agricultural) land.

(EcoSanRes, 2004)

- The goal is to significantly reduce risks – zero risk is not possible
  - ”Minimise” risks (considering viable/practical/realistic measures)
  - Insignificant amounts of pathogens
  - No additional individuals inflicted by disease

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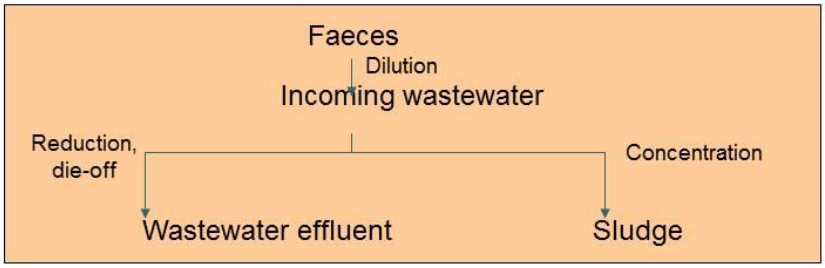
So, as stated: To reduce the risks from using excreta a combination of barriers is recommended. We see treatment as the main barrier in sustainable sanitation systems. The goal is to significantly reduce the overall risk, and it can also be viewed as minimizing risks or decreasing the number of pathogens to insignificant levels so that no additional cases of disease occur as a result of using excreta for fertiliser. As previously described, a total inactivation of pathogens is not achievable and it is not viable to aim at a zero risk for a sanitation system.

One example to prevent disease transmission is the various treatment steps for drinking water, e.g. filtration and disinfection. For waste products we can also talk about treatment as one barrier and other measures to limit people’s exposure to pathogens as other barriers. The exposure is decreased either by an actual reduction of pathogens in the material (that is, the human waste, the organic fertilizer or the crop) or by actually preventing people (and animals) from coming into contact with the material. A wider definition used by the WHO is that a barrier is any health protection measure. This definition includes measures such as chemotherapy and immunization, and health and hygiene promotion to decrease the risk of infection.

Wastewater treatment

3.3–21

- Treatment steps - barriers
- Microorganisms reduced by 70-99,99% in STP (Sweden)
- Treatment plants not optimised for pathogen removal
- Generally, no regulations on outgoing (treated) wastewater
- Disinfection is an efficient method, but causes other problems
- Sewage sludge has high concentration of pathogens



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STP = Sewage Treatment Plant

Treatment of wastewater, sludge, faecal material, and urine is viewed as barriers. We start with wastewater and sludge treatment before expanding on treatment of faeces and urine.

Each step in the wastewater treatment plant constitutes a barrier to transmission of disease. However, wastewater treatment plants are not optimized for pathogen removal and have other primary functions such as reduction of solids and chemicals. It is only the final disinfection step that aims at pathogen reduction. In many countries disinfection is not included (if the wastewater is treated at all) and therefore it is important to include a barrier at the point of disposal – that is, there needs to be a barrier preventing people and animals from coming in contact with the outgoing wastewater. This can be done by choosing a suitable point of discharge. Under such circumstances part of the pollution problem may also be solved by dilution, for example by discharging effluent in the deep sea far from beaches or recreational areas.

3.3–22

Treatment of faeces

- **Storage**
  - Ambient conditions
- **Biological methods**
  - Composting (heat, microbial competition, pH-changes)
  - Anaerobic digestion (heat, microbial competition, pH-changes)
- **Chemical treatment**
  - Alkaline treatment
    - Ash, lime (pH-elevation and desiccation)
    - Urea (ammonia)
- **Incineration**

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To give an overview of possible methods for treating faeces the following categorization can be made**.** In Chapter 4, details and practical advice on how to perform treatments is given.

Storage can be considered the simplest method of treatment. The material is contained so that exposure and seepage are minimized and seepage. Exposure should also be minimized by choosing a proper place for the storage and the material should be covered. Since storage is done at ambient conditions the reduction of pathogens will vary tremendously, and storage requires proper containment.

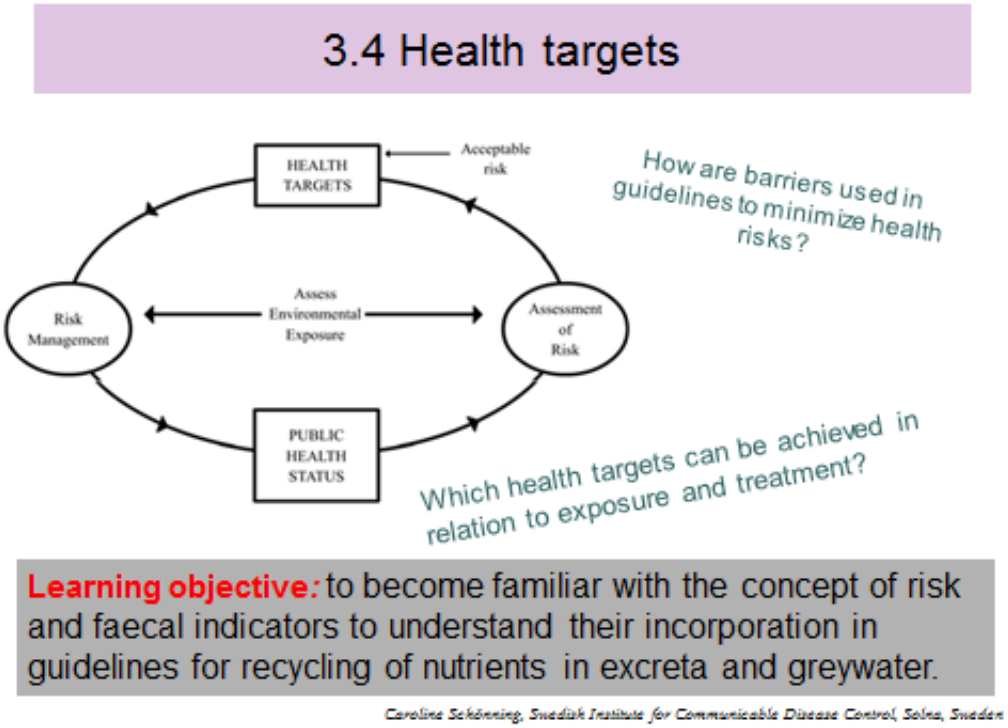
Biological treatment means composting and anaerobic digestions, which both mainly rely on an increase in temperature to reduce pathogens as described in Chapter 4.

Chemical treatment involves the addition of a chemical, either from a "natural" source such as wood ash or pure urea. The increase in pH and the production of ammonia that occurs in the controlled type of urea treatment (ammonia treatment) is effective in reducing pathogens. On a large scale, lime treatment can be used, but is probably more common for sludge treatment, and results in a significantly elevated pH (pH 12). The addition of ash on the other hand is generally used in small–scale treatment, where some elevation in pH and desiccation result in pathogen inactivation. The chemicals need to be properly mixed with the faecal material to be effective.

Incineration of faeces is also possible but not commonly used since it requires lots of energy to burn such high-moisture material (see Chapter 4).

List of reference:

Höglund, C. (2001) "Evaluation of microbial health risks associated with the reuse of source-separated human urine" (http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-3090)



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.

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Wastewater, excreta and greywater use – Background and health concerns

3.4–2

- 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

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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.

Risk assessment and analysis – new way to quantify and manage risks

3.4 – 3

- Risk assessment
  - Qualitative or quantitative estimation of possible negative health effects associated with exposure to a certain hazard

  Includes: Hazard identification
  Exposure assessment
  Dose-response assessment
  Risk characterisation

- Risk management
  - Control and management of risks, weighing alternatives, standpoints, implementation of legislation, etc.
- Risk communication
  - Communication (two way-communication) of risks to responsible bodies, "stakeholders", the public

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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.

Why risk assessment?

3.4 – 4

- 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

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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.

Microbial risk assessment - Examples of application (1)

3.4 – 5

- Ensure the quality of provided food during production and further handling
- Determine whether the drinking water treatment is satisfactory relation to the accepted level of infection in society
- Assess different exposures and how pathogen transmission can be avoided in new systems, e.g. local reuse of faeces or greywater
- In comparisons of e.g. different wastewater systems
- 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

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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.

3.4 - 6

Step 1: Hazard identification and how to estimate the amount of pathogens

- **Direct counts**
  - Often possible, but problematic if the risk level is below the microbe detection level e.g. 500 samples of 2 000 L to detect "acceptable" Cryptosporidium risk
- **Analysis of index organisms**
  - the density of organisms assumed to be proportional to pathogen(s) e.g. Clostridium perfringens for viruses/protozoa (in water treatment)
- **Indirect measurements**
  - measure the density of index organisms in incoming water and their reduction, 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)

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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).

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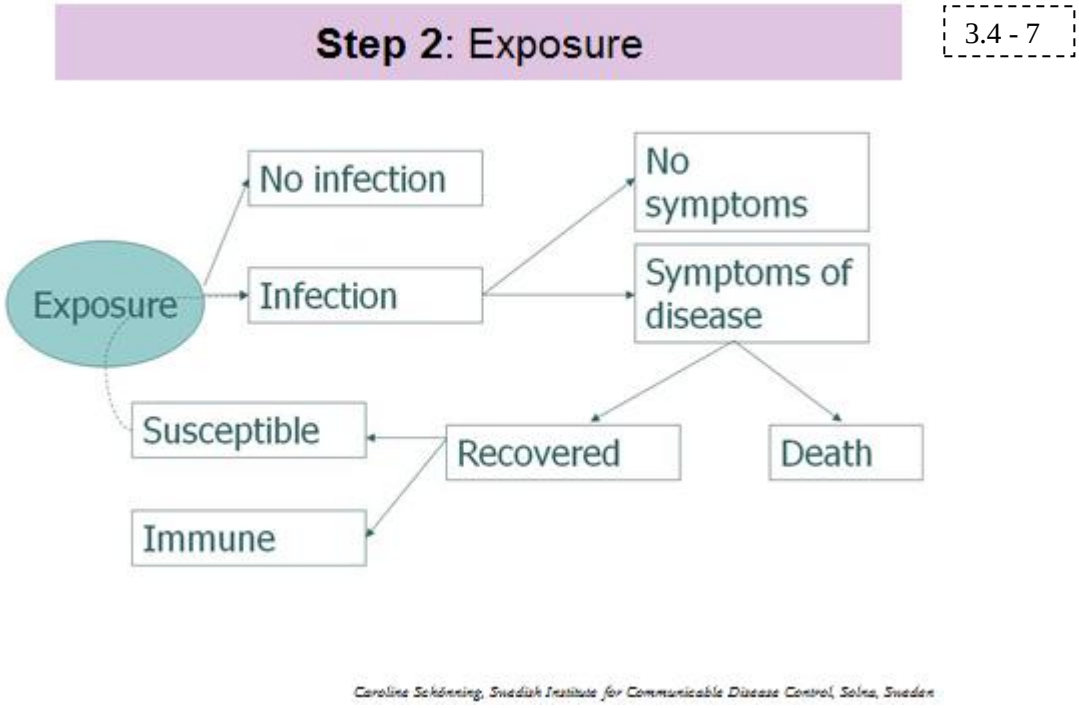

Given the concentration of pathogens in the studied environment or case, the next step is to identify how humans may be exposed to them. Even if exposed to pathogens or ingesting them, does not necessarily lead to infection or disease (See sketch). Therefore, finding points of exposure is more about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

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 x 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 x 10^{-4} viruses/day** will be ingested

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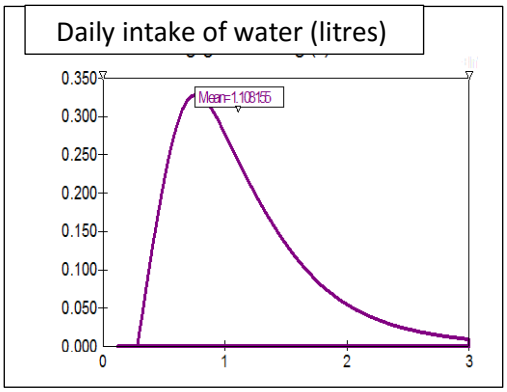
Exposure to pathogens can occur in many ways. The slide provides two examples of exposure through ingestion, but it could also happen through skin penetration or breathing aerosols.

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.

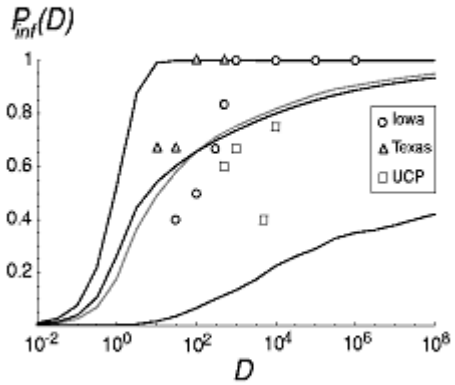
Bathing in surface water. The author makes the assumption that a person (accidentally) ingests 50 mL per hour while swimming. A (long) swim takes 2.6 hours and if swimming is done 7 times a year, which corresponds to a daily average ingestion of 7/365 x 2.6 x 0.05 = 0.0025 L/day. If the bathing water is found to contain for example 0.1 virus/L, then 0.0025 x 0.1 = **2.5 x 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).

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



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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).

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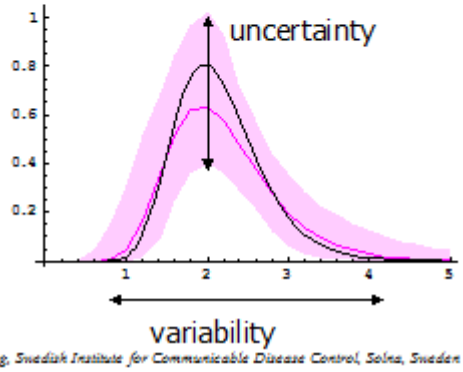
3.4–10

Step 4: Risk characterisation

- 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



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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.

3.4 – 11

Linking tolerable disease burden and quality of water source for some 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)

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."

Drawbacks in microbial risk assessment

3.4 – 12

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

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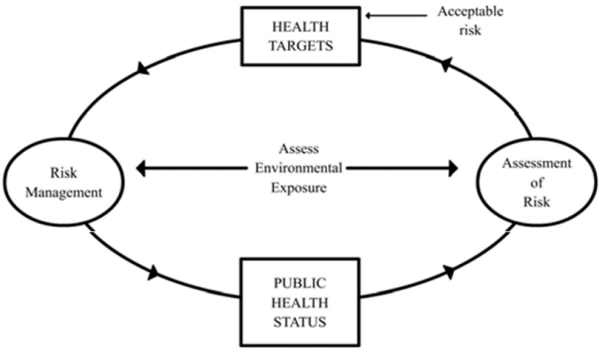
Quantitative microbial risk assessments (QMRA) often include several assumptions. There are also other drawbacks, or limitations. The dose-response models are based on healthy individuals and do not consider vulnerable populations such as the elderly, the very young, pregnant women, or immunocompromised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

Health-based targets and acceptable risk

3.4 – 13

- **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.

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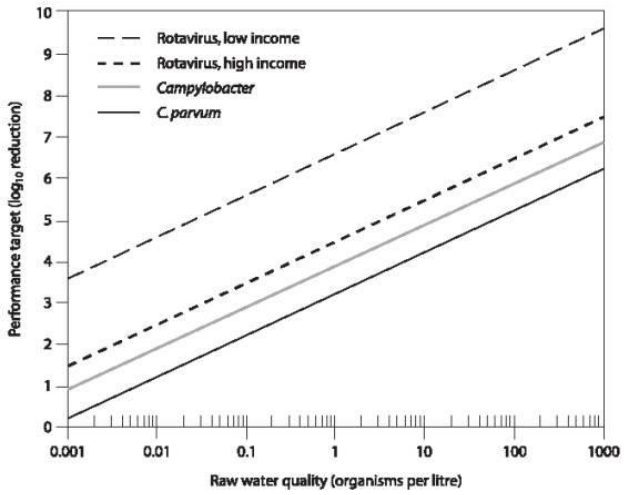
WHO Guidelines – risk

3.4 – 14

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



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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.

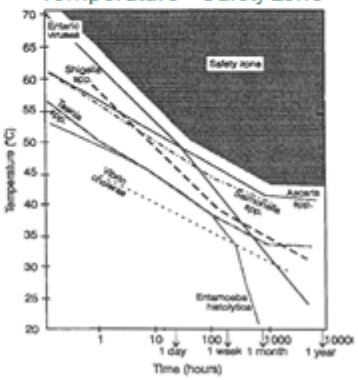
How can we use the indicators?

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)

Temperature – safety zone



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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 for testing water and wastewater quality

3.4 – 16

Examples of indicator organisms:

- 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 these rely less on indicators

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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.

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.

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3.4 – 18

What is an ideal faecal indicator organism?

Indicator organisms are to:

indicate a presence of faecal contamination by human faeces, sewage, animal dropping, etc.

Why do we want indicators?

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

- Occur in the intestinal microflora
- Present in greater numbers than the pathogen itself
- Do not multiply in the environment
- Are non-pathogenic
- Occur together with pathogens
- Equally persistent as pathogens
- Detected easily with affordable methods

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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.

3.4 – 19

Faecal indicators – abundant in faeces

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.

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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?

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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.

3.4–21

Are the indicators always reliable?

- Potential growth in greywater:
  - *E. coli* show ~1000 times higher faecal contamination than the chemical compound coprostanol due to growth
  - Faecal streptococci show ~100 times higher contamination than coprostanol
- Potential growth in wastewater:
  - Indicator bacteria show ~10 times higher faecal contamination than the chemical compound coprostanol

Possible growth in faecal matter/sludge/urine

→ **Overestimation of the risk** (Ottoson, 2005)

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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.

Need to look for alternatives to indicators
– related to sanitation and agricultural practices

3.4 – 22

- Quality guidelines (e.g. WHO)
  - indicators are found to be of 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

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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.

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

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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

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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.

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

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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.

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.

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)

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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.

3.4 – 27

Performance targets for viable helminth eggs
when applying faecal matter and faecal sludge to fields

Starting point

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

Yearly helminth load from irrigation (applying 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 ton manure/ha per year at 25 % TS = 250 g TS/m² per year

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

or dry-weight faecal matter/sludge must contain ≤ 2 eggs/g

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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.

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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.

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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.

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.

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.

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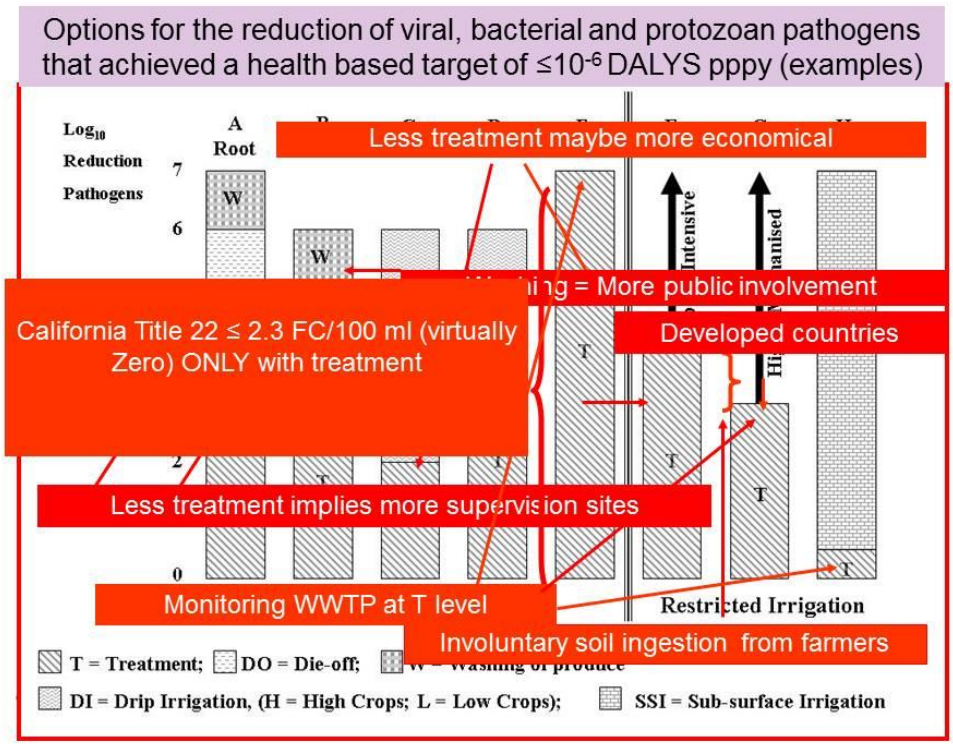
The information on potential pathogen reduction (in log-units) was estimated by WHO from various research reports. The list includes measures that farmers and household can take to protect health. These measures can be combined and thereby reaching a cumulative reduction. For instance, by withholding 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



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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).

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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)

3.4 – 32

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.

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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.

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

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

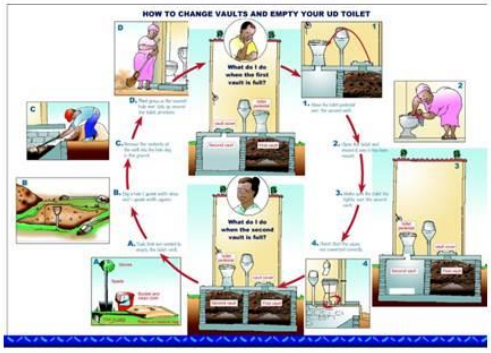
The guideline values for risk levels are harmonised with what is required for wastewater monitoring in agriculture. In smaller systems, greater emphasis is placed on operational monitoring, observations and system performance, than on verification monitoring. The guidelines need to deal with frequency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

3.5 Risk management

Can we measure a risk of disease transmission?

How can sanitation systems be evaluated?



Learning objective: to be aware of how the potential health impacts of sanitation systems can be evaluated and compared regarding their potential health impact. To be familiar with the different parts of Quantitative Microbial Risk Analysis (QMRA).

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In this module microbial risk assessment is dealt with in more detail by giving some examples of QMRA studies that have been published in journals. They are related to developed areas (Sweden and Denmark) but the same approach has been applied in the epidemiological studies performed in developing areas with a worse background sanitary situation with a high incidence of parasitic infections. The studied interventions were implemented in order to improve the public health situation. However, as stated in Modules 3.3. and 3.4, risk management is crucial in any sanitation system and this module elaborates on the performance of barriers (health protection measures) in practice.

The scientific assessment of health risks related to water and sanitation can be conducted by microbial analysis of waste flows (that are either to be discharged or recycled), by epidemiological studies or by microbial risk assessments. Assessments can be either qualitative or quantitative. All approaches have drawbacks, but the cumulative knowledge that is used for creating guidelines can motivate that risk management strategies build on combined results, using all three methods.

The examples of studies in this module aim at giving a system overview, providing examples of exposure scenarios and results showing the common need for administering several barriers.

3.5 - 2

Risk management – policy development

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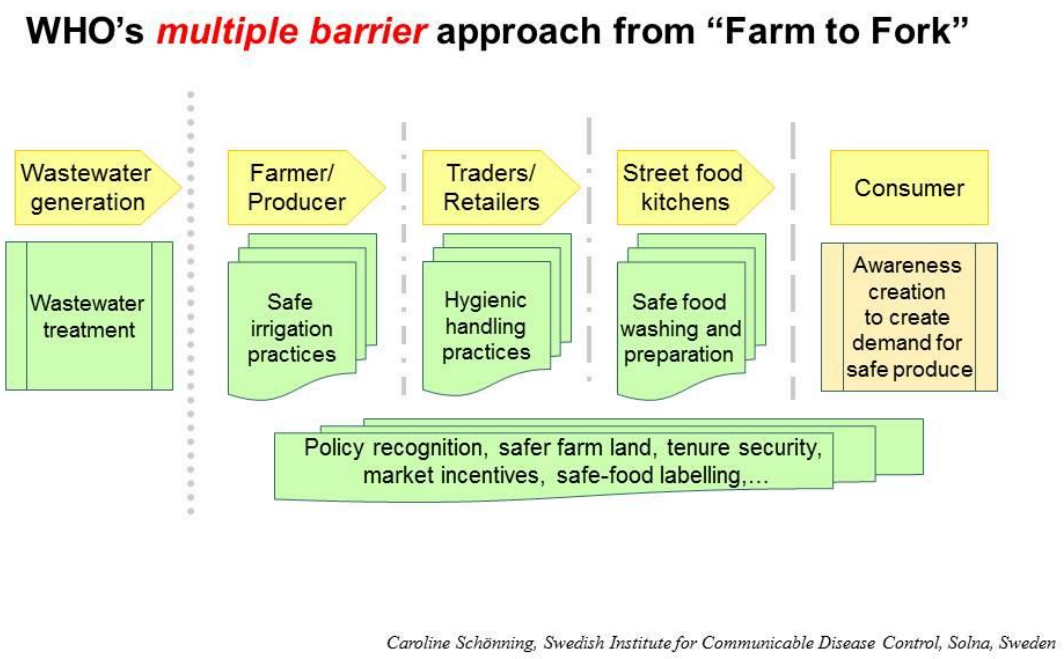
To address health issues in sanitation systems and to successfully contribute to improvements, the work plan shown in the above diagram could be followed. Policies and guidelines are often based on theory and basic research and oftentimes modified to suit general national conditions. Implementation and use of the policies in the local environment involves some adaptation to local conditions. Experiences gained from policy implementation may also generate additional general knowledge or identify areas which need further research. Policies are being developed in such loops which gradually integrates new facts and findings.

Dissemination, communication and education are crucial parts in any risk management system.

Regulations, policies and guidelines for reuse systems aim at reducing risks to acceptable levels and treatment is one important part of risk reduction. Treatment processes can be clustered into categories according to the level of safety that they provide. The hygienic standard of a waste product can be judged by testing for the presence of various microorganisms (both indicators and pathogens) or by measuring the reduction in the presence of these microorganisms, i.e. comparing the number of organisms present in the material before and after the treatment process. Restrictions on usage (e.g. crop restrictions) are other barriers, so is choice of irrigation or application method. Other regulations deals with how to transport and store the waste product and how to protect workers and residents. Procedures related to microbial analyses may also be introduced to raise the validity of results.

Risk reduction strategies

3.5 - 3



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Module 3.2 introduced the idea of barriers to reduce exposure to pathogens. The F-diagram shows how good practices such as handwashing and careful handling of food constitute barriers. Treatment of excreta and other waste represents another kind of barrier both for reuse systems and for systems that do not recycle the waste as a resource.

Treatment is an important part of existing guidelines and regulations, e.g. in the WHO guidelines and in national EPAs (Environmental Protection Agency). Such rules and regulations build on both research and practical experiences. The WHO guidelines state that adaptation to local conditions is necessary, and a treatment system needs to be accepted and well managed in order to be a part of a sustainable sanitation system. Practical experiences leads to new challenges that demands additional research to further develop guidelines and advices for practical implementation. One research area to be developed is that of management of waste flows and recycling of resources e.g. nutrients and water to agriculture.

After treatment of excreta or wastewater there are a number of additional barriers or health protection measures that could be applied to further reduce risks. These include:

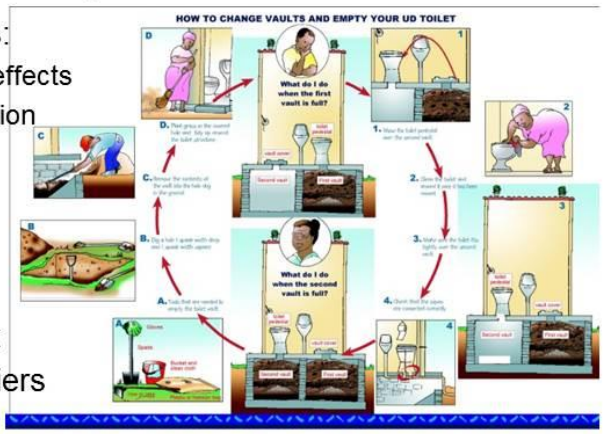
- Safe irrigation practices, which are the responsibility of farmers and food producers. Safe practices protect farmers and at the same time limit the exposure to surrounding humans and animals.
- Hygienic handling practices, which are the responsibility of traders and retailers.
- Safe washing and preparation of food, which are the responsibility of traders and retailers.

All these measures will in the end reduce the risk for the consumer, and such improvements can be driven by awareness which will increase the demand for safe produce.

Overview of risk management

3.5 - 4

- Different types of studies to understand the "real" situation:
  - Epidemiology – disease incidence, interviews, surveillance
  - Risk assessment – built on assumptions by professionals
  - Sampling and microbial analysis
- Range of interventions:
  - Hard to differentiate effects
  - Single or in combination
- Identifying need of risk management and barriers
  - Health protection measures



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The studies presented in this module show that a sanitation system may introduce new transmission routes while removing others, resulting in higher or lower risks for infections. It is evident that implementation of sanitation systems can improve public health, for example, by reducing diarrhoea (e.g. 3.1–7). The degree of success depends to a large extent on the local situation – for example what the initial system (or lack of sanitation) was like, the local incidence of infections and how the waste produced within the system is handled (e.g. if it is recycled or not).

Epidemiological studies can be said to analyse the "real" situation (see 3.1-17; 3.2-2). Risk assessments evaluate situations and systems, using both estimates and known data, trying to calculate typical risks or risks related to worst-case scenarios. For example, the concentrations of protozoa and helminths that were measured in the faecal material in households in eThikwini (Trönnberg et al., 2010 on slides 19–20) were found to be lower than the calculated concentration for the same situation using literature data on excretion and duration as done in risk assessments. It is also known that collecting representative samples and analyzing for pathogens is a difficult task, and in Module 3.4 it is shown that faecal indicators cannot do the job for us in all situations.

In spite of the differences and the difficulties in obtaining hard facts, all the different types of studies help in identifying risks to be managed. In the final analysis, it is not exact data that is needed for introducing barriers and protection measures. These are successfully developed from reasonably representative data, practical experience, and expert valuation. Health protection measures include both technical measures and behavioral measures such as washing hands.

Comparison of sanitation systems

3.5 - 5

- Diverting systems:
  - Small volumes
  - Easier to treat (but not wastewater)
  - Suitable fertiliser products
  - Handling requires restrictions
- Mixed (conventional)
  - Large volumes of ”hazardous” waste
  - Extensive treatment
  - Reuse products: wastewater, sludge
  - Downstream pollution risk

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A simple comparison can be made from a health point of view between diverting and mixed sanitation systems, i.e. systems where urine, faeces and greywater are kept separate and systems where these fractions are mixed in one flow. Properly managed, both systems can function well. However, how sustainable they are is intensely debated and depends on aspects such as the time frame and system boundaries.

The diverting system produces small volumes of homogenous and easy-to-treat faecal matter and urine, while polluted wastewater still needs to be handled. However, handling may be more labor intensive and require close contact with the waste. Mixed systems produce one large volume of non-homogenous liquid waste that is more challenging to treat.

Both systems generate waste products that can be recycled in agriculture, but their features vary. What is important in relation to health risks is that they can be properly managed; that is, it is possible to limit exposure and the number of pathogens can be reduced. Therefore health and hygiene issues do not need to be the considerations that decide which sanitation system is suitable in a particular situation. Again, local adaptation is a key to control risks of disease transmission.

The following pages deal with health protection measures concerning urine, faecal matter, and greywater.

Impacts of interventions on diarrhoeal disease

3.5 -6

Intervention area	Reduction in diarrhoea frequency
Hygiene	37%
Sanitation	32%
Water supply	25%
Water quality	31%
Multiple	33%

In WHO, 2008, adapted from Fewtrell et al., 2005

The effects of different interventions to reduce diarrhoea have been investigated in many studies. A systematic review, a so-called meta-analysis, was made by Fewtrell et al. (2005) in order to draw conclusions regarding interventions. In total, 2000 abstracts were screened and 38 studies were selected for the meta-analysis.

They found that most interventions reduced diarrhoea incidence by a quarter to one-third, and improved hygiene seems to be most important. It may be surprising that multiple interventions do not fare better. Even though it is not apparent from the results shown in the table above, water, sanitation and hygiene interventions interact, but the impact of each may vary widely according to local circumstances. Interventions to reduce vector-borne disease are even more related to local conditions since they are mostly related to the environmental situation.

The results from the studies from El Salvador (slide 3.5 – 17) and Durban (slide 3.5 – 19) should be seen in the light of these general impacts of various interventions.

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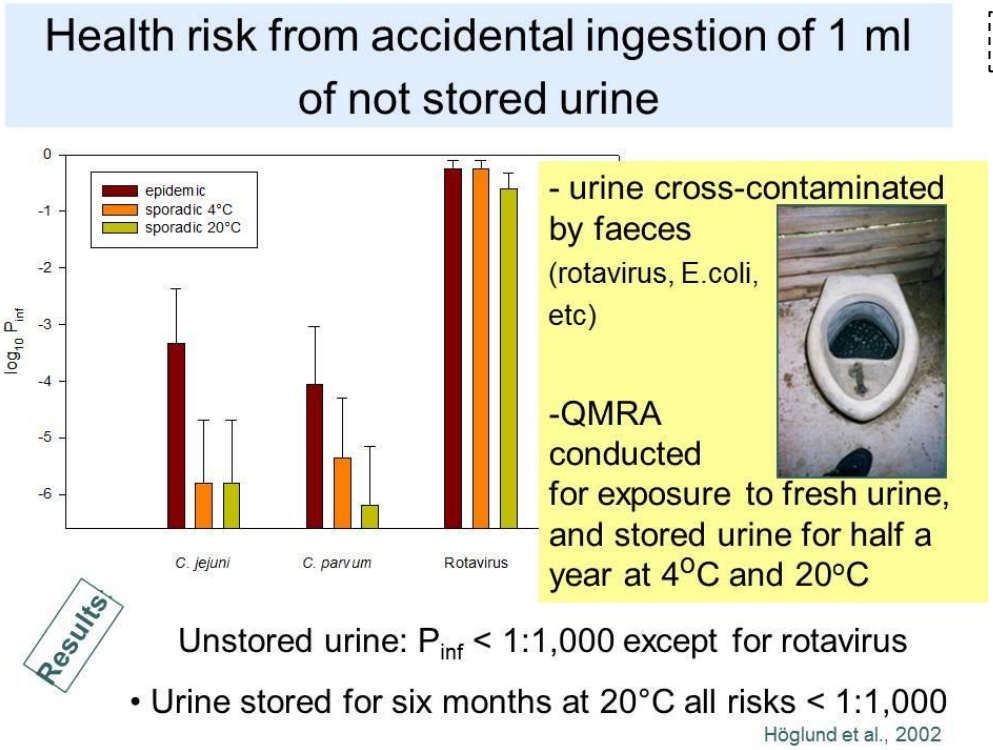


Module 3.1 provides information about pathogen content in urine and faeces which indicates that the concentration is very low in urine. Cross-contamination is common, however, and the picture shows how some faecal matter ends up in the urine. The urine in this case is assumed to contain faecal pathogens. Findings from Swedish QMRA studies on faecal contamination and survival of enteric microorganisms in urine-diverting system are being used here (Höglund et al., 2002; http://wmr.sagepub.com/content/20/2/150.full.pdf+html).

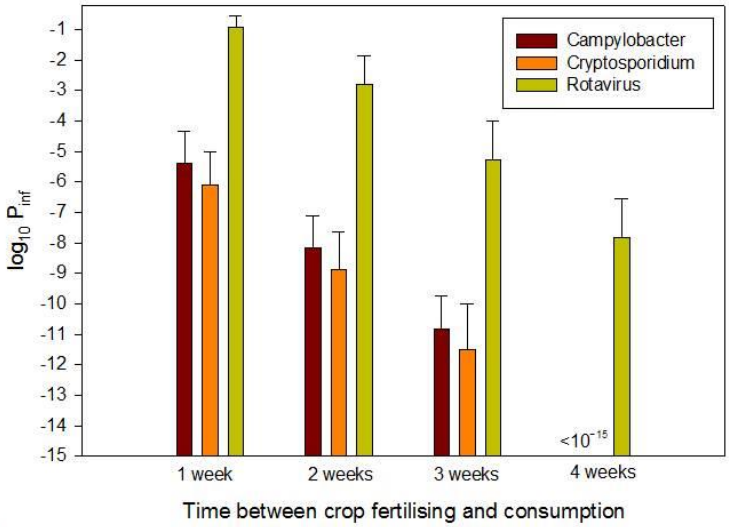
The concentration of faecal sterols (coprostanol) in the collected urine was measured and used to estimate the level of faecal contamination. Three pathogens, representing different organism groups, were examined more closely: *Campylobacter jejuni*, rotavirus, and *Crypto-sporidium parvum*. National surveillance data on incidence was used to calculate potential concentrations of these pathogens in the urine. The results from survival studies (Module 3.3) were used to calculate concentrations after storage and exposure scenarios were determined, i.e. theoretical scenarios and estimated amounts (volumes) of urine that could be ingested were determined.

The graph shows the risk for infection, P_{inf}, after ingesting 1 ml of fresh urine cross-contaminated by faecal matter, at different hypothetical levels of infection in the population. The worst case scenario is an epidemic event in which all the people connected to a urine-diverting system were infected right before the urine tank was emptied. The three left-hand bars for each pathogen (dark) present the number (in $\log_{10}$ values) of each pathogen. The other two bars represent a situation where all users of the urine collection tank are infected during the whole period in which the urine is collected. The storage temperature is 4°C (red bar) or 20°C (green bar).

Overall, risks were calculated using dose-response models and showed to be less than 1:1000 for one exposure at each event (scenario), except for the probability of rotavirus infection that was higher. If the urine mixture was stored for six months at 20°C the risks of infection from accidental and aerosol ingestion of rotavirus were also less than 1:1000. These results comply with the general rule that higher inactivation of the organism is achieved in higher temperature and thus represents a lower risk.

Health risk from ingesting 100 g urine-fertilised crop

3.5 - 8



Results

- Inactivation of pathogens continue in the field
- Risk level depends on time between fertilization and consumption of the crop

(Höglund et al., 2002)

The previous page illustrated the health risks of ingesting 1 ml of contaminated urine, and it showed the positive impact of the barrier of storing urine. Slide 3.3 - 5 shows that a further die-off takes place when (stored) urine has been sprinkled on crops which are not eaten immediately.

The bar chart above shows another example on health risks of ingesting urine-fertilized crops. The inactivation of microorganisms will continue in the field and the risk will thus vary depending on the time that passes between sprinkling the leaves and harvest or consumption. Even if the urine has not been stored, the risk simulations show that the risk for bacterial and protozoan infections is already low after one week. After three weeks the risk for viral infections was also low and on that same level (this specific case corresponds to eating a fresh crop that holds as much water as lettuce). Storage is an effective barrier.

'Rules of thumb' for handling of faecal matter

3.5 - 9

- The risk of infection is too high (>1:10 000) when faeces is used without treatment
  - The highest risk from exposure to not-stored material was attributable to rotavirus
- 12 months storage – sufficient reduction of most pathogens (compared to a risk level 1:10 000)
  - The highest risk from exposure to stored faeces is attributable to *Ascaris*
  - the protozoa *Giardia* and *Cryptosporidium* are of greater concern in the European population
- The risks of infection can be reduced by simple measures such as longer storage, or treatment with a pH-elevating compounds such as ashes and lime

(Schönning et al., 2004)

There is a high level of uncertainty regarding inactivation of pathogens in faecal material (See module 3.2), and further studies are recommended. The risks of infection can be reduced by measures such as longer storage, adding a pH-elevating substance, or heating. The variations in the risk of infection depend on the pathogen in question and were up to 12 orders of magnitude in a specific scenario. If the material was stored for 12 months the typical risk (50th-percentile) in general decreased with 3–7 orders of magnitude when compared with no storage. The risk from EHEC is eliminated if the material is stored for 12 months and the typical risk of being infected by *Salmonella* is also very low. Viruses and parasites generally survive longer in the environment, and require lower infectious doses, which result in higher risks for rotavirus, the protozoa and *Ascaris*. The following storage options were evaluated by WHO:

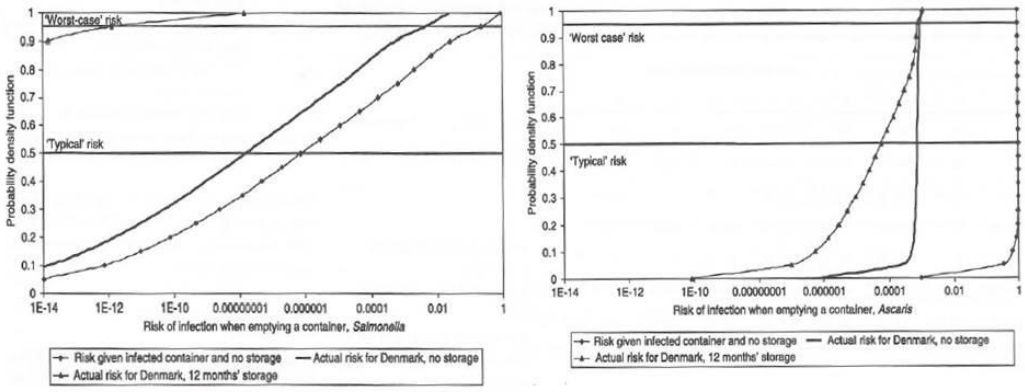
1. Application of the material after storage for 0 months
2. Application of the material after storage for 6 months
3. Application of the material after storage for 12 months
4. Application and incorporation of the material in soil after storage for 6 months
5. Application and incorporation of the material in soil after storage for 12 months

Results showed that 12-months' storage before use was sufficient for the inactivation of most pathogens to acceptable levels. When working or spending time in the garden the annual risk of infection by Ascaris was still slightly above 1:10 000 in these scenarios, although the incidence rate for Ascaris is very low in the targeted population. Measures to further reduce the hygienic risks include longer storage or treatment of the faeces. The results can easily be extended to other regions with different incidence rates.

Even if a thermophilic (high-temperature) composting process was aimed for in the previously investigated systems, temperatures never rose above 20°C and were, at most, 7°C higher than the ambient temperature. The faeces could thus be said only to be treated by means of storage prior to application in the garden. The pH of the faeces varied from 6.7 to 8.4 and the dry substance content was 22–39% (J. Møller, Royal Veterinary and Agricultural University, Denmark, personal communication).

Infection risk when emptying faecal container

3.5 - 10



Salmonella Ascaris

Risk of infection presented as probability functions.
- the typical risk is shown to be in the 50th percentile
- the worst case risk is shown by the 95th percentile.

(Schönning et al., 2004)

A quantitative risk assessment was performed for urine-diverting toilets in Denmark (http://www.iwaponline.com/jwh/005/0117/0050117.pdf). The aim was to evaluate the risk of transmitting infectious diseases when recycling of faeces as a fertilizer. Pathogenic micro-organisms (bacteria, viruses, protozoa and helminths) capable of being transmitted to humans via the faecal-oral route were selected for study. And among these, those were selected which:

- were relatively common in Denmark
- were persistent
- required low infectious dose
- severe consequence of the disease
- had reasonably large amount of background information available.

The following assumptions were made for human exposure scenarios:

- faeces-soil intake (Larsen,1998) for children was around 200 mg (max of 5-10 g).
- adults ingest 15–50% of this amount, with a maximum of 100 mg.
- the container is emptied once a year and only adults were exposed during this process.
- the median number of exposures through recreation was 3.5 times per week (during June-August).
- 50% of the households were exposed through gardening once a week (during May-September).
- one exposure corresponded to two hours of gardening that occurred a maximum two times per day.

The evaluated human exposures included accidental ingestion of small amounts of faeces, or a mixture of faeces and soil, while emptying the storage container and while applying the material in the garden, during recreational stays in the garden, and while gardening. The four QMRA steps were applied for the selected pathogens. The probability that the faeces in the storage container from a typical household contained at least one type of pathogen was calculated to be 11.6%. The probability that a typical container would contain at least two types of pathogens was 0.5%. Rotavirus and Giardia were found to be the most prevalent pathogens. They were present in 4.7% and 4.3% of the containers respectively.

The risk of infection is greatest when emptying the container, since the material at this stage is partly fresh and not yet mixed with soil, and no reduction of pathogens has occurred. To remedy the situation, a urine-diverting toilet should have two faecal chambers or two collection bins, one of which is in use while the other is resting.

The two graphs illustrate the calculated risks when handling the content of faecal containers. The highest risk was attributed to rotavirus (3×10^{-2}), whereas *Ascaris* constituted the highest risk after 6 or 12 months' storage, although this infection is quite uncommon in the Danish population. The study suggests that local handling of faeces may open a new route of infection for *Ascaris* in a population where this helminth is rare.

For *Salmonella*, the health risk depends more on storage time as a barrier than on incidence rate. The risk levels over time differ by several orders of magnitude. For other pathogens (e.g. *Ascaris*) the storage has limited importance because of 1) the high persistence of eggs/pathogens, and 2) is instead dominated by the low prevalence of Ascaris eggs/pathogen in the population in question.

The typical risk is defined by the 50th-percentile and worst case is defined by the 95th percentile. The large differences between the typical risk and the worst-case risk indicate that, in general, viruses, protozoa and helminths may constitute a problem due to the substantial level of uncertainty. Furthermore, the risk increases significantly if the material is stored for less than 12 months. The importance of the estimated incidence rates differs greatly between pathogen species. The incidence rate of the region is less important when the decay of the pathogen is rapid, whereas the overall risk is dominated by the initial incidence rate of the pathogen when the decay rate is low.

In approximately nine out of ten gardens, the use of stored faeces as a fertilizer will not result in a risk of infection in Denmark. This is because no family member in these households was infected, and thus no pathogens were excreted into the container. In the remaining 11.6% of the gardens there was a risk of infection; however, most exposures will not lead to infection as too few pathogenic organisms will be ingested. If one judges the risks according to previously identified acceptable levels (10^{-4} per year), the practice of using faeces that has been stored for one year, but is otherwise untreated, should be regarded as unacceptable, since the risk for infection is too high. The risk of infection is due mainly to the helminth *Ascaris*. Furthermore, the risk level is very sensitive to changes in the incidence rate.

Without storage, the material in the containers was highly infectious for all the pathogens involved except bacteria. After 12 months of storage the typical risk associated with emptying the container was less than 10^{-4} for all of the pathogens. When considering typical risks associated with gardening and recreational activities in the garden, the yearly risk of infection was only higher than 10^{-4} for *Ascaris*. As such, the risks were just below the acceptable level suggested by Regli et al. (1991).

Wastewater and sludge – hazards & exposure

3.5 - 11

In another study conducted at a 12,500 m^3/day treatment plant utilizing tertiary wastewater treatment and mesophilic sludge digestion, a Hazard Analysis and Critical Control Points (HACCP) was applied (where QMRA was one step) to identify and control exposure to pathogenic microorganisms encountered during normal sludge and wastewater handling (http://www.iwaponline.com/wst/05002/0023/050020023.pdf). The treated sludge was assumed to be applied to vegetables.

The quantitative microbial risk assessment (QMRA) included assessment of the risk from rotavirus, adenovirus, hemorrhagic *E. coli*, *Salmonella*, *Giardia* and *Cryptosporidium* was conducted in order to prioritize barriers for pathogen hazards. The exposure scenarios considered were identified in collaboration with staff at the wastewater treatment plant (WWTP).

Data from the literature was used for most of the information that was needed to calculate the concentrations of pathogens in the various waste flows. Site-specific data on removal of indicators in the treatment plant was used to calculate their concentration in the outgoing wastewater. Human exposures were treated as individual risks, but were also related to the endemic situation in the general population.

The hazardous scenarios considered were human exposure during treatment of wastewater (the eight pictures above):

(1) during pre-aeration; (2) at the belt press, exposure via water at the wetland-area; (3) someone falling in; (4) child playing and recreational swimming; (5) exposure during treatment, handling and soil application of sludge; (6) child playing at storage site; (7) contractor/farmer spreading sludge; and (8) exposure from crop consumption.

The following two slides present the details from this exposure study.

3.5 - 12

Exposure scenarios for the Danish wastewater treatment study

Type of exposure	Volume ingested (mL or g)	Frequency (times*year^{-1})	Number of persons affected
1. WWTP worker at pre-aeration	1	52	2
2. WWTP worker at belt press	5	208	1
3. (Un)intentional immersion at wetland inlet	30	1	2
4. Child playing at wetland inlet	1	2	30
5. Recreational swimming	50	10	300
6. Child playing at sludge storage	5	1	2
7. Contractor spreading sludge	2	30	2
8. Consumption of raw vegetables	1	2	500

Westrell et al., 2004

The table shows, for each of the eight scenarios, the estimated volume possibly ingested, and the number of times per year that this occurred (all in theory). In the site-specific investigation the numbers of persons that could be exposed and affected were also estimated.

The highest individual health risk per single exposure was through exposure to droplets and aerosols for workers at the treatment plant (exposures 1 and 2), particularly at the belt press for sludge dewatering, and through contact with digested sludge (exposures 6 and 7) with a risk of viral infection equal to 1 or nearly 1. The lowest risk was from swimming in the lake (exposure 5). In this case, the wastewater treatment followed by polishing in a wetland and dilution in the receiving lake water reduces the number of pathogen to a great extent. However, if currents in the lake transport undiluted wetland discharge to the bathing area, the risk could increase a thousand times.

The viruses constitute the highest risk for a single exposure due to high influent concentrations, low infectious doses and lower removal rates than for bacteria and protozoa. *Giardia* is more infectious than *Cryptosporidium*, and this is reflected in the risk calculations. The higher risk for EHEC than for *Salmonella* was due mainly to the difference in dose-response equations and the median infectious doses. Haas et al. (2000) have however reported a median infectious dose for EHEC 500 times higher than the one used here.

3.5 - 13

Number of yearly infections in Danish study

Exposure	EHEC	*Salmonella*	*Giardia*	*Cryptosporidium*	Rotavirus	Adenovirus
1 					1.98 (1.69-2.00)	1.99 (1.30-2.00)
2 			0.57 (0.05-0.99)		1.00 (0.99-1.00)	1.00 (0.97-1.00)
3 						0.21 (0.02-1.87)
4 						0.23 (0.02-5.21)
5 						0.18 (0.01-4.26)
6 					0.76 (0.23-1.28)	1.87 (0.22-2.00)
7 			0.52 (0.04-1.75)	0.13 (0.006-1.25)	2.00 (1.64-2.00)	2.00 (1.49-2.00)
8 						0.41 (0.01-20.51)

The absence of a reading indicates <0.0001 infections

Westrell et al., 2004

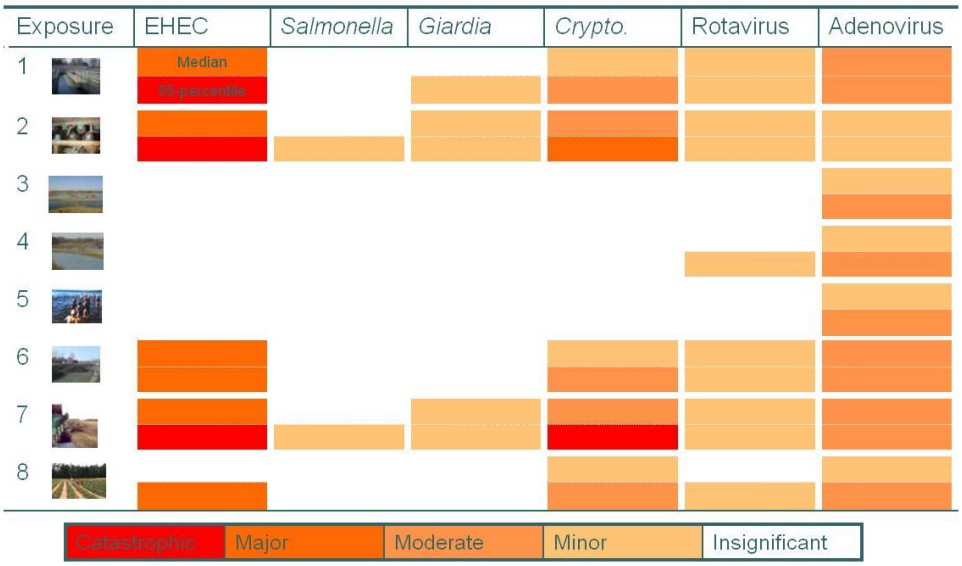
The annual number of infections estimated to occur per hazardous exposure was generally very low for non-viral pathogens (<<1). The number of cases should, however, be compared to the number of exposed individuals. Viruses constitute the major risk in exposure scenarios 2 and 7, and nearly reached 1 in scenario 1, with the maximum number of infections, for both adenovirus and rotavirus. This means that the workers at the treatment plant and the entrepreneurs handling and spreading sludge were quite certain to become infected at least once during one year of performance, unless already immune or protected. Antibodies against enteric viruses, e.g. adenovirus, have been reported among wastewater treatment plant workers with higher prevalence among those subjected to high aerosol exposure (Clark, 1987).

The consumption of vegetables grown in sludge-amended soil constituted a lower risk and a lower number of yearly infections than expected. A significantly higher risk would, however, result if the organisms occurred in higher concentrations in lumps of sludge rather than being homogeneously distributed as assumed. In the current Swedish legislation ten months must pass between sludge fertilization and the harvest of crops that are eaten raw, but in this study a worst-case scenario assuming a waiting period of one month was applied.

Classification of exposures

3.5 - 14

(Westrell et al., 2004)



In order to rank the hazardous exposures according to severity of consequences, a comparison was made to the endemic level of these diseases in the community. An increase in the number of EHEC infections is considered more serious than an increase in the incidence of any of the other infections, since EHEC is associated with symptoms other than diarrhoea (e.g. renal failure) and often requires hospitalization.

Item	Definition
Catastrophic	Major increase in diarrhoeal disease >25% or >5% increase in more severe disease or large community outbreak (100 cases) or death
Major	Increase in more severe diseases* (0.1-5%) or large increase in diarrhoeal disease (5-<25%)
Moderate	Increase in diarrhoeal disease (1-<5%)
Minor	Slight increase in diarrhoeal diseases (0.1-<1%)
Insignificant	No increase in disease incidence (<0.1%)

* In this study represented by EHEC

Although several of the exposures only resulted in much fewer infections they had a large impact on the community as a whole. This was due to anticipated low prevailing numbers of infection. The largest impact on the community would arise if children ingested sludge at the unprotected storage site, although in the worst-case situation the largest number of infections would arise from vegetables fertilized with sludge and eaten raw (see slide above Number of yearly infections, up to 20 cases for adenovirus).

Viruses generally posed the highest risks and resulted in the largest number of potential cases, while EHEC and *Cryptosporidium*, with only a few cases constituting the endemic level, were identified as having the largest impact on the community, with above 5% (major) and 25% (catastrophic) increase in disease rates, respectively.

Barriers or control measures for exposures

3.5 - 15

- **Exposure 1**
  Easy to control with:
  - Personal Protective Equipment (PPE)
  - Covering of basins

- **Exposure 2**
  Easy to control with:
  - PPE
  - Optimisation of sludge treatment (baffles against short-circuiting, thermophilic digestion etc.)

Westrell et al., 2004

Wastewater treatment does normally not achieve anything like complete barriers since the treatment processes are not optimized for pathogen removal, although each process generally inactivates or removes some of the pathogens. The most hazardous exposures identified in this case study included some of the early processes in the treatment and handling of sludge. From the society's perspective it is most important to control exposures 1, 2, 6 and 7 at this sewage treatment plant.

Exposures at the treatment plant could be controlled by the use of personal protection equipment (PEE), covering the basins to reduce aerosols, and improving treatment of the sludge.

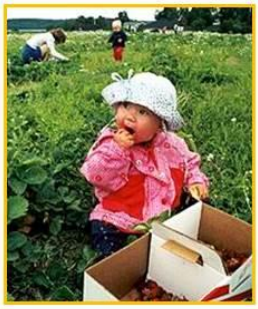
3.5 - 16

Control measures (con't)

- **Exposure 6**
  - Fence storage area
  - Optimisation of sludge treatment

- **Exposure 8**
  - Crop restrictions
  - Minimum time between fertilisation and harvest
  - Optimisation of sludge treatment
  - Prolonged sludge storage

- **Exposure 7**
  - Use of PPE
  - Optimisation of sludge treatment
  - Prolonged sludge storage



Westrell et al., 2004

An easy control measure to prevent children from getting access to the sludge storage (exposure 6) would be to fence the area. Other improvements that would also increase the safety in the subsequent exposures of handling sludge or eating vegetables grown in sludge amended soil would be to change from mesophilic to thermophilic digestion or prolong the storage times.

3.5 - 17

Epidemiological study in rural El Salvador

- Study **prevalence of parasitic infections** in 109 rural households with 449 residents
- **Types of toilets** (UD = urine-diverting):
  - UD solar desiccating toilet (single vault)
  - UD double-vault desiccating toilet(LASF)
  - Pit latrine toilet
  - No toilet
- In El Salvador, the **solar toiletis recommended**
  - Includes urine diversion
  - Better results than pit latrine
- **Limitations of the study**
  - Different communities compared
  - Small sample size

Corrales et al., 2006

Epidemiological studies are often difficult and expensive to conduct. Such studies conducted on sanitation systems are therefore considered particularly valuable, and have the potential to give credibility to both interventions and policies. Reviews of epidemiological studies related to sanitation are included in several publications, among them the WHO *Guidelines on Safe use of excreta and greywater in agriculture* (2006) (See slide 3.5-24).

A study of the prevalence of parasitic infections was conducted in El Salvador in a community with 109 households (449 people). The purpose of this study was to examine the impact of various dry sanitation systems on the prevalence of helminths and protozoa infections while accounting for other individual and household risk factors. Therefore, the selection of households was done to include various sanitation arrangements: pit-latrine toilets (147), Urine-diverting toilets (UD) solar desiccating single (127) and double vault (79), and households with no toilet (102).

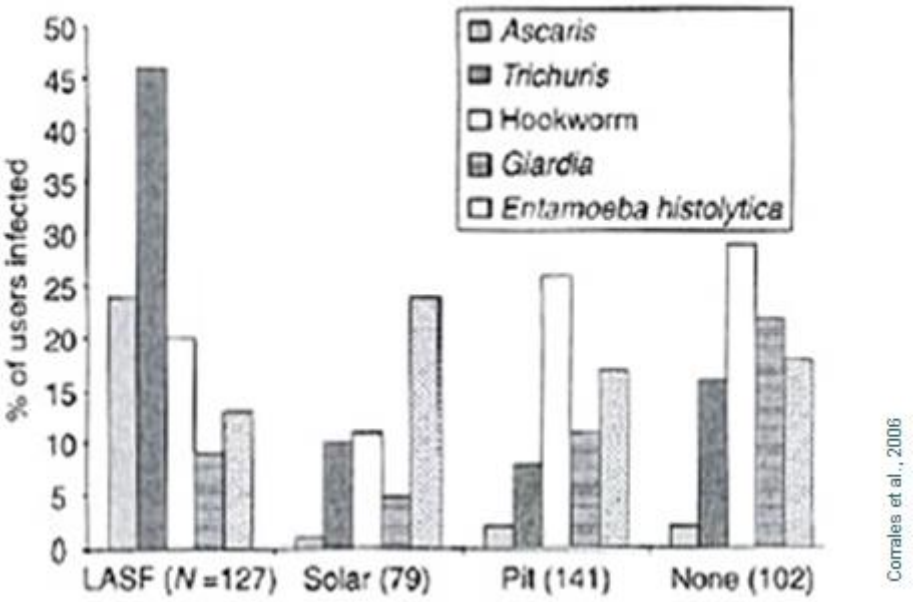
http://www.watersanitationhygiene.org/References/EH_KEY_REFERENCES/SANITATION/General%20Sanitation%20References/Parasites%20and%20Sanitation%20(Tropical%20Medecine).pdf

In El Salvador, the solar toilet is recommended since it allows to recycle urine and it gave better results than pit latrines in this study (i.e. lower prevalence of a majority of the infections). When published, the results were somewhat unexpected and caused heated debate on the possible health impacts of the types of toilets that had been promoted in the country.

The authors identified some limitations of the study: it is not possible to compare households with different latrine types in the same community because latrine interventions were carried out as community-wide programs, and the small sample sizes limited analyses for certain variables.

Prevalence of parasitic infections by toilet type

3.5 - 18



The table above shows a high prevalence of five parasites among users of all kinds of toilets. More than half of the users were infected with at least one type of intestinal parasite, indicating that these pathogens represent a significant health problem.

The pit latrine toilet users fare well in comparison with users of other kinds except for hookworm infection. This shows the great importance of containing faecal matter in the pit and wearing shoes, since hookworms are spread via feet on top of the slab. The higher prevalence of Ascaris and Trichuris infections among LASF users when compared with persons using solar toilets, pit latrine toilets or no sanitation suggests that LASFs may pose an increased risk for transmission of these helminths.

A comparison should always take into account how persistent the pathogens are, since this impacts the measures to reduce risks. For example, users of UD-toilets (both solar and LASF) display lower prevalence of the less environmentally persistent pathogens (hookworm, *Giardia*, *Entamoeba*), suggesting that such eco-san toilets can reduce transmission of these pathogens.

The users of LASF had a higher prevalence of more environmentally persistent pathogens (*Ascaris*, *Trichuris*). Based on the patterns of infection observed here and in previously obtained data on ova viability, it is likely that these toilet vaults do not consistently achieve the conditions necessary for more or less complete inactivation of these organisms in the faecal material (called “biosolids” by the authors).

The authors (Corrales et al.) had previously examined ova recovery and viability in stored samples collected from LASF and solar latrines in the same studied communities. Viable *Ascaris* and *Trichuris* ova were detected in LASF samples that had been stored for up to 2 years, while no viable ova were recovered from solar latrines. Solar latrines generally achieved higher internal temperatures than LASFs, the key determinant of *Ascaris* destruction, and produced a safer end product than the LASFs (Moe et al., 2001). The results of this study indicate that LASF and solar latrines protected against hookworm and *Giardia*, suggesting effective containment and destruction of these less environmentally persistent pathogens.

Using “biosolids” (faecal matter) as fertilizers resulted in a higher prevalence of infections (*Trichuris* and protozoan infections) compared to households that buried the material. This indicates a risk associated with the dispersal of biosolids around the home. If the biosolids are buried, human exposure and the potential for parasitic transmission are reduced. However, emptying and transferring contents from the toilet vault to a pit introduces an additional opportunity for parasitic transmission if the biosolids still contain infective pathogens. This may explain the higher prevalence of the more persistent helminths (*Ascaris* and *Trichuris*) among users of eco-san latrines who buried biosolids when compared with pit latrine users. Although most *Ascaris* and *Trichuris* infection was observed among children under 12 years, the prevalence of infection for members of households where biosolids were buried was much higher among adults than among children (57% in adults >31 years, vs. 14% in children <12 years). This finding lends further support to the hypothesis that transmission is more likely to occur during emptying of the latrine (a task performed by adults), than from contact with the biosolids after they have been buried (see 3.5-10).

High prevalence of some infectious agents in urine-diverting toilets highlights the need for further work on better designs, better use and maintenance and better information for users as well as further evaluation under different local environments and cultures.

Epidemiological study in rural Durban, SA

3.5 - 19

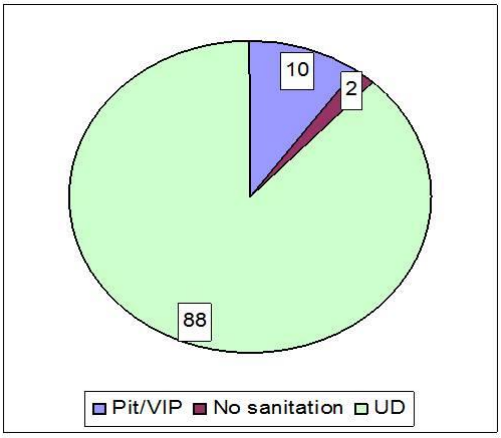
- Peri-urban area, eThekweni municipality, in Durban
  - 1337 households incl. in study
- Intervention
  - Sanitation – dry UD-toilets
  - Safe water (200 L per day)
  - Health and hygiene education
- Purpose and method
  - Measure reduction in diarrhoea associated with the interventions
  - Prospective cohort study
  - Disease incidence questionnaire (6 visits)

Picture provided by Teddy Gounden

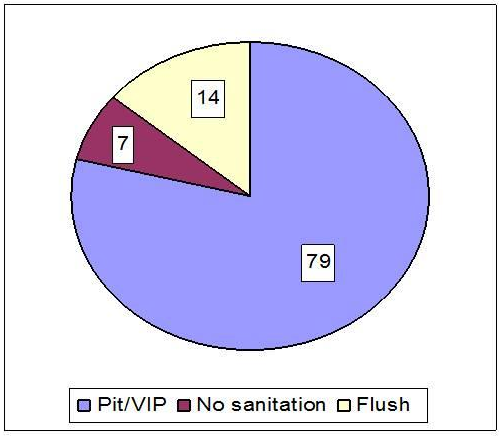
(Knight et al., manuscript)

The Durban city council embarked on a major upgrading of provision to 63 000 households in rural parts of the municipality (picture on next slide). By the end of 2007 the households had been provided with urine diversion (UD) toilets and free supply of 200 litres of safe water per day, complemented with health and hygiene education.

An epidemiological study was undertaken among 1337 households to investigate the effects of the combined intervention comprising new toilets, provision of safe water, and health and hygiene education. The circular diagrams below tell what toilet systems were available in the two areas. A prospective observational cohort study design was utilized including a disease incidence questionnaire. Each household was visited every two weeks, and in total six visits were made to reduce information bias (Knight et al. manuscript).



Intervention area with 660 households



Unexposed area with 667 households

Results from the Durban epi-study

3.5 - 20

41% reduction in diarrhoea

- Benefits 3 times greater for children <5 years
- Fewer acute water-related health incidences
- Duration of diarrhoea episodes decreased (54% fewer days reported)

Picture provided by Teddy Gounden

Not possible to disaggregate the separate effect of each intervention

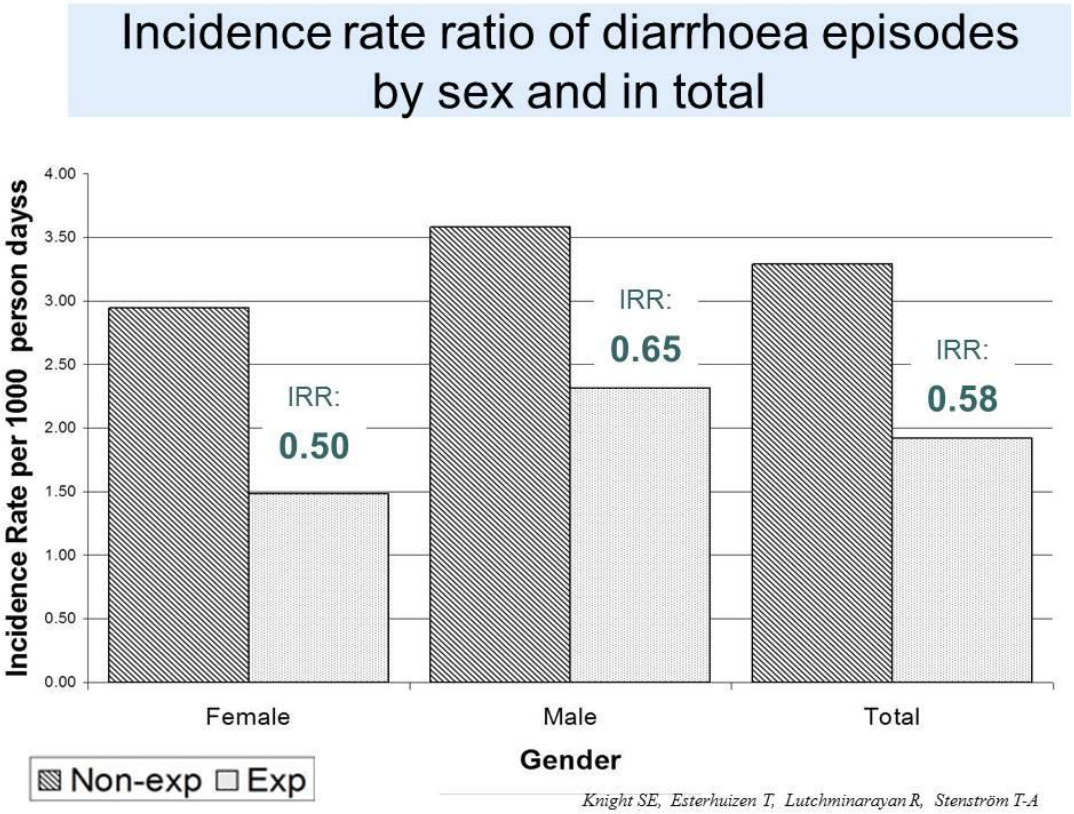
Knight et al., manuscript

The overall conclusion in the study is that the intervention resulted in a 41% reduction of diarrhoea compared to unexposed areas. The incidence rate for diarrhoea was 0.71 episodes per person per year in exposed areas compared to 1.23 episodes per person per year in unexposed areas. For children, the number of diarrhoea episodes was higher, especially for those under the age of 5. However, this group benefitted the most of the intervention and the number of episodes was reduced to one-third of that of the unexposed group.

Furthermore, the duration of diarrhoea episodes was shorter in the intervention areas than in the unexposed areas: 5.6 days compared to 9.9 days which resulted in 54% fewer days of diarrhoea in total.

The study design did not allow for disaggregation of the effect of each separate intervention. (Knight et al. manuscript). The general perception from many studies is that improved sanitation has a greater positive impact than improved water quality (See Module 3.1).

3.5 - 21



The table shows the incidence rate per thousand person-days for men and women is between 3 - 3.5 or about once a year. Two significant differences are found: females have a lower rate of diarrhea than males, and the intervention halved the diarrhoea episodes for females while that of men is reduced by 30% only. One possible explanation for this could be that women stay at home more often than men and thus receive a greater benefit from the interventions (Knight et al. manuscript).