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 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).

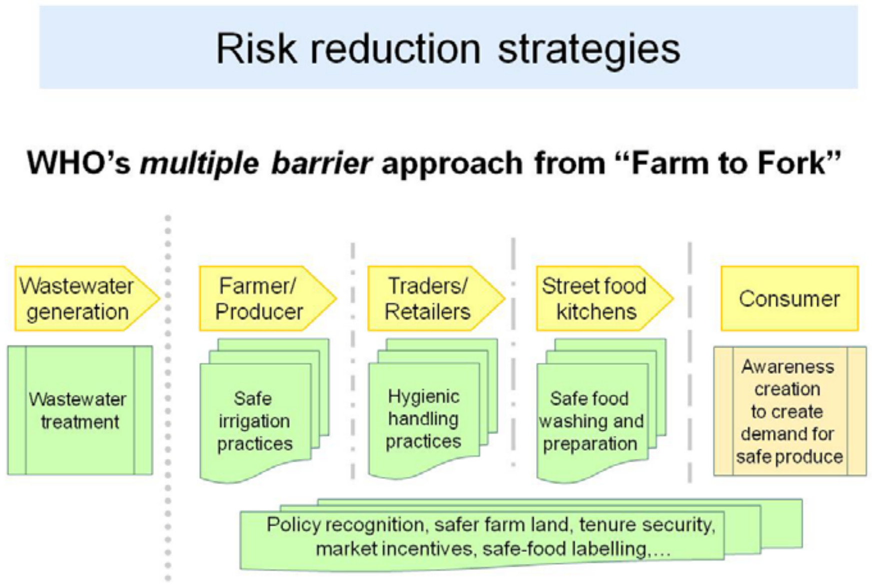
In this module microbial risk assessment is dealt with in more detail by giving a few examples on QMRA-studies that have been published in scientific journals. They are all related to developed areas (Sweden and Denmark) but the same approach could be applied to any sanitation system. The epidemiological studies presented were performed in developing areas with a worse sanitary situation to start with, high incidence of parasitic infections, and thus where the interventions are mainly needed in order to improve the public health situation on a global level. However, as stated also in module 3.3. and 3.4 risk management is crucial in any sanitation system and this module elaborates on barriers (health protection measueres) in practice.

To address health issues in sanitation systems and to successfully contribute to improvements this work plan could be followed. Policies and guidelines are often based on theory and basic research. Implementation and use of the policies in practice with necessary local adaptations will lead to local experiences. These are either applicable only on the local level or may generate general knowledge that also can identify needs for further research. Policies can then be adapted to new facts and findings. Dissemination, communication and education are crucial parts in any risk management system.

Treatment as a health protection measure

- The most important barrier to manage risks?
- Handling (contact) of excreta should be minimized, but necessary to some extent
- What is practically, socially and culturally acceptable?
  - Adapted to local conditions, education and information, sustainability
- Treatment recommendations important part of the guidelines
- Will develop, on-going research

Treatment of excreta or other waste flows can be taken as an example in this respect. It may be the most important part of a sanitation system, perhaps both in reuse systems and in systems that do not utilise the waste as a resource. Treatment is an important part of existing guidelines and regulations, e.g. looking at WHO or national EPAs, and these build on both theory and research. It is stated by WHO that the adaptation to local conditions is necessary, and a treatment system need to be accepted and well managed in order to be a part of a sustainable sanitation system. Facts are however lacking and additional research to develop guidelines and practical implementation advice is constantly requested. The area is likely to develop due to the increasing need of sanitation, management of waste flows and resources (e.g. nutrients and water to agriculture).



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

- Safe irrigation practices, which is the responsibility of farmers and food producers and at the same time they are protected but it will also limit the exposure to surrounding humans and animals.
- Hygienic handling practices, which is the responsibility of traders and retailers.
- Safe washing and preparation of food, which is the responsibility of traders and retailers.

All these measures will in the end reduce the risk for the consumer, and improvements can be driven by awareness creation to create demand for safe produce.

Examples of how to design regulations

- Treatment
  - define processes,
  - different levels (categories)
- Validation of the treatment process
- Microbiological/hygienic quality
  - presence of microorganisms,
  - reduction of microorganisms
- Restrictions on usage
- Fertilising (irrigation) methods
- Handling of the product (e.g. transport, storage)
- Protection of workers
- Sampling
- Analytical methods

Regulations, policies and guidelines for reuse systems aim at managing risks, to reduce them to acceptable levels. They can contain a range of different aspects, where again treatment is one important part, and here processes can be defined. If judged to give the same level of safety the processes can be clustered into categories (that in turn may be related to different additional requirements). Hygienic quality of a waste product can be judged by analysing for presence of various microorganisms (both indicators and pathogens) or by measuring the reduction, i.e. comparing the content of organisms before and after the treatment process. Restrictions on usage (e.g. crop restriction) are another part, so is choice of irrigation or application method. There can be demands on how to transport and store the waste product and on how to protect workers. Related to microbial analyses, sampling and methods can be regulated (or suggested).

Comparison of sanitation systems

- Diverted
  - Small volumes
  - Easier to treat
  - Suitable fertiliser products
  - Handling requires restrictions

- Mixed (conventional)
  - Large volumes of ”hazardous” waste
  - Extensive treatment
  - Reuse products: wastewater, sludge
  - Downstream pollution

A simple comparison can be made from a health point of view between diverted and mixed sanitation systems, i.e. where urine, faeces and greywater are diverted or mixed in one flow. Well managed they can both function well, how sustainable they are depend on the time frame and system boundaries and is heavily debated. A diverted system creates smaller volumes that need to be handled. However it may involve more labour intensive handling and close contact that need to be restricted. In mixed systems large volumes need to be treated and downstream pollution avoided. Both systems generate waste products that can be utilised in agriculture, but their features vary. What is important in relation to health risks is that they always can be managed, that is, it is possible to limit exposure and pathogens can be reduced, in comparison to many chemicals. Therefore health and hygiene issues do not need to be the aspect that is decisive for which sanitation system that is suitable to implement. Again, local adaption is a key to control risks for disease transmission.

Assessment of health risks

- Microbial analysis
  - Indicators not always reliable
- Epidemiological studies
  - Scarce, complex
- Microbial risk assessment
  - The main approach (?)

As described in module 3.4 assessment of health risks related to water and sanitation in a more scientific way can be conducted by microbial analysis of waste flows (that are either to be discharged or used), by epidemiological studies or by microbial risk assessments, that can either by qualitative or quantitative. All approaches have drawbacks, but the knowledge today that is used for creating guidelines and can motivate risk management strategies builds on combined results, using all methods. Further on a few examples of studies will be described. The examples aim at giving a system overview, exemplifying exposure scenarios and results showing the need for several barriers. See the connection to guidelines in 3.4.

Microbial Risk Analysis

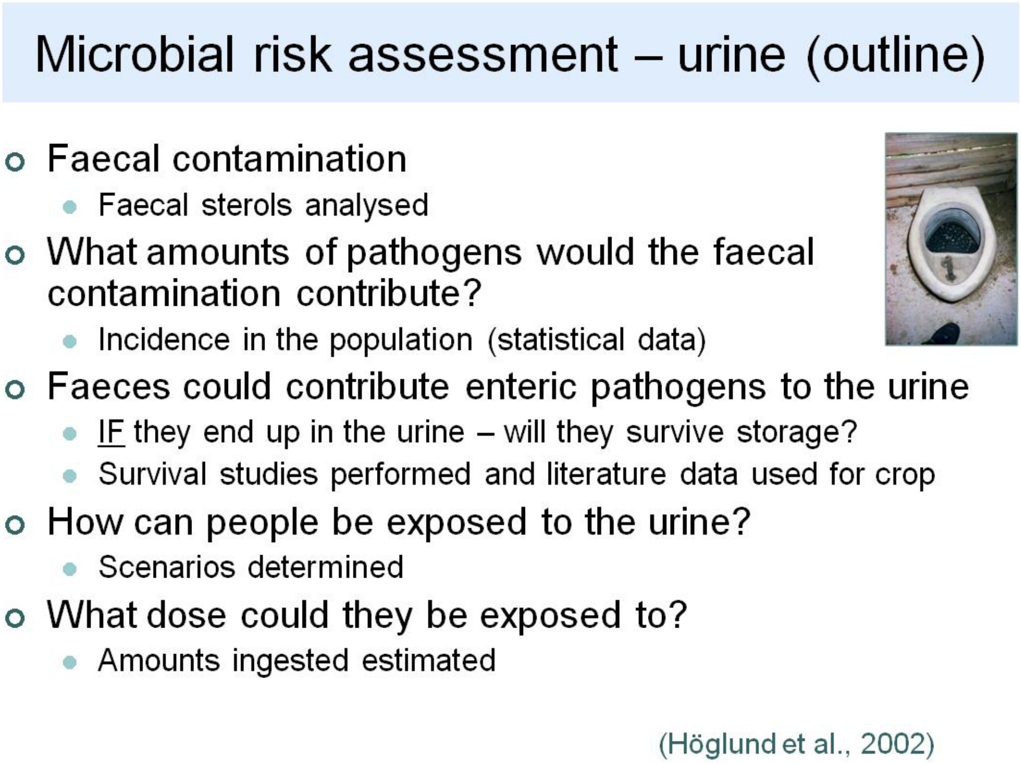
- Risk Assessment
  - Qualitative or quantitative
  - Systematic procedure
  - Acceptable risks
- Risk Management
  - To handle the risks
  - Aims at reducing risks
- Risk Communication
  - Essential part in all systems
  - Necessary for awareness raising and health protection
  - Involve ”all” stakeholders

Risk management is central in microbial risk analysis (MRA). It is in general to handle risks by reducing them. Risk communication can however also be considered to be a part of risk management, since the communication for example aims at promoting correct behaviour of e.g. users of the system and consumers of products. MRA is covered in more detail in module 3.4.

Quantitative Microbial Risk Assessment (QMRA)

- Hazard Identification
  - All enteric pathogens potentially in excreta
- Exposure assessment
  - Exposure points, site-specific data on removal
  - Literature data on occurrence of pathogens, removal in treatment and survival in environment
  - Exposure scenarios evaluated (ingestion, volumes)
- Dose-response assessment
  - Published mathematical models
- Risk characterisation
  - Risk of infection per exposure and yearly, DALYs
  - Comparison with endemic level of disease (underreporting)

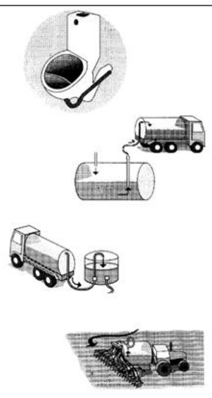
To summarize the steps in Quantitative Microbial Risk Assessment (QMRA) for a sanitation system the Hazard identification involves all enteric pathogens potentially present in excreta. The Exposure assessment includes the identification of exposure points (transmission routes), site-specific or literature data on e.g. occurrence of pathogens, removal during treatment and survival in the environment and the setting of exposure scenarios evaluated with choice (estimates) of how often ingestion occurs and what volumes that are ingested. The Dose-response assessment uses mainly published mathematical models and in the Risk characterisation risk of infection per exposure or yearly risk can be calculated. Risk for illness and calculations of DALYs are possible subsequent steps. To characterize the risk as impact on a population, comparisons with present endemic levels can be made.



To summarize the findings from the previous studies on faecal contamination and survival of enteric microorganisms a Quantitative Microbial Risk Assessment was conducted for a urine diverting system in Sweden (Höglund et al., 2002; http://wmr.sagepub.com/content/20/2/150.full.pdf+html). To quantify the faecal contamination, faecal sterols were analysed, i.e. the concentration of coprostanol in collected urine were analysed. We then chose three pathogens to look closer at, representing different organism groups *Campylobacter jejuni*, rotavirus and *Cryptosporidium parvum*. National surveillance data on incidence was used to calculate potential densities of these pathogens in the urine. The results from survival studies (module 3.3) were used to calculate densities after storage. Exposure scenarios were determined, i.e. theoretical scenarios and estimated amounts (volumes) of urine that could be ingested were determined.

Microbial risk assessment – urine (outline)

- Input: faecal contamination, prevalence of infection, excretion densities, excretion days, inactivation rates
- Scenarios:



Exposure	Risk
Cleaning of blocked pipes	Ingestion of pathogens
Accidental ingestion when handling unstored urine	Ingestion of pathogens
Accidental ingestion when handling stored urine	Ingestion of pathogens
Inhalation of aerosols created when applying urine	Inhalation of pathogens
Consumption of crops fertilised with urine	Ingestion of pathogens

- Dose-response models
- Output: probability of infection

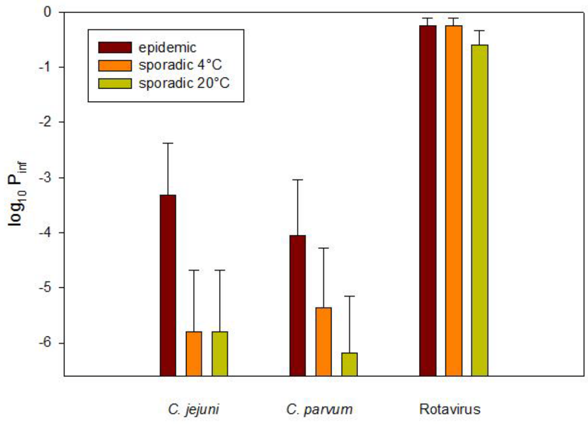
(Höglund et al., 2002)

The inputs used in the calculations were thus the measured faecal contamination, prevalence of infection, excretion densities, excretion days and inactivation rates, resulting in a certain concentration of the pathogen.

The scenarios investigated were accidental ingestion of 1 ml of unstored urine and of urine stored for different time periods at different temperatures. Also, aerosol formation during fertilization was looked at and the consumption of fresh crops fertilized with urine.

As an output the probability of infection was obtained. The final relationship used were dose-response models for the three pathogens, where the calculated dose a person ingests resulted in a certain risk or probability of becoming infected.

Risk from accidental ingestion of 1 ml unstored urine



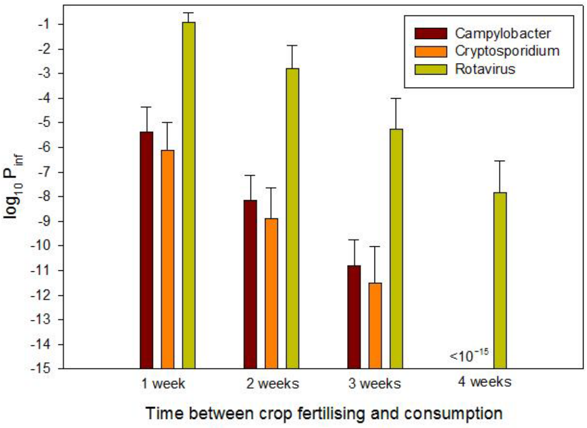
- Unstored urine P_{inf} < 1:1000 except for rotavirus
- Storage for six months at 20°C all risks < 1:1000

(Höglund et al., 2002)

Overall, risks were calculated 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 for rotavirus from accidental and aerosol ingestion also were less than 1:1000.

This graph shows the risk for infection after ingestion of 1 ml of unstored urine at different scenarios of infections in the population. Epidemic, is if all the people connected to a urine-diverting system is infected at the same time, right before the urine tank is emptied, a sort of worst case scenario, whereas the other two bars represent when the cases of infection are evenly spread during the time the urine is collected. They differ in that the urine is collected either at 4°C or 20°C, resulting in higher inactivation of the organism, and thus a lower risk, for urine that has been collected at 20°C.

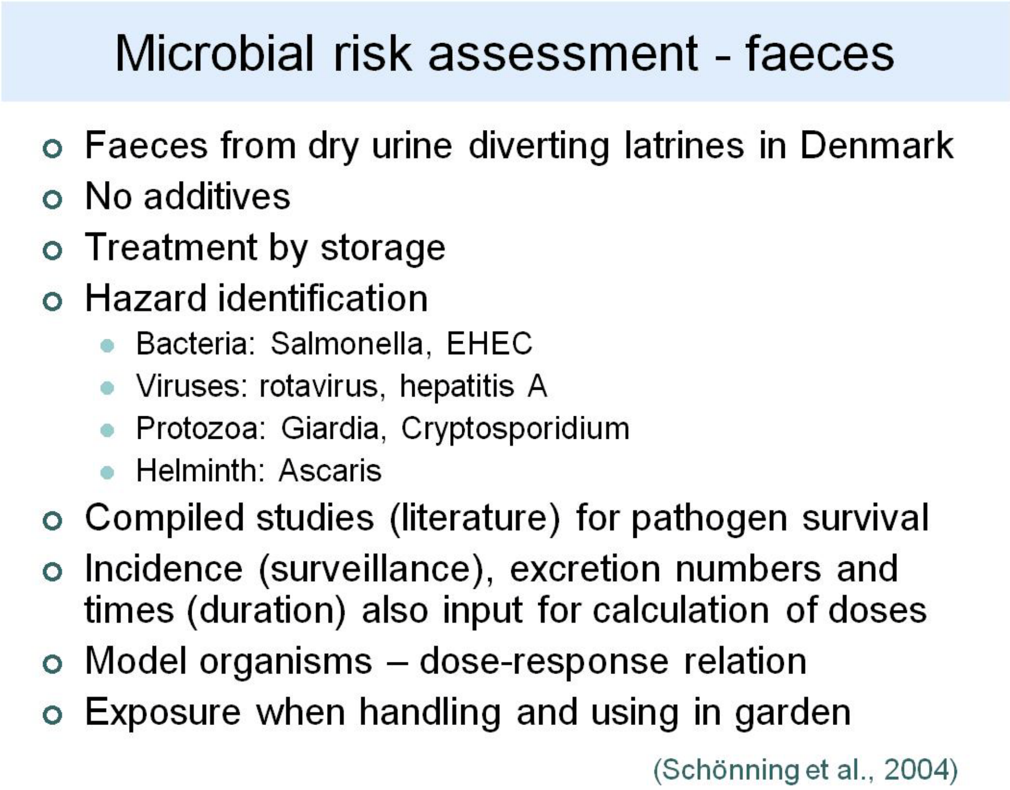
Risk from accidental ingestion of 100 g crop



- Inactivation will continue in the field
- Risk dependent on time between fertilising and consumption

(Höglund et al., 2002)

Another example is the ingestion of 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 fertilization and harvesting, or consumption. Even if unstored urine was to be used, the risk simulations showed that the risk for bacterial and protozoan infections was low already after 1 week. After 3 weeks the risk for viral infections was on the same level. (This specific case corresponds to eating a fresh crop that holds as much water as lettuce.)



Another quantitative risk assessment was performed for a urine diverting system in Denmark (http://www.iwaponline.com/jwh/005/0117/0050117.pdf). Here risks related to handling and use of the dry collected faeces were evaluated. Representatives from the various groups of pathogenic microorganisms that can be transmitted through faeces to humans by the faecal-oral route were chosen based on the following criteria:

- The organisms should be relatively common in Denmark
- The most persistent microorganisms should be included
- Organisms having low infectious doses should be included
- Some organisms giving severe sequelae should be included
- Reasonable background information about the organism should be available

Using the incidences assessed 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%. A total of 0.5% of the containers would contain at least two types of pathogen. Rotavirus and Giardia would be the most frequently occurring pathogens, present in 4.7% and 4.3% of the containers, respectively.

Exposure scenarios

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

(Schönning et al., 2004)

Theoretical scenarios were evaluated by using data collected from previous studies of this type of toilet. 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 a maximum 7°C higher than the ambient temperature. The faeces could thus be said only to be treated by means of storage prior to the 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). The following scenarios were evaluated:

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 after storage for 6 months
5. Application and incorporation of the material after storage for 12 months

The following assumptions were made for the exposure scenarios:

- The faeces-soil intake (Larsen,1998) - children around 200 mg of soil (max of 5-10 g).
- Assumed that adults ingest 15-50% of this amount, with a maximum of 100 mg.
- The container emptied once a year assuming only adults exposed.
- The number of exposures through recreation was a median value of 3.5 times per week (during June-August).
- 50% of the households were exposed through gardening once a week (during May-September).
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Conclusions - pathogens

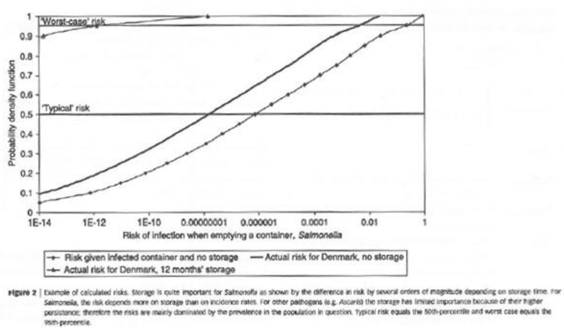
- There is an "unacceptably" high (>1:10 000) risk of infection when faeces is used without treatment
  - The highest risk from exposure to unstored material was attributable to rotavirus
- 12 months storage – sufficient reduction of most pathogens (compared to a risk level 1:10 000)
  - The highest risk from exposure to stored faeces was 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 compound

(Schönning et al., 2004)

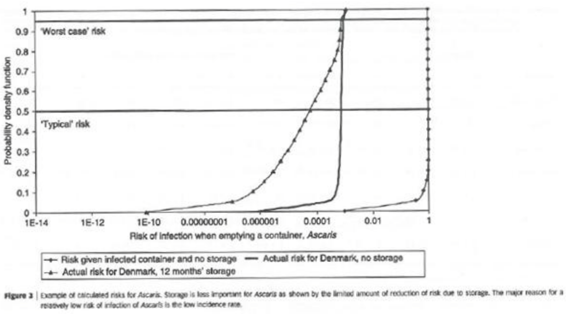
In approximately nine out of ten gardens, the use of stored faeces as a fertilizer will not result in a risk of infection in Denmark. This is because none of the family members was infected, and thus no pathogens were excreted into the container. In the remaining 11.6% of the gardens there is a risk of infection; however, most of the exposures will not lead to infection as too few pathogenic organisms will be ingested. If strictly comparing the risks with previously identified acceptable levels (10^{-4} per year), the practice of using one year stored but otherwise untreated faeces should be regarded as unacceptable. The risk of infection is mainly dominated by the helminth *Ascaris*. Further, the risk is very sensitive to changes in the incidence rate, indicating that local handling of faeces is an important route of exposure. The risk of infection will be greatest when emptying the container of collected faeces as the material at this stage has not then been mixed with soil and no further reduction of pathogens has occurred. Emptying the container will result in potential exposure to pure faeces that have been stored for 0–12 months. The highest risk resulting from exposure to un-stored material was attributable to rotavirus (3×10^{-2}), whereas *Ascaris* constituted the highest risk after 6 or 12 months' storage, even if 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.

There is a high level of uncertainty regarding inactivation of pathogens in faecal material, and further studies are recommended. The risks of infection can be reduced by measures such as longer storage, treatment with 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 0 months of 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 have lower infectious doses, which result in higher risks for rotavirus, the protozoa and *Ascaris*. Without storage, the material in the containers was, with the exception of bacteria, highly infectious. 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).

Risk for infection when emptying container



Salmonella



Ascaris

Examples of how risk for infection are presented as probability density functions. The typical risk equals the 50th-percentile and worst case equals the 95th-percentile.

(Schönning et al., 2004)

These graphs are shown as examples of calculated risks. Storage is quite important for *Salmonella* as shown by the difference in risk by several orders of magnitude depending on storage time. For *Salmonella*, the risk depends more on storage than on incidence rates. For other pathogens (e.g. *Ascaris*) the storage has limited importance because of their higher persistence; therefore the risks are mainly dominated by the prevalence in the population in question. Typical risk equals the 50th-percentile and worst case equals the 95th-percentile.

Storage is less important for *Ascaris* as shown by the limited amount of reduction of risk due to storage. The major reason for a relatively low risk of infection of *Ascaris* is the low incidence rate.

The large differences between the typical risk and the worst-case risk indicate that, in general, viruses, protozoa and helminths may constitute a problem because of a substantial level of uncertainty. Furthermore, the risks increased significantly if the material was stored for less than 12 months. The importance of the estimated incidence rates differs greatly between the different pathogens. 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.

Microbial risk assessment – wastewater and sludge

- Hässleholm municipality with 28 600 residents
- 12 500 m^3 wastewater per day
- Wastewater treatment: pre-aeration, pre-sedimentation, activated sludge, chemical precipitation, three-media filter
- Sludge treatment: anaerobic digestion, dewatering, outdoor storage
- Sludge use: Application to vegetables (theoretical)

(Westrell et al., 2004)

In another study Hazard Analysis and Critical Control Points (HACCP) was applied (where QMRA was one step) for identifying and controlling exposure to pathogenic microorganisms encountered during normal sludge and wastewater handling at a 12,500 m3/d treatment plant utilizing tertiary wastewater treatment and mesophilic sludge digestion. The sludge was assumed to be applied to vegetables.

(http://www.iwaponline.com/wst/05002/0023/050020023.pdf)

Microbial risk assessment – wastewater and sludge

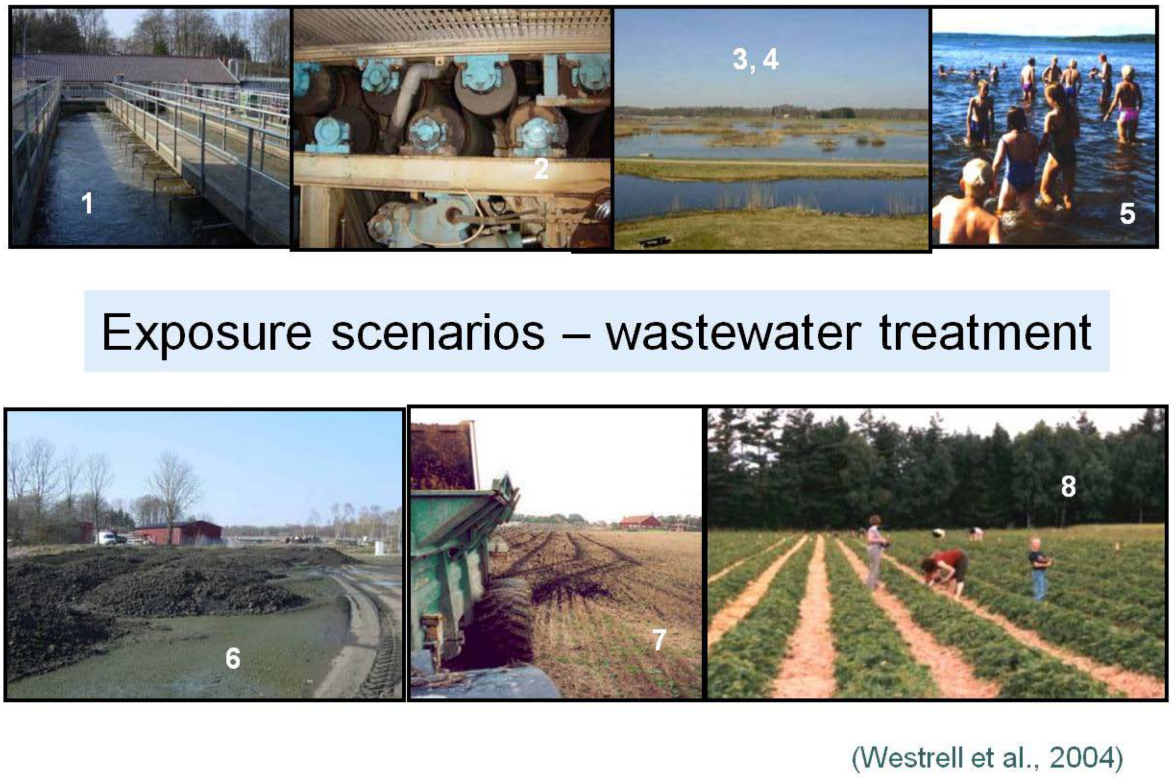
- Hazard Identification
  - All entero-pathogens potentially in wastewater
  - Enterohaemmorhagic *E.coli* (EHEC), *Salmonella*, *Giardia*, *Cryptosporidium*, rotavirus and adenovirus
- Exposure assessment
  - Exposure points identified together with WWTP staff
  - Site-specific data on removal of indicators in WWT
  - Literature data on occurrence of pathogens in ww, removal in sludge treatment and survival in environment
- Dose-response assessment
  - Published dose-response models
- Risk characterisation
  - Monte Carlo simulations
  - Risk of infection per exposure
  - Yearly number of infections in study population
  - Comparison with endemic level of disease (epidemiological statistics adjusted for underreporting and morbidity rates)

(Westrell et al., 2004)

A quantitative microbial risk assessment (QMRA), including rotavirus, adenovirus, hemorrhagic *E. coli*, *Salmonella*, *Giardia* and *Cryptosporidium*, was performed in order to prioritize pathogen hazards for control purposes. The exposure scenarios considered were identified together with staff at the wastewater treatment plant (WWTP).

Literature data was used for most information that was needed to calculate the concentrations (densities) of pathogens in the various waste flows. Site specific data on removal of indicators in the treatment plant was applied to the pathogens to calculate their density in outgoing wastewater.

Human exposures were treated as individual risks but also related to the endemic situation in the general population.



The hazardous scenarios considered were human exposure during treatment of wastewater (1. at the 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 exposure from crop consumption (8.).

Exposure scenarios – wastewater treatment

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)

For each scenario the volume possibly ingested was estimated, and the number of times per year that this occurred was also determined in theory. By the site specific investigation the numbers of persons that could be exposed and affected were also estimated.

Risk of infection per exposure

All risks $>10^{-4}$ are shown in orange

Exposure		EHEC	*Salmonella*	*Giardia*	*Cryptosporidium*	Rotavirus	Adenovirus
1		$6x10^{-4}$	$3x10^{-5}$	$1x10^{-3}$	$2x10^{-4}$	$9x10^{-2}$	$2x10^{-1}$
2		$2x10^{-3}$	$1x10^{-4}$	$4x10^{-3}$	$9x10^{-4}$	1	1
3		$3x10^{-5}$	$2x10^{-6}$	$3x10^{-4}$	$3x10^{-5}$	$5x10^{-2}$	$1x10^{-1}$
4		$1x10^{-6}$	$6x10^{-8}$	$1x10^{-5}$	$1x10^{-6}$	$2x10^{-3}$	$4x10^{-3}$
5		$9x10^{-10}$	$5x10^{-11}$	$2x10^{-7}$	$5x10^{-8}$	$1x10^{-5}$	$6x10^{-5}$
6		$1x10^{-2}$	$6x10^{-4}$	$2x10^{-2}$	$6x10^{-3}$	$4x10^{-1}$	$9x10^{-1}$
7		$5x10^{-3}$	$3x10^{-4}$	$1x10^{-2}$	$2x10^{-3}$	$3x10^{-1}$	1
8		$2x10^{-6}$	$9x10^{-8}$	$2x10^{-6}$	$9x10^{-6}$	$2x10^{-4}$	$4x10^{-4}$

(Westrell et al., 2004)

The highest individual health risk per single exposure was achieved 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 nearly or equal to 1. The lowest risk was from swimming in the lake (exposure 5). The wastewater treatment, the wetland and the dilution in the receiving water reduce the pathogen numbers to a great extent. If currents transport undiluted wetland discharge to the bathing area the risk could increase a thousand times. The viruses gave the highest risk for a single exposure due to high influent concentrations, low infectious doses and lesser removal than bacteria and protozoa. *Giardia* is more infectious than *Cryptosporidium*, which was reflected in the risk calculations. The higher risk for EHEC than for *Salmonella* was mainly due 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.

Number of yearly infections

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)

0 is equivalent to <0.0001 infections

(Westrell et al., 2004)

The yearly 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. The major risk was due to viruses, with maximum number of infections reached for both adenovirus and rotavirus in exposure scenarios 2 and 7 and nearly in scenario 1. This means that the workers at the treatment plant and the entrepreneurs handling and spreading sludge were quite certain to become infected 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 gave 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 harvest of crops that is to be eaten raw, but in this study a worst-case scenario assuming only one month was applied.

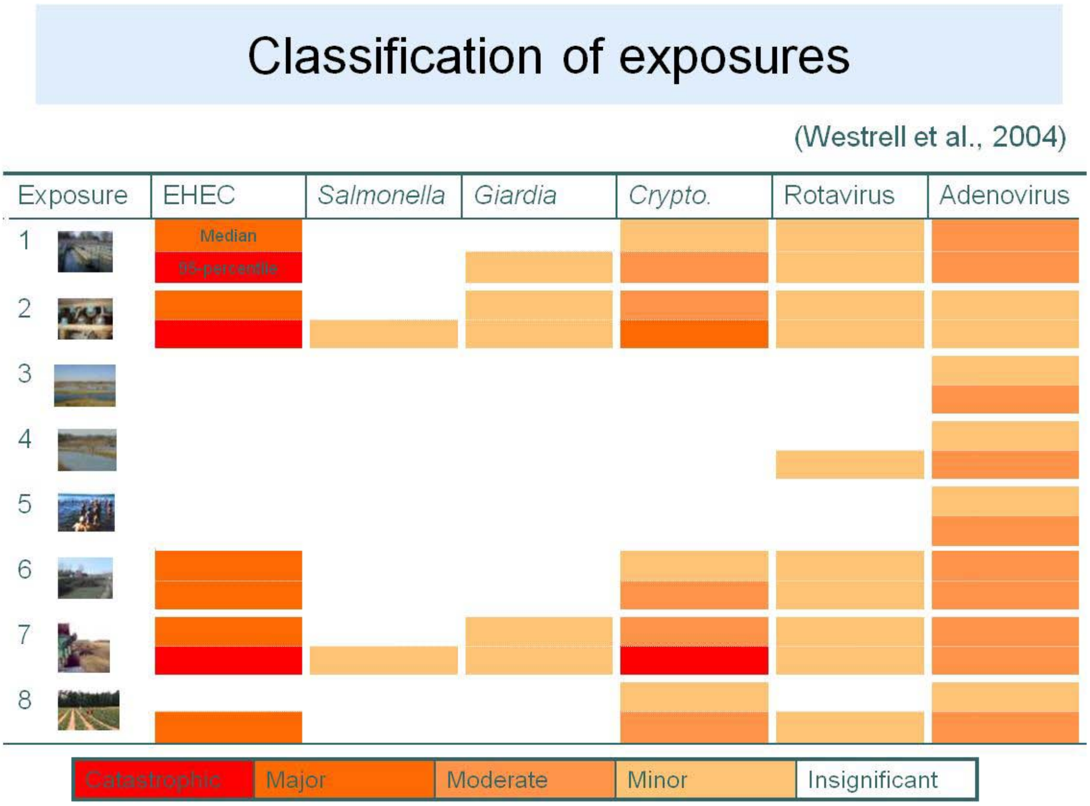
Severity of hazards

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

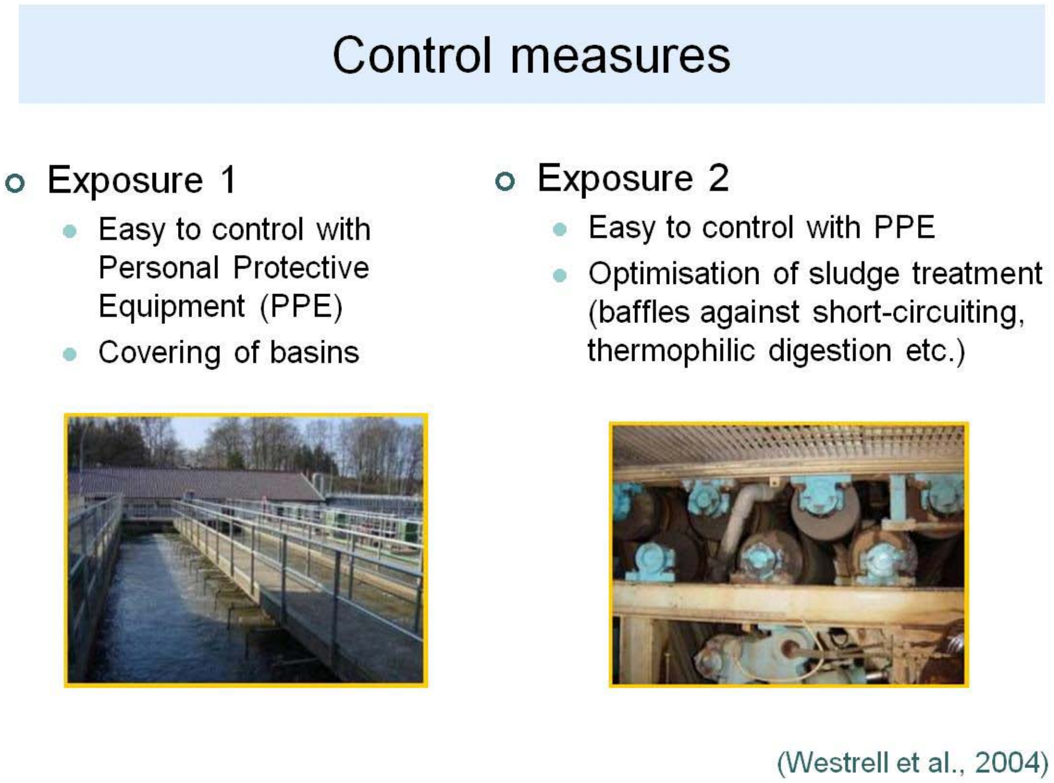
(Westrell et al., 2004)

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 worse, since it gives other symptoms (e.g. renal failure) than diarrhoea and often requires hospitalization.



Although several of the exposures only resulted in fractions of 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 through vegetables fertilised with sludge and eaten raw (see slide above Number of yearly infections, up to 20 cases for adenovirus).

Viruses generally yielded 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, was identified as having the largest impact on the community (i.e. major to catastrophic), with above 5% and 25% increase in disease rate, respectively.

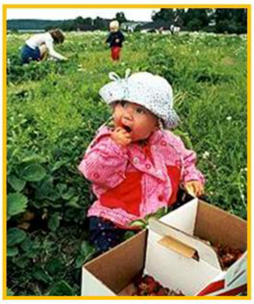


From the society's perspective it is most important to control exposures 1, 2, 6 and 7 at this sewage treatment plant. Wastewater treatment does normally not include any complete barriers and the treatment processes are not optimized for pathogen removal, although each process generally inactivates or removes a part of the pathogens. Control points for all of the hazardous exposures could be to make sure that the each treatment step maintains measurable process parameters within operational limits and does not exceed established critical limits. The most hazardous exposures identified in this case study included some of the early processes in treatment and the sludge handling. These could be controlled by use of personal protection equipment and extended treatment of the sludge.

Control measures

- 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)

In order to avoid children from getting access to the sludge storage (exposure 6) an easy control measure 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.

Worst-case situation 2002

Acknowledgements

- Per-Åke Nilsson and staff at Hässleholm wastewater treatment plant
- Swedish research council FORMAS
- MISTRA Urban Water program

(Westrell et al., 2004)

According to the Swedish Meteorological and Hydrological Institute (SMHI) this type of flooding could occur every 50 years, probably outweighing the calculated risks.

Epidemiological study - El Salvador

- 107 households, 449 people
- Prevalence of parasitic infections
- Type of latrines
  - UD solar desiccating latrine (single vault)
  - UD double-vault desiccating latrine (LASF)
  - Pit latrines
  - No latrines

  - UD = urine diverting

(Corrales et al., 2006)

Epidemiological studies are, as stated, often difficult and expensive to conduct. Such studies conducted on sanitation systems are therefore considered specifically 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).

In El Salvador a study of the prevalence of parasitic infections was conducted in a community with 107 households (449 people) that had different type of latrines. 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.

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

Prevalence of parasitic infections

- Use of UD-latrines (both solar and LASF) – lower prevalence of the less environmentally persistent pathogens (hookworm, Giardia, Entamoeba)
- Use of LASF – higher prevalence of more environmentally persistent pathogens (Ascaris, Trichuris)

L. F. Corrales *et al.* **Sanitation design and enteric parasitosis**

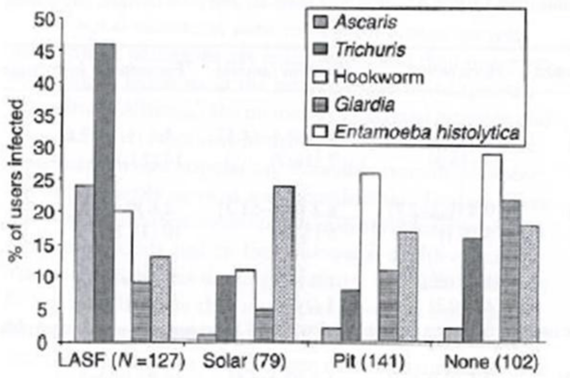


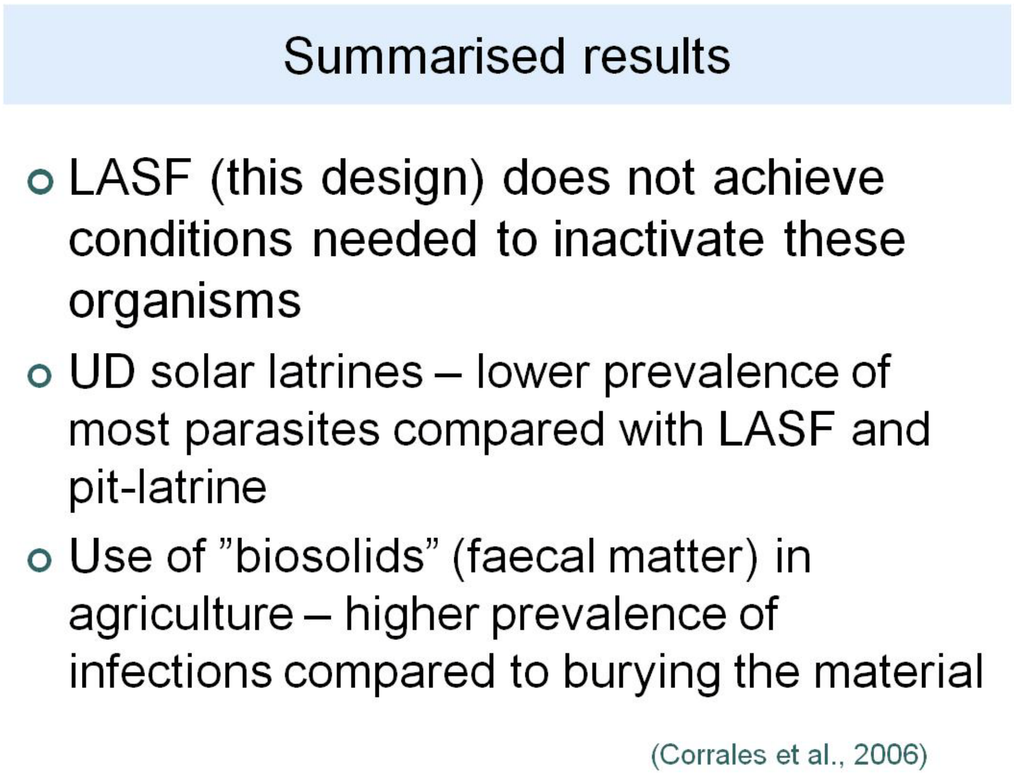
Figure 2 Prevalence of parasitic infection by latrine type.

(Corrales et al., 2006)

The use of UD-latrines (both solar and LASF) resulted in lower prevalence of the less environmentally persistent pathogens (hookworm, *Giardia*, *Entamoeba*), suggesting that eco-san latrines are an intervention that can reduce transmission of these pathogens.

The people using LASF had a higher prevalence of more environmentally persistent pathogens (*Ascaris*, *Trichuris*). Based on the patterns of infection observed here and previously obtained data on ova viability, it is likely that these latrines 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).

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



The authors previously examined ova recovery and viability in stored samples collected from LASF and solar latrines in the study 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 were protective for hookworm and *Giardia*, suggesting effective containment and destruction of these less environmentally persistent pathogens.

Use of ”biosolids” (faecal matter) in agriculture resulted in higher prevalence of infections (*Trichuris* and protozoan infections) compared to households burying the material, 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 latrine 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 subjects from 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.
(http://www.watersanitationhygiene.org/References/EH_KEY_REFERENCES/SANITATION/General%20Sanitation%20References/Parasites%20and%20Sanitation%20(Tropical%20Medecine).pdf)

Conclusions

- In El Salvador, the solar latrine is recommended
  - Includes urine diversion
  - Better results than pit latrine
- High prevalence of some infections in diverting latrines identifes the need for
  - Further work on better designs
  - Better use and maintenance, information
  - Further evaluation under different local environments and cultures
- Limitations of the study
  - Different communities compared
  - Small sample size

When published, the results were somewhat unexpected and heated the debate on possible health impacts of the type of latrines that had been promoted.

In El Salvador, the solar latrine is recommended since it includes urine diversion and it gave better results than pit latrines in this study (i.e. lower prevalence of a majority of the infections). More than half of the study subjects were infected with at least one type of intestinal parasite, indicating that these pathogens represent a significant health problem. The higher prevalence of Ascaris and Trichuris infections among LASF users when compared with persons with solar latrines, pit latrines or no sanitation suggests that LASFs may pose an increased risk for transmission of these helminths.
High prevalence of some infections in diverting latrines identifies the need for further work on better designs, better use and maintenance and information to users as well as further evaluation under different local environments and cultures.

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

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

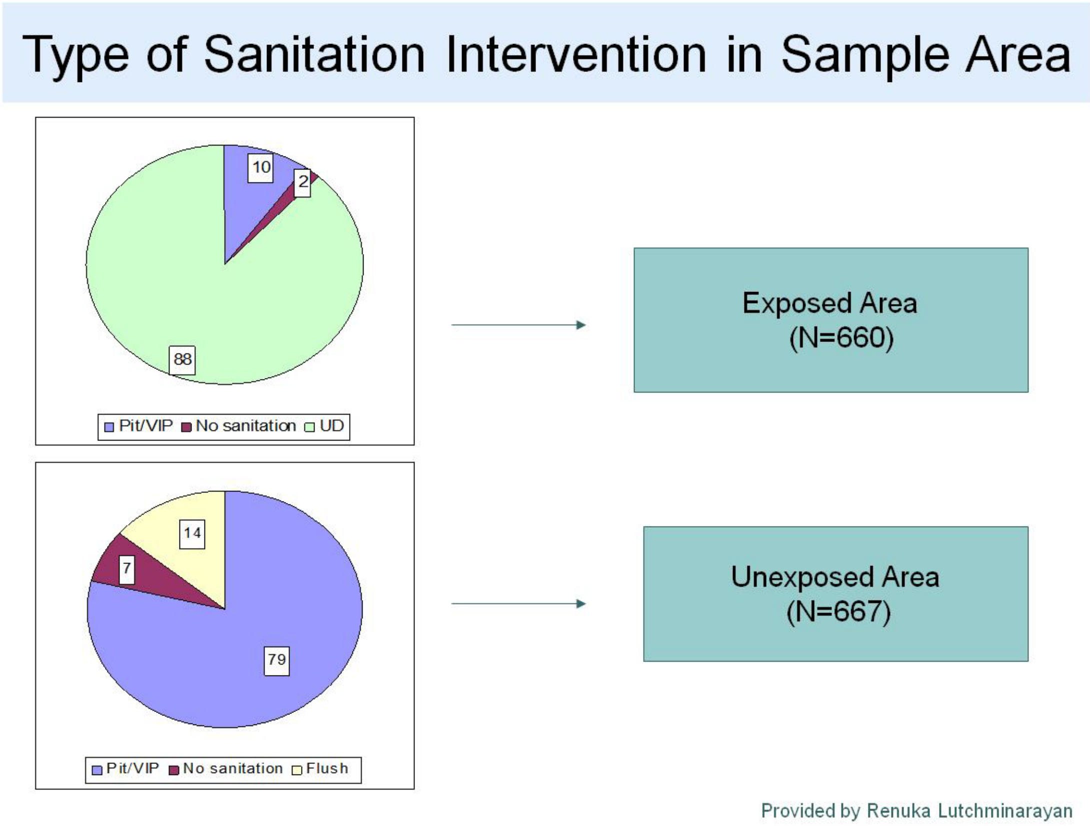
Epidemiological study South Africa

- Peri-urban area, eThekwini Municipality, 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)

In eThikwini municipality outside Durban in South Africa an epidemiological study was undertaken to investigate the effect of the intervention of sanitation, provision of safe water and health and hygiene education. By the end of 2007 urine diversion (UD) toilets, a free bulk of 200 litres of safe water per day and health and hygiene education had been supplied to 63 000 households in this municipality. A prospective observational cohort study design was utilized including a disease incidence questionnaire. Each household was visited every two weeks, and in total 6 visits were made to reduce information bias. (Knight et al. manuscript).



660 households from areas exposed to the combined intervention (i.e. areas which had the water, sanitation and hygiene intervention) and 667 households from unexposed areas (i.e. no intervention) were selected for the study.

Epidemiological study South Africa - Results

- 41% reduction in diarrhoea
  - Benefits 3 times greater for children <5 years
  - Fewer acute water related health outcomes
  - Duration of diarrhoea episodes decreased (54% fewer days reported)
- Not possible to disaggregate the effect of each separate intervention

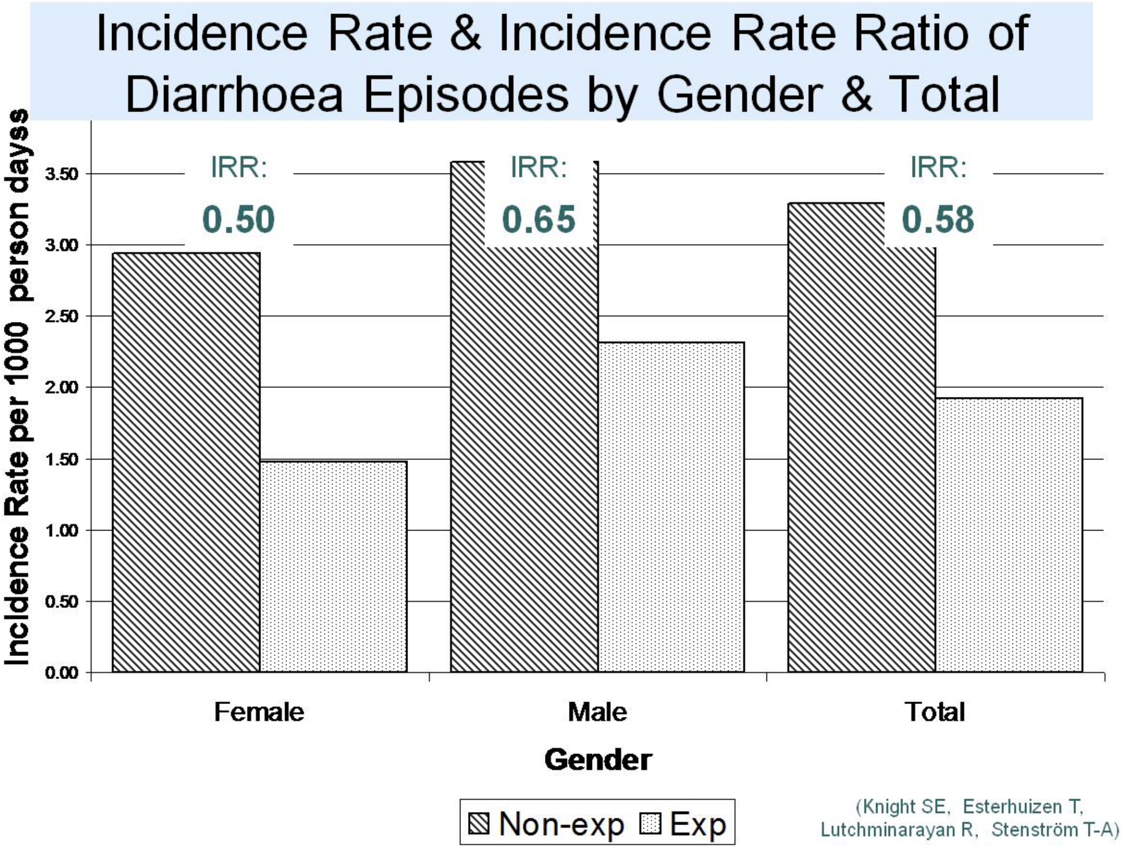
Picture provided by Teddy Gounden

(Knight et al., manuscript)

The overall conclusion was that the intervention resulted in a 41% reduction of diarrhoea if compared to unexposed areas. The incidence rate for diarrhoea episodes was 0.71 episodes per person and year in exposed areas compared to 1.23 episodes per person and year in unexposed areas. For children the number of diarrhoea episodes is higher, especially for those under the age of 5. For this group the benefit of the intervention was concluded to be three times greater.

Furthermore, the duration of diarrhoea episodes was shorter in the exposed 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 from each separate intervention. (Knight et al. manuscript).



A gender difference was detected in that there was a higher reduction of diarrhoea episodes for women compared to men, which could indicate that women that live/stay at home receive a greater benefit from the interventions (Knight et al. manuscript).

Impacts on diarrhoeal disease reduction by interventions

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

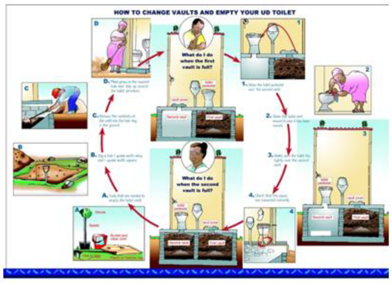
(In WHO, 2008, adapted from Fewtrell et al., 2005)

The effects of different interventions on diarrhoea have been investigated in several studies. A systematic review, a so called meta-analysis, was made by Fewtrell et al. (2005) in order to draw conclusions from published studies regarding interventions. In total, 2000 abstracts were screened and 38 studies were used in the meta-analysis. Even though it is not concluded from the table, water, sanitation and hygiene interventions interact, and 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 mostly are related to the environmental situation.

Summary of module on risk management

- Different types of studies
  - Possible to investigate the ”real” situation?
  - Epidemiology – underestimation in disease incidence
    - Interviews, surveillance
  - Risk assessments – assumptions made, over- or underestimating risks (?)
  - Sampling and microbial analysis
- Illustrates the importance of various studies
- Range of interventions possible and needed in combination
  - Difficult to differentiate effects
- Identifying need of risk management and barriers
  - Health protection measures of different kinds



The studies presented in this module show that sanitation systems can introduce new transmission routes, resulting in higher risks for infections. It is also obvious that implementation of sanitation systems can improve public health, e.g. reducing diarrhoea. It depends much 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 reused or not).

The epidemiological studies can be said to analyse the “real” situation, even though it is often stated that observational studies using questionnaires underestimate the disease incidence. Also surveillance systems are known to underestimate the incidence of an infectious disease in the community. In QMRA we try to correct for this underestimation according to studies on “known” community incidence, e.g. from studies where “all” diarrhoeal incidences were reported and the causing agent (pathogen) identified (e.g. Wheeler at el. 1999). Risk assessments evaluate situations and systems in theory, using both estimates and known data, trying to calculate typical risks or risks related to worst-case scenarios. As a comparison, the concentrations of protozoa and helminths that were measured in the faecal material in households in eThikwini (Trönnberg et al., 2010) were concluded to be lower than if calculating the concentration by 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 was 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 the need for managing risks and introducing barriers in the systems. It is also clear that health protection measures need to be both technical and behavioural (e.g. washing hands).