1.

Urine diversion
– hygienic risks and microbial guidelines for reuse

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1. INTRODUCTION

1.1 History

At the time when latrine contents were collected in buckets from each household in Swedish cities, urine was often collected separately and poured into the drain to avoid smells and to prevent the latrine from filling too quickly (Sondén 1889). Already in 1867 it was known that “the proportion of value of the fertilising ingredients held in solution in urine to that contained in faeces is as six to one” (Krepp 1867, in Drangert 1999) while Müller, a German scientist at that time, saw it as a necessity to separate the urine from the faeces in order to produce a fertiliser that was of manageable proportions (Müller 1860, in Mårald 2000). The separation, or diversion, of urine and faeces was made possible by the use of Marino’s toilet (Figure 1).

In many other parts of the world it is also a tradition to keep the urine and faeces apart. The old Japanese practice of nightsoil recovery from urban areas separated urine and faeces, since urine was regarded as a valuable fertiliser (Matsui 1997). In Yemen the urine is drained away and evaporated on the outer face of multistorey buildings to obtain the faeces as a dry fraction without smell for later use as fuel, a system that has been in use for hundreds of years (Esrey *et al.* 1998).

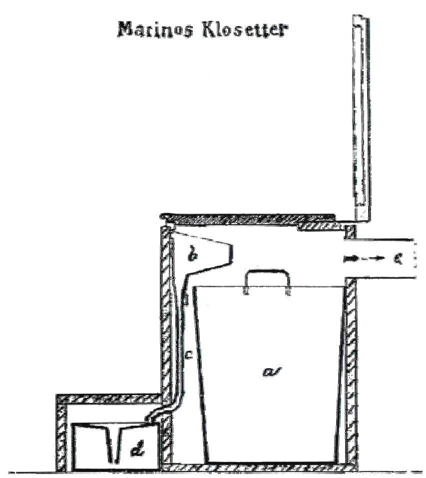


Figure 1. *Marino’s toilet*

Another product used as fertiliser was urat, consisting only of urine mixed with peat litter (Bachér *et al.* 1944). During the 19th Century urine was stored and used as a detergent for washing clothes in Denmark (Hansen 1928, in Drangert 1998). In Sweden urine has been used to smear wounds and dry skin and to some extent to drink as therapy (Frode-Kristensen 1966). Other historic uses of urine include tanning of hides and production of gunpowder (Stenström 1996).

The conventional wastewater system has been considered to be based on a principal error in its use of large volumes of clean water to dilute and transport small volumes of human waste. To increase sustainability (recycle nutrients, decrease outlets etc.) alternatives to conventional treatment have been suggested and the aim is often to reuse the plant nutrients from excreta as a fertiliser. One concept is source-separating sanitation systems which include blackwater systems, where the wastewater from toilets is treated separately, urine-diverting systems with separate handling of urine and different types of dry systems where human excreta is handled without the use of flushwater. Blackwater can be mixed with organic household waste and treated by liquid composting or digestion. Treatment and possible reuse of faeces is discussed in Chapter x.

1.2 Nutrient content and volume of domestic wastewater

The major plant nutrients nitrogen (N), phosphorous (P) and potassium (K) are found in human excreta and thus in domestic wastewater but the contents will vary depending on the food intake. In societies where meat is a more common the content of nitrogen protein will be higher (see also Section 3).

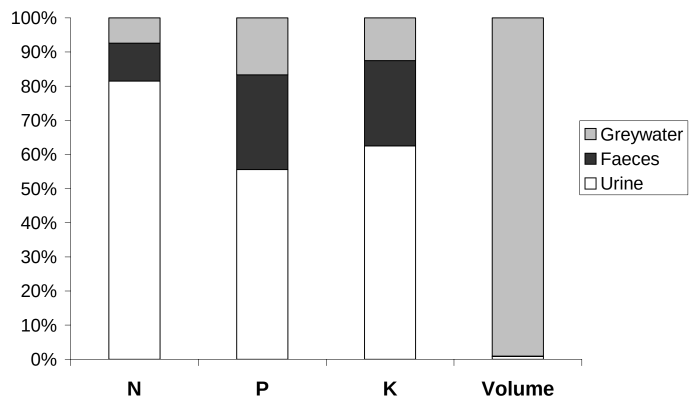


Figure 2. *Content of major plant nutrients and volume in Swedish domestic wastewater. The daily mean excretion per person and day is: 14 g N, 2 g P and 4 g K in a volume of 150-200 litre.*

Urine is the fraction that contains the major part of the nutrients in domestic wastewater, approximately 80% of the nitrogen, 55% of the phosphorous and 60% of the potassium (Figure 2). At the same time it constitutes less than 1% of the total wastewater volume. Thus it is possible to collect a relatively concentrated fertiliser by diverting urine from the wastewater. Furthermore, the content of metals in urine is very low (Jönsson *et al.* 2000).

2. URINE DIVERSION

Today the alternatives to the conventional wastewater system include systems that separate or divert urine and faeces in order to utilise the nutrients more efficiently. In regions without piped sewerage, nutrient utilisation as well as improved sanitation is possible to achieve by avoiding mixing the fractions. If the faecal fraction is kept dry there will be less leaching from e.g. pit latrines and in many places the faeces are also reused. Thus, the two main reasons to separate urine and faeces are to recycle the plant nutrients in urine and to obtain a faecal fraction that is more practical and safer to handle.

Facilitating the composting of faeces might be another reason for keeping the liquid separate from the solids. In the Clivus Multrum™ toilet the urine and leachate drains to the bottom of the composting chamber where it is collected in a separate tank (Del Porto and Steinfeld

2000). This system is manufactured around the world but has been criticised for wasting the urine resource (Esrey *et al.* 1998; Drangert 1999). Another system, the Aquatron™ can either be connected to a conventional toilet or a urine-separating toilet (see below). Through centrifugal forces the liquid is separated from the solids, which drop down into a composter. The liquid, containing flushwater, possibly urine and suspended solids from faecal matter, is treated in an UV-unit and disposed of as greywater (Del Porto and Steinfeld 2000). It is worth adding that in order to compost faeces at thermophilic temperatures addition of organic household waste or other material usually is necessary.

The latter are examples of techniques that literally first mix the two fractions urine and faeces, and then separate them. The term *urine diversion* has been used when the fractions are never mixed (Esrey *et al.* 1998). In Sweden however, the English term *source-separation* has been used analogously with source-separation of solid waste. The term used throughout this chapter is *urine diversion* and *urine-diverting toilets*.

2.1 Urine diversion in Sweden

In Sweden porcelain urine-diverting toilets were introduced in the beginning of the 1990s. At present there are three models on the market that use flushwater. A number of dry toilets that divert urine from faeces and add-ons to simple dry toilets used in summer houses are also available.

(a) (b) (c)

Figure 3. *Urine-separating toilets originating from Sweden. (a) Model DS from Wost Man Ecology AB; (b) Dubbletten™ from BB Innovation & Co AB; (c) Nordic 393U from Gustavsberg.*

There is either a separate flushing mechanism for the urine and faeces or the flush rinses both bowls. The faeces may also be collected dry for composting. The urine is usually collected in a tank placed underground or in a basement under the house. When the tank is full the urine is transported to a farm for later use as a fertiliser on agricultural land. Before its utilisation the urine is stored either in the housing area or near the field (Figure 4). For individual households the urine may also be utilised in the garden directly from the collection tank, without separate storage. Investigations were conducted on both small-scale and large-scale systems.

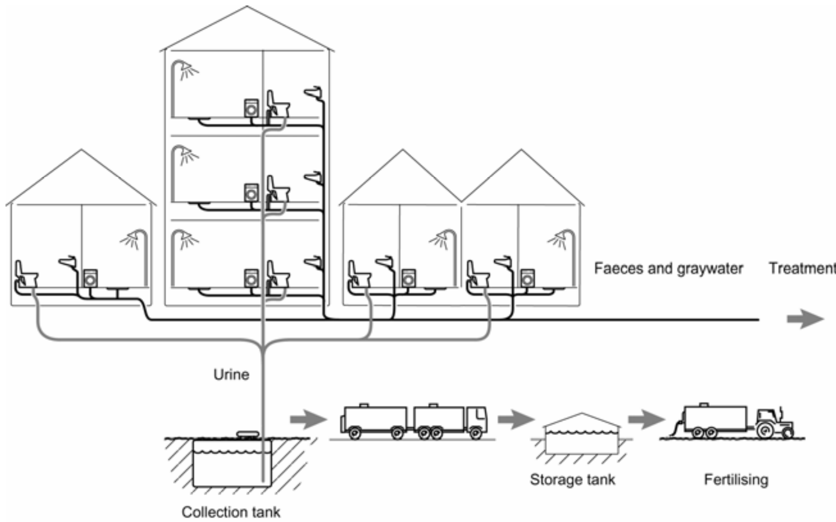
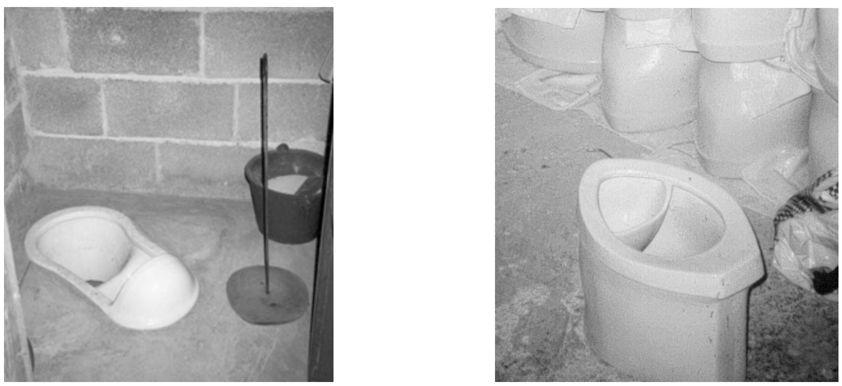


Figure 4. *A large-scale urine-separating wastewater system (from Jönsson et al. 2000).*

Research presented in this chapter was conducted on both small-scale and large-scale systems using the toilets Dubbletten™ or Wost Man Ecology DS or ES.

2.2 Source-separation of urine in other parts of the world

Dubbletten™ and Wost Man Ecology's toilets are marketed in several European countries and in the USA. The old tradition of using human excreta in agriculture is still practised in China and new types of toilets that separate urine from faeces are also being introduced on a large scale (www.ecosanres.org). In Vietnam various types of dry latrines (double-vault and bucket latrines) with urine-separation are in use, although without complete utilisation of the urine (Carlander and Westrell 1998; Esrey *et al.* 1998). These have been promoted since 1956 followed by health education programmes to ensure safe reuse of the faeces (Esrey *et al.* 1998). In India a demonstration area has been built in Kerala with toilets that separately collect the urine and the water used for anal cleaning into an evapo-transpiration reedbed (Esrey *et al.* 1998; Calvert 1999). In Mexico around 100 000 separating toilets made of cement have been distributed, however only part of them along with necessary education in health and maintenance for the users (Clark 1997). Dry urine-separating toilets are also in use in Central America, often provided with a separate urinal (Gough 1997; Esrey *et al.* 1998). Several projects are on-going in Africa, e.g. in Zimbabwe, in Kenya and in Ethiopia (Ahlgren and Evjen 1999; Faul-Doyle 1999; Morgan 1999; Sundin 1999; SUDEA 2000).



(a) (b)

Figure 5. *Urine-separating toilets in (a) China and (b) Mexico.*

2.3 Ecological Sanitation

Ecological sanitation involves treating human excreta as a resource, sanitising them and then recycling the nutrients contained in the excreta (Esrey et al. 1998). In developing countries ecological sanitation often refers to a dry system where the urine is diverted from the faeces. The Swedish International Development Cooperation Agency (Sida) is promoting ecological sanitation including the "don't mix" approach to human excreta, since a lot can be gained in health and nutrient resources compared to e.g. traditional pit latrines (Winblad 1996). Furthermore, it is impossible to provide the whole world with sewers and wastewater treatment (Winblad and Kilama 1985; WRI 1996). Currently it is estimated that approximately 2.4 billion people are lacking safe sewage disposal (WHO 2002) and that less than 10% of the wastewater in developing countries are treated (WRI 1996). With the current growth in World population (UNFPA 1999) the sewage problem will increase and alternative solutions are necessary.

3. URINE AS A FERTILISER IN AGRICULTURE

3.1 Characteristics of diverted human urine

Collected diverted human urine (urine mixture) has different characteristics than freshly excreted urine since it sometimes is mixed with flushwater and often transported through pipes to a tank or small container. In Sweden most collection tanks are placed outdoors, usually buried underground. The temperature generally varies between 3°C and 19°C depending on climate and season. The pH of fresh urine is normally between 4.8 and 7.5 but after collection it is around 9.0. When urine is excreted, the major fraction of the nitrogen is present as urea and in the pipes this is converted to ammonium. The pH is related to the concentration of ammonium.

The amount of flushwater used for the urine bowl depends on the type of toilet used. The volume of collected urine mixture (urine + flushwater) was measured along with the concentration of plant nutrients. The nitrogen content was measured to 2.5 - 3.5 g/l, with more than 95% present as ammonium, and the phosphorous content was 0.3 g/l (Jönsson *et al.* 2000). Since the concentration of nitrogen in fresh urine is around 7 g/l a dilution of 1-2 parts of water per part urine was common.

Mass balance exists over the human body also for plant nutrients. This means that the same amount of nitrogen, phosphorous, potassium and sulphur that is consumed with the diet also is excreted, and this excretion is almost entirely with the urine and faeces. During adolescence this is not completely true, since some substances is accumulated in our growing bodies. Calculations show however that this accumulation is negligible, as it has been calculated to be less than 2% of the consumed nitrogen between the ages 3 and 13.

This mass balance means that the flow of nutrients with the urine, and the concentrations of nutrients in the urine, varies with the diet, and thus varies between countries and individuals (Table 1).

Table 1. *Excretion of N, P and K for Sweden 1992 (Swedish EPA, 1995) and estimated from food consumption (FAO, 2001) for Kenya 1996. Concentrations of nutrients in urine calculated assuming 1.5 litres of urine per person and day in parenthesis*

	Nitrogen [kg/person, year (g/l)]	**Phosphorous** [kg/person, year (g/l)]	**Potassium** [kg/person, year (g/l)]
Sweden, urine	4.0 (7.3)	0.37 (0.7)	0.9 (1.7)
Sweden, faeces	0.6	0.18	0.4
Kenya, urine	2.1 (3.8)	0.23 (0.4)	0.8 (1.5)
Kenya, faeces	0.3	0.12	0.3

3.2 Collection and storage of the urine – developing countries

Only rarely is flush water used in urine diverting systems in developing countries, which means that the concentration of nutrients probably is of the same order as in the Swedish urine mixture. For maintenance and investment reasons it is recommended to minimise the amount of piping used for collection of the urine. Sometimes the piping can be eliminated, otherwise it should be kept very short. This means that the urea often will not have time to degrade during the short and rapid pipe transport. This degradation is desirable, since it raises the pH to around 9 and thus enables hygienisation of the urine (see Section 6). One way of supporting the degradation of urea in the collection container is to avoid to wash this when it has been emptied. Instead, bottom sludge should be allowed to accumulate since this contains urease, the enzyme active in the degradation of urea. Addition of some (2-3 table spoons) of good fertile garden soil into the collection container might help to start up the process.

The urine can be collected in ordinary jerricans or, if this is more suitable, in large tanks. If ordinary jerricans are used, separate storage during a few days is easy to arrange. Instead of having just one jerrican, two or more are included in the system. When the collecting jerrican is full, the urine which has been stored the longest is used for fertilisation. When the jerrican has been emptied, it is again used for collection, while the just full one is closed and placed for storage.

The ventilation of the collection and storage system should be kept at a minimum, to prevent losses of nitrogen in the form of ammonia and to prevent odour problems. No storage is needed to fertilise crops within the same household collecting the urine, as long as crops are not harvested within a month of fertilisation (see Section 8). In this case the risk of direct disease transmission within the household, via hand contact etc. is far larger than that via fertilisation with urine.

3.3 Urine as a fertiliser

The pH effect of fertilising with urine is small. When excreted, the pH of urine is around 6-7. The degradation of urea to ammonium/ammonia raises the pH to around 9 (Equation 1).

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^- \qquad (1)$$

In the soil the ammonium is nitrified, releasing two protons (Equations 2 and 3), thus acting as an acid

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 1\ H_2O + 2\ H^+ \qquad (2)$$

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \qquad (3)$$

Finally, when taking up the nitrate ion from the soil liquid, the root emits a hydroxide ion. In summary, in the urea degradation one hydroxide ion is released, in the nitrification two protons and in the plant uptake one hydroxide ion again. Thus, in total two protons and two hydroxide ions are released, which means that the net effect on the soil pH is small.

The nutrient balance and content of the urine well reflects what the crops have removed from the fields and thus the average need of fertilisation. The reason for this is that urine contains far more nutrients than the faeces and together urine and faeces contain the same amount of plant nutrients as the food. This means that the nutrient content and balance of the urine is similar to that of the consumed food. Since the nutrients of the food have been removed from the fields, they also show the amount of nutrients needed to not deplete the field. This is true for all nutrients and thus for the balance between them.

The nutrients in urine are in forms which are readily plant available. The nitrogen is in the form of urea, which readily degrades to ammonium and nitrate that both are plant available.

The phosphorous is mainly in the form of phosphate ions, the potassium in the form of potassium ions and the sulphate in the form of sulphate ions. This means that they all are in forms which readily are taken up by plants. This makes urine a unique biologic fertiliser. In most biologic fertilisers, like compost, the nutrients are mainly in organic form and these have to be mineralised before the nutrient becomes plant available. This is especially true and important for nitrogen, the nutrient which in most farming systems limits the harvest the most and which gives the largest response when supplied.

Ammonia in high concentrations is toxic to all living cells and this is utilised to sanitise the urine during storage (Section 6). Also nitrite (NO_2^-), an intermediate product formed in the nitrification of the urine, is toxic to most living cells. Both ammonia and nitrite can be toxic to plants. This means it is an advantage if the fertilisation is done a few days before seeding. The plants can also be fertilised later on, but the urine should not be applied on the plants, because the ammonia content of the urine might burn the them, neither should it be applied so close to the plants that most of the roots are soaked. If all the roots are soaked, the plant might die during that short period when most of the nitrogen is in the form of nitrite. Instead, the urine should be applied a small distance from the plants, but still close enough for the roots of the plants to reach the nutrients.

3.4 Crops to fertilise

Urine is a complete fertiliser with high concentrations of plant available nitrogen. Therefore, the fertilising response is especially good for crops which normally are very limited by the supply of nitrogen. Examples of such crops are cereals like maize, rice, millet, sorghum and wheat. Also, vegetables like chard, turnip, carrots and cale ought to give a good response and so should fruits and bushes, like banana, paw-paw, oranges, tea and coffee.

Initially, until we have more experience, it might be wise to not primarily fertilise crops known to be sensitive to ammonia (like beans and clover), nitrite, sodium or chloride (like Irish potatoes, tomatoes, strawberries and cucumber), which also are prevalent in fairly high concentrations in urine. To avoid burns on the plant and on the roots and to avoid loss of nitrogen in the form of ammonia, the urine should be applied on the soil and directly be incorporated into it. The urine is preferably applied in small holes or groves either before planting or a short distance (~20 cm) from the plant. To avoid ammonia loss and to decrease the hygienic risk the grove or hole is closed as soon as the urine has soaked into the soil or alternatively water is applied to the hole or grove soon after fertilisation, to flush the remaining urine and ammonia into the soil. It is advantageous and saves labour if the urine is utilised without dilution. It is also advantageous to apply water after fertilisation to better flush the urine into the soil.

The equipment used for fertilising with urine is normally very simple. Often the urine can be poured from the jerrican directly. However, it is an advantage if a flexible hose is connected to the opening, to increase precision in application and to prevent splashing. If the urine is fetched from a big tank, watering cans can be used, and if the operation is to be mechanised the normal tankers for spreading slurry can be used.

3.5 Dosage

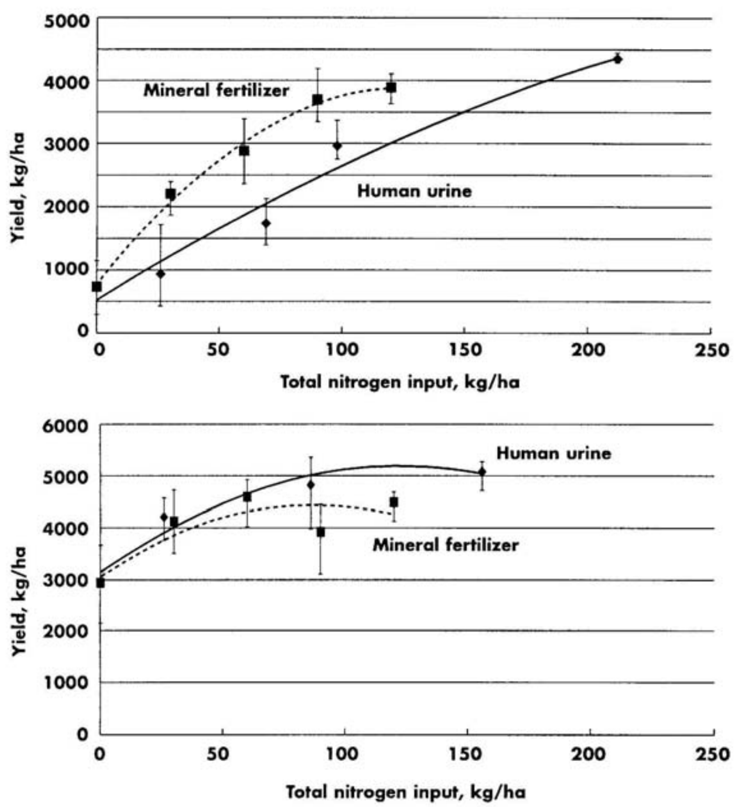
The fertilising effect of nitrogen in the form of urine has is Swedish experiments with cereals on average been approximately 90% of that of the same amount of nitrogen in the form of chemical fertiliser (Section 3.6). This means that results from experiments done with chemical fertilisers can be used when the application rate is to be decided upon.

If no such experiments are available, a very crude rule of thumb for many crops can be that the urine from one person during one day (1-1.5 litres/day) should be applied to about 1 m^2, if the maximum fertilising effect is desired. This will usually mean a nitrogen application rate of somewhere between 40 and 120 kg/ha and most crops respond well to application rates in this range. However, if the space is limiting, at least for some cereals, like maize, and some fruit trees the application rates can be increased by a factor of three to five. For these crops the yield normally increases with the dosage, even if not proportionally.

3.6 Fertilising experiments

Many fertilising experiments with urine have been performed, however only few of these have been well planned, performed and documented.

Based on two pot experiments (Kirchmann & Pettersson, 1995; Kvarmo, 1998) and a three year field experiment (Figure 6; Richert Stintzing *et al.*, 2001) it has been concluded that the nitrogen effect of source separated urine, is 85-95% of the effect of the corresponding amount of nitrogen in chemical fertilisers. In these experiments, the total amount of nitrogen in the urine has been compared to the total amount of nitrogen in chemical fertilisers.



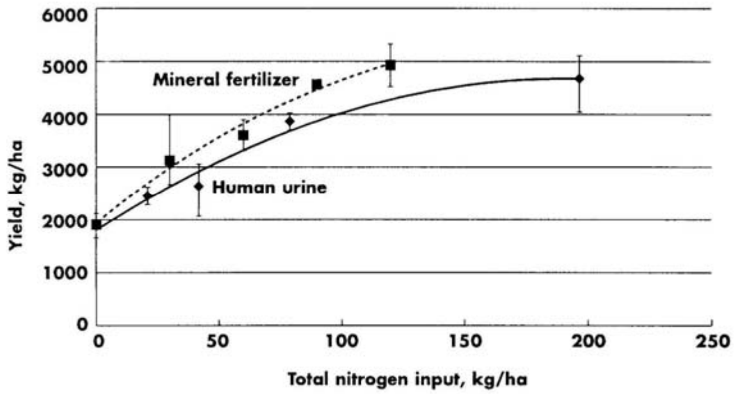


Figure 6. *Barley yields in plots fertilised with diverted human urine compared to plots fertilised with mineral fertiliser. At the top 1997, below that 1998 and at the bottom 1999 (from Johansson et al., 2001).*

Kirchmann & Pettersson (1995) also investigated the phosphorous effect of source separated human urine. They found this to be as good, or better, than that of chemical fertilisers.

In experiments in Ethiopia Sundin (1997) compared the yield of urine fertilised Swiss chard to the yield without any fertilisation. She found the yield to be on average 3.9 times higher for the fertilised plants than for the unfertilised ones. Interesting experiments have been performed also in many other countries, for example in Zimbabwe and Uganda. However, so far we do not have results from these experiments.

3.7 Acceptance

Of crucial importance also is the acceptance of urine as a fertiliser by the market. At present the EU does not include human urine on the list for approved fertilisers in organic farming, where it would probably be of best use. The Swedish association for organic farming (KRAV) follows the EU regulations, whereas the International Federation of Organic Agriculture Movements (IFOAM) allows urine (and faeces) if sanitary requirements are met (IFOAM 2000). These requirements should be established by standardising organisations.

4. PATHOGENIC MICROORGANISMS IN URINE

In a healthy individual the urine is sterile in the bladder. When transported out of the body different types of dermal bacteria are picked up and freshly excreted urine normally contains <10 000 bacteria per ml (Tortora *et al.* 1992). By urinary tract infections, which in more than 80% of cases are caused by *E. coli* (Murray *et al.* 1990), significantly higher amounts of bacteria are excreted. However, these have not been reported to be transmitted to other individuals through the environment. Pathogens causing venereal diseases may occasionally be excreted in urine but there is no evidence that their potential survival outside the body would be of health significance (Feachem *et al.* 1983).

The pathogens traditionally known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and *Schistosoma haematobium* (Feachem *et al.* 1983).

Leptospirosis is a bacterial infection causing influenza-like symptoms and is in general transmitted by urine from infected animals (Feachem *et al.* 1983; CDC 2000a). It is considered an occupational hazard e.g. for sewage workers and for farm workers in developing countries (CDC 2000a). In tropical and subtropical climates it is an important disease in domestic animals both for the risk for humans and due to economical losses. It is a severe disease with a 5-10% mortality (Olsson Engvall and Gustavsson 2001). The bacteria survive for several months in still freshwater and moist environments at neutral pH and temperatures around 25°C (Olsson Engvall and Gustavsson 2001). Leptospiras from urine-contaminated environments, such as water and soil, enter the host through the mucous membranes and through small breaks in the skin. Human urine is not considered to be an important route for transmission since the prevalence of the infection is low (Feachem *et al.* 1983; CDC 2000a).

Infections by *S. typhi* and *S. paratyphi* only cause excretion in urine during the phase of typhoid and paratyphoid fevers when bacteria are disseminated in the blood (Feachem *et al.* 1983). This condition is rare in developed countries (Lewis-Jones and Winkler 1991). Even though the infection is endemic in several developing countries with an estimated 16 million cases per year urine-oral transmission is probably unusual compared to faecal-oral transmission (Feachem *et al.* 1983; CDC 2000b).

Schistosomiasis, or bilharziasis, is one of the major human parasitic infections mainly occurring in Africa (Feachem *et al.* 1983). When infected with urinary schistosomiasis caused by *Schistosoma haematobium*, the eggs are excreted in urine, sometimes during the whole life of the host. The eggs hatch in the environment and the larvae infect specific aquatic snail species, living in fresh water. After a series of developmental stages aquatic larvae emerge from the snail, ready to infect humans through penetration of the skin (Feachem *et al.* 1983). The disease does not occur in Europe or in the US (CDC 2000c).

Mycobacterium tuberculosis and *Mycobacterium bovis* may be excreted in urine (Bentz *et al.* 1975; Grange and Yates 1992) but tuberculosis is not considered to be significantly transmitted by other means than by air from person to person (CDC 1999a). *M. tuberculosis* is exceptionally isolated in nature, but was identified in wastewater coming from hospitals (Dailloux *et al.* 1999). Humans are able to infect cattle with both the bovine strain and the human strain and it has been reported that individuals on farms have transmitted bovine tuberculosis to cattle by urinating in the cowsheds (Huitema 1969; Collins and Grange 1987). Feachem *et al.* (1983) doubts that transmission of either human or bovine tuberculosis is significantly affected by exposure to wastes or polluted water. Other mycobacterial species (atypical or environmental mycobacteria) may also be isolated from urine. They are also widely distributed in the environment and commonly found in waters, including as contaminants in drinking water (Grange and Yates 1992; Dailloux *et al.* 1999).

Microsporidia are a group of protozoa recently implicated in human disease, mainly in HIV-positive individuals (Marshall *et al.* 1997; Cotte *et al.* 1999). The infective spores are shed in faeces and urine, and urine is a possible environmental transmission route (Haas *et al.* 1999). Microsporidia have been identified in sewage and in waters, but no water- or foodborne outbreaks have been documented although they have been suspected (Cotte *et al.* 1999; Haas *et al.* 1999).

Cytomegalovirus (CMV) is excreted in urine, but the transmission of CMV occurs person to person and the virus is not considered to be spread by food and water (Jawetz *et al.* 1987;

CDC 1999b). CMV infects a large proportion of the population, 50-85% by the age of 40 was reported for the USA (CDC 1999b). Two polyomavirus, JCV and BKV, are excreted in urine (Bofill-Mas *et al.* 2000). Both have been found in sewage in various countries, including Sweden. Even though the occurrence in waste products enables transmission to other humans in the environment, a majority of the population will be infected by close contact within the family or outside the family at a young age (Kunitake *et al.* 1995; Bofill-Mas *et al.* 2000). In one Japanese investigation it was found that 46% of persons aged 20-29 years excreted urinary JCV (Kitamura *et al.* 1994). One foodborne outbreak of hepatitis A caused by lettuce contaminated by urine has been reported (Ollinger-Snyder and Matthews 1996). Hepatitis B was also found in human urine and urine was suggested as a potential route of transmission in hyperendemic areas (Knutsson and Kidd-Ljunggren 2000). Adenovirus may also be excreted in urine, especially from children with hemorrhagic cystitis, transplant patients and HIV-positive individuals (Mufson and Belshe 1976; Shields *et al.* 1985; Echavarria *et al.* 1998). However, the public health concern from urinary transmission has not been recognised.

It can be concluded that pathogens that may be transmitted through urine are rarely sufficiently common to constitute a significant public health problem and are thus not considered to constitute a health risk related to the reuse of human urine in temperate climates. An exception in tropical areas is *Schistosoma haematobium*, which however implies a low risk due to its lifecycle. Furthermore, the inactivation of urinary excreted pathogens in the environment reduces their ability for transmission.

Table 2. *Pathogens that may be excreted in urine and the importance of urine as a transmission route*

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	-

5. FAECAL CONTAMINATION

Environmental transmission of urinary excreted pathogens is of limited concern in temperate climates, but any faecal cross-contamination that may occur by misplacement of faeces in the urine-diverting toilet is regarded as a possible health risk. Also in tropical climates contamination by faeces may be considered as the greatest risk but urinary-transmitted pathogens also need to be considered. To estimate the risk of pathogen transmission during handling, transportation and reuse of diverted urine, the amount of faecal material contaminating the urine fraction was determined by analysing various indicators in the urine mixture, i.e. the collected urine and flushwater.

5.1 Analysis of indicator bacteria to determine faecal contamination

The concentrations of different groups of indicator bacteria (see below) were determined in samples from urine collection tanks (Höglund *et al.* 1998). A total of fifteen tanks were sampled and samples were collected from the upper part of the liquid (referred to as urine samples) and from the bottom, where a sludge layer had formed (referred to as sludge samples).

Total coliforms were found in varying concentrations with a mean of 260 colony-forming units per ml (CFU/ml; median 21 CFU/ml). *E. coli* was seldom found; in 84% of the samples the concentration was below the applied detection limit of 10 CFU/ml. Clostridia spores were also found in varying concentrations, ranging from <1 to 2 000 CFU/ml. Faecal streptococci occurred in high and varying concentrations with 76% of the samples having concentrations above 1 000 CFU/ml and 16% >100 000 CFU/ml. The concentrations in the sludge samples were generally higher than in the urine samples from the upper part of the tanks. In Figure 7 the median and maximum concentrations for the different indicator bacteria in urine and sludge samples are compared. The results from the different sampling rounds gave comparable results, indicating unit specific variation.

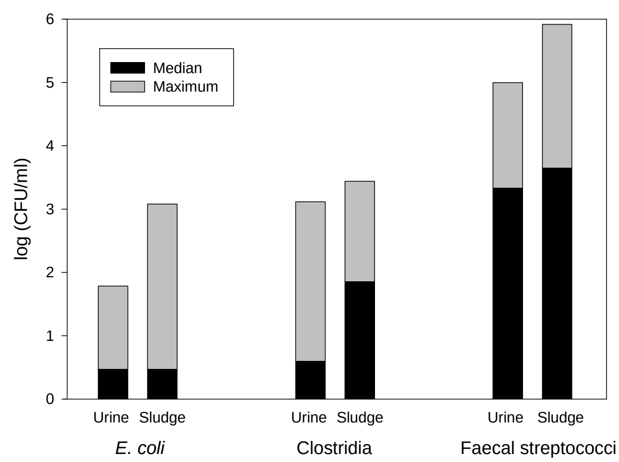


Figure 7. *Median and maximum concentrations of E. coli, clostridia and faecal streptococci in urine and sludge samples. The median values for E. coli were below the detection limit (<10 CFU/ml).*

The varying results implied that indicator organisms normally used in water quality analysis are not suitable for this type of sample. The value of total coliforms as a faecal indicator is small since the bacteria may emanate from sources other than faecal contamination, e.g. from the technical system itself. *E. coli* was seldom found, which was later explained by its short survival in urine (see Section 6.1), making it unsuitable as an indicator for faecal contamination. Clostridia spores were persistent but are only excreted by 13-35% of the population and are therefore less suitable for quantification of faecal contamination. In some samples the concentration of faecal streptococci corresponded to 100% faeces, a degree of contamination that would be impossible and not indicated by *E. coli* or clostridia. The high concentration of faecal streptococci in the collection tanks may be explained by a growth within the system or in the biofilm in the pipes.

5.2 Analysis of faecal sterols to determine faecal contamination

As an alternative or complement to microorganisms in detecting faecal contamination chemical biomarkers have been suggested as indicators. The most widely studied biomarkers are probably coprostanol and structurally related faecal sterols (Vivian 1986). These compounds are metabolites of cholesterol formed in the intestine and excreted in faeces. One advantage compared to bacterial analysis is that samples can be analysed after some time of storage. However, rather sophisticated and complex equipment is needed.

Urine and sludge samples that contained faecal matter from cross-contamination were identified through analysis of various faecal sterols and calculated ratios of these sterols (Schönning *et al*. in press). Eight out of 36 (22%) urine samples indicated episodes of faecal cross-contamination (Figure 8; Group A). Furthermore, two indeterminate samples (Group C) were after further investigation re-assigned to contaminated. In tanks where the urine was found to be contaminated, it was possible to calculate the amount of faecal matter still in suspension. Using an average value of 4 μg coprostanol per mg faeces, contamination was calculated to vary between 1.6 and 18.5 mg of faeces per l urine mixture with a mean of 9.1 ± 5.6 mg/l.

Faecal contamination was more often evident in sludge samples collected from the bottom of the tanks, which probably reflects accumulation of past contamination. Eleven out of 30 sludge samples (37%) were contaminated. However, it is not feasible to calculate an accurate average faecal contamination over time because the sludge layer is partly retained within the tanks after emptying.

It was clear that once faecal contamination became apparent via the sterol profile, coprostanol concentrations were all above 5 μg/l (Figure 8). Similarly in the sludge samples, the contaminated faecal sterol profile became evident at coprostanol concentrations over 155 μg/g. These results suggest that in the majority of cases a coprostanol threshold might be sufficient to determine faecal cross-contamination. However, the ratio criteria remains the most reliable method for determining the presence of human faecal contamination and a valuable check for borderline samples.

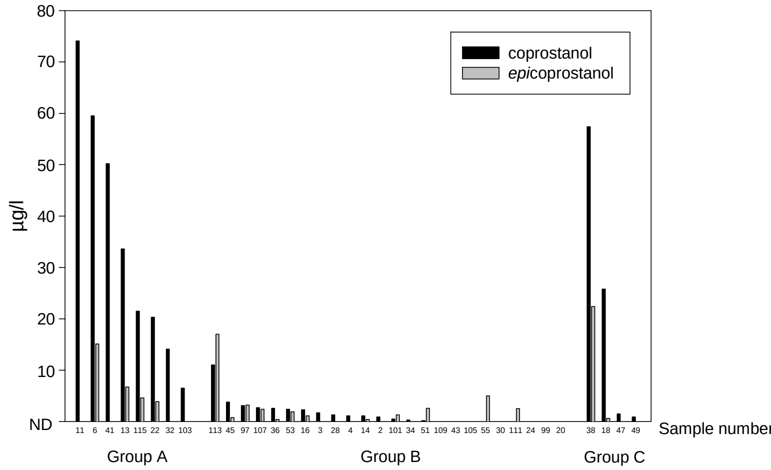


Figure 8. *Coprostanol and epicoprostanol concentrations in urine samples from collection tanks sorted into groups A = contaminated, B = uncontaminated and C = indeterminate by criteria based on sterol ratios and by concentrations of coprostanol.*

Six out of fifteen systems showed signs of recent faecal contamination on at least one of the sampling occasions (urine samples) and a further three systems had had previous cross-contamination episodes significant enough to be detected (sludge samples). Since a larger proportion of the samples collected from eco-village and public places were contaminated compared to individual households it is suggested that there is a greater risk of contamination the more users that are connected to a tank.

5.3 Discussion

In summary, the various indicator bacteria implied different degrees of faecal contamination if evaluated according to their normal abundance in faeces, which in further investigations partly could be explained by different growth and survival characteristics (Jönsson *et al.* 2000). It was concluded that none of the commonly used indicator bacteria were suitable to quantify faecal cross-contamination in diverted urine. Further evaluation of the faecal streptococci might however be valuable in systems with shorter pipes to see if a growth occur in thee type of systems as well. Faecal sterols seem to be more suitable for detecting and quantifying faecal cross-contamination. If only coprostanol is analysed there will be an overestimation of contamination whereas if the coprostanol concentration is compared to other faecal sterols (ratios), false positives can be avoided. Analysis of faecal sterols are time consuming and require sophisticated equipment. Some cross contamination may instead be accounted for when estimating health risks and suggesting routines for handling and reusing urine both in developed and developing countries (see section 7 and 8). No correlation was found between coprostanol and indicator bacteria, which is probably a consequence of the varying survival and growth characteristics of the indicator bacteria in contrast to the stability of coprostanol.

6. PERSISTENCE OF MICROORGANISMS IN URINE

The fate of the enteric pathogens entering the urine tank is of vital importance for the hygiene risks related to the handling and reuse of the urine. To determine the duration and conditions for sufficient storage of the urine mixture before its use as a fertiliser, it is therefore necessary to estimate the survival of various microorganisms in urine as a function of time. Temperature, dilution, pH and ammonia were the parameters considered that may affect the persistence of microorganisms in urine tanks. The technical design of the urine-diverting system, e.g. flushing and storage procedures, may also have an influence.

6.1 Survival of bacteria

Survival studies of bacteria in urine were performed at 4°C and 20°C. Their persistence was also investigated at some different dilutions of the urine and at different pH-values. Bacteria were added or originally present in the urine mixture. At different time intervals the bacteria were enumerated and T_{90}-values (time for 90% inactivation) for the different organisms were then estimated (Table 3; Höglund *et al.* 1998).

The short survival of *E. coli* in urine makes it unsuitable as an indicator for faecal contamination. Gram-negative bacteria such as *Campylobacter* and *Salmonella* cause a majority of gastrointestinal infections. All bacteria belonging to this group were inactivated rapidly in urine mixture, indicating a low risk for transmission of gastrointestinal infections caused by bacteria when handling diverted urine. The Gram-positive faecal streptococci had a longer survival and the spore-forming clostridia were not reduced at all during a period of 80 days (Figure 9).

Table 3. *Results from survival studies on bacteria in source-separated human urine. Die-off values given as T_{90}-values, i.e. time for a 90% reduction, in days. Estimations was needed when the die-off was rapid or when analysis of the inactivation curves was difficult (resulting in < values)*

Parameter investgated		***Escherichia coli***	***Salmonella senftenberg***	***Salmonella typhimurium***	***Pseudomonas aeruginosa***	***Aeromonas hydrophila***	**Faecal streptococci**
pH							
	4.5	<1	<1	<1	<1	<1	4
4°C	6.0	5	<3	<3	<3	<3	
	8.9	<1	<3	<3	<3	<3	30
	10.5	<1	<1	<1	<1	<1	<1
	4.5	<1	<1	<1	<1	<1	
20°C	6.0	5	<3	<3	<3	<3	
	8.9	<1	<3	<3	<3	<3	5
	10.5	<1	<1	<1	<1	<1	
Dilution							
	undiluted	3	<1	<1	<1	<1	<35
4°C	1:1	<5	<1	<1	<1	<1	<35
	1:9	14	<20	<20	<20	<20	<35
	undiluted	1	<1	<1	<1	<1	7
20°C	1:1	<5	<1	<1	<1	<1	
	1:9	5	<20	<20	<20	<20	19

A lower temperature and a higher dilution involved a longer survival of most bacteria. pH-values the furthest from neutral had the most negative effect on survival of the organisms. At pH 6 most of the bacteria had a better survival than at pH 9. The reduction of bacteria at high pH-values may be an effect partly of the pH and partly of the presence of ammonia.

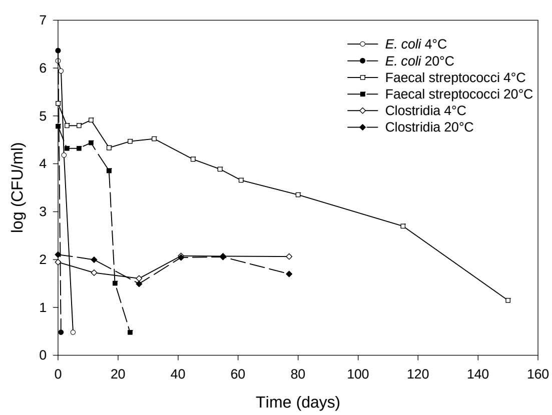


Figure 9. *Inactivation of E. coli, faecal streptococci and C. perfringens spores (clostridia) in diverted human urine (pH 9) at 4°C and 20°C.*

6.2 Survival of protozoa

Cryptosporidium parvum is known to be persistent in waste products as well as in water and to be resistant to disinfectants (Meinhardt *et al.* 1996) and was chosen as a representative to study the survival of protozoa in urine (Höglund and Stenström 1999). The inactivation in buffers was investigated as a comparison to evaluate the effect of pH. Two different *in vitro* viability methods, excystation (Robertson *et al.* 1993) and inclusion or exclusion of the vital dyes DAPI and PI (Campbell *et al.* 1992) were used.

In urine mixture at pH 9 and 4°C, the oocysts were inactivated to below the detection limit (<1/300) within 63 days according to both dye exclusion (Figure 10) and excystation. The T_{90}-value for *Cryptosporidium* was determined at 29 days according to the dye permeability assay. At 20°C the T_{90} was estimated at 5 days.

By pairwise comparisons of the inactivation coefficients (*k*) it was shown that the inactivation rate of *Cryptosporidium* oocysts in urine at pH 9 was significantly higher ($p < 0.01$) than in the controls and in urine at pH 5 and pH 7, according to the dye permeability assay. In buffer solutions (pH 5, 7 and 9) there were no significant differences in inactivation rate between pH-values for methods and T_{90}-values ranged from 115 to 168 days. When correlating urine samples with the corresponding buffer samples it was only at pH 9 that the inactivation rate was significantly higher ($p < 0.01$) in urine.

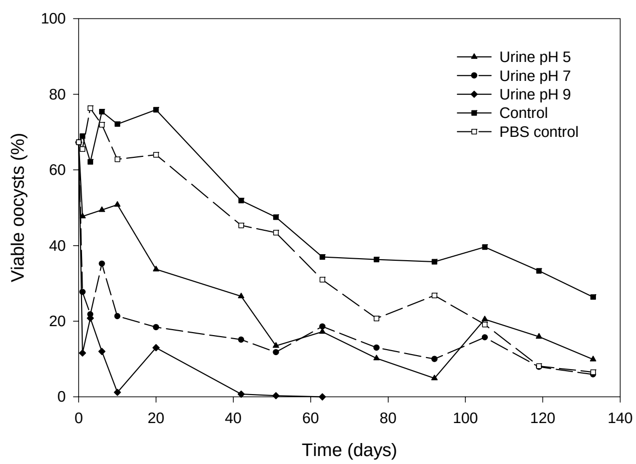


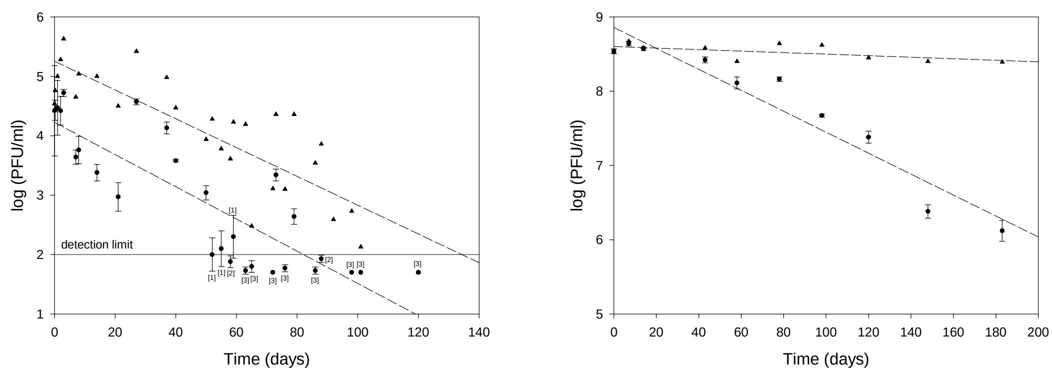
Figure 10. *Inactivation of Cryptosporidium parvum oocysts in diverted human urine with different pH values at 4°C, assessment of viability performed by dye permeability assay with DAPI and PI. Control is oocyst stock solution and PBS control is oocysts in Phosphate Buffered Saline, pH 7.4.*

The overall results indicated that the inactivation of *Cryptosporidium* oocysts is more rapid in diverted urine than in controls and that pH alone does not have an effect on oocyst viability. The results thus indicated that the antiprotozoan effect of urine at pH 9 is mediated by other factors besides the actual pH. Ammonia (NH_3) has been demonstrated to act as an inactivating agent for *Cryptosporidium* (Jenkins *et al.* 1998). The concentration of free ammonia (NH_3) in the urine (pH = 9; T = 4°C) was around 0.03 mol/l (Höglund and Stenström 1999). Thus it is likely that ammonia present in the urine mixture may have an effect on the inactivation of the oocysts.

6.3 Survival of viruses

To investigate virus inactivation during storage of diverted human urine, *rhesus* rotavirus (RRV) and *Salmonella typhimurium* phage 28B (phage 28B) were chosen as viral models and their persistence was followed during a period of six months at 5°C and 20°C (Höglund *et al.* in press *a*). Rotaviruses were enumerated as peroxidase stained plaques in infected MA-104 cell monolayers (reported as PFU/ml). Phage 28B was quantified by the double agar layer method. The inactivation of RRV and phage 28B were assumed to follow first order kinetics and the inactivation rate, *k* (log_{10} inactivation per day), was determined as the slope of the inactivation curves.

In summary, no significant inactivation of either rotavirus or the phage occurred at 5ºC during six months of storage, while the mean T_{90}-values at 20ºC were estimated at 35 and 71 days for rotavirus and the phage, respectively (Figure 11). In pH-controls (pH 7), the inactivation of rotavirus was similar to that in urine at both temperatures, whereas no decay of the phage occurred at either 5ºC or 20ºC. Rotavirus inactivation therefore appeared to be largely temperature dependent, whereas there was an additional virucidal effect on the phage in urine at 20ºC (pH 9).



(a) (b)

Figure 11. *Inactivation of (a) rhesus rotavirus and (b) Salmonella typhimurium phage 28B in diverted human urine (●) and control medium (▲) at 20°C. For urine each data point is a mean of triplicate samples (three counts for each sample), error bars represent one standard deviation. For the control the data points represent one sample (mean of three counts). The dashed lines are generated from linear regression. Numbers in brackets (a) indicate the number of samples that were below the detection limit on the day of analysis.*

6.4 Discussion

For diverted human urine mainly temperature, pH and ammonia were considered. The presence of other microbes, available oxygen and, for bacteria, available nutrients, will most certainly have an effect on microbial behaviour in the urine as well. Gram-negative bacteria were rapidly inactivated. Oocysts of the protozoa *Cryptosporidium parvum*, which are known to be resistant to environmental pressures, were reduced by approximately 90% per month in the urine mixture. Viruses were the most persistent group of microorganisms with no inactivation in urine at 5°C and T_{90}-values of 35-71 days at 20°C. Temperature seemed to affect all microorganisms investigated and may be considered the most important parameter (results are summarized in Table 4). For bacteria further dilution of the urine prolonged the survival, which may be due to lower concentrations of harmful compounds. The effect of pH is difficult to separate from the effect of ammonia, except for *C. parvum* oocysts where there was no difference in inactivation in buffer solutions with pH 5, 7 and 9 and thus an additional impact of ammonia or other compound in the urine was verified. Rotavirus was neither affected by pH nor ammonia since the inactivation in buffer (pH 7) was similar to that in urine. According to Hamdy *et al.* (1970, in Feachem *et al.* 1983) urine is ovicidal and *Ascaris* eggs are killed within hours. Olsson (1995) however reported the reduction of *Ascaris suum* in urine to be minor. The investigations of *Ascaris suum* in 4°C and 20°C indicated a reduction of 15-20% during a 21-day period. Early studies also reported inactivation of *Schistosoma haematobium* in urine (Porter 1938, in Feachem *et al.* 1983). Further studies of helminths including *Ascaris* is necessary, especially if the system is to be promoted in developing countries.

Table 4. *Summarised results from the survival experiments, given as T_{90}-values (time for 90% reduction), for further details see text*

	Gram-negative bacteria	Gram-positive bacteria	*C. parvum*	Rhesus rotavirus	*S. typhimurium* phage 28B
4°C	1	30	29	172[a]	1 466[a]
20°C	1	5	5	35	71

[a] survival experiments performed at 5°C

7. MICROBIAL RISK ASSESSMENT OF URINE-DIVERTING SYSTEMS

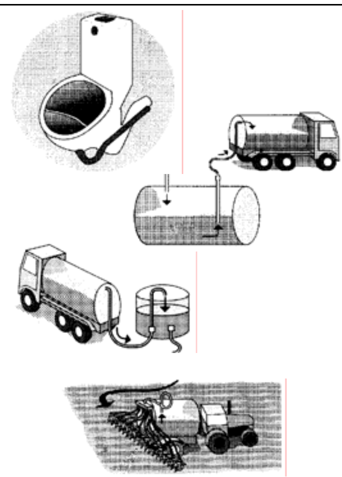
7.1 Quantitative Microbial Risk Assessment

Quantitative Microbial Risk Assessment (QMRA) is a tool used to predict the consequences of potential or actual exposure to infectious microorganisms (Haas *et al.* 1999). Microbial risk assessments were first developed for drinking waters (Regli *et al.* 1991) and have later been applied to practices such as irrigation of crops. An advantage of QMRA is that it allows prospective studies. QMRA starts by a problem formulation where all the transmission routes and pathogens of interest are identified. It then assesses the dose of a certain pathogen to which an individual may be exposed and uses this dose in a dose-response model to calculate the probability of infection. Dose-response experiments for bacteria, protozoa and viruses have been conducted with healthy volunteers where they are fed known doses of a pathogen (e.g. DuPont *et al.* 1995). Risks may finally be characterised by taking into consideration the frequency of the exposure events for the range of pathogens studied, to estimate a total risk.

7.2 Exposure scenarios – example from a developed country (Sweden)

The assumptions used in the QMRA were often conservative, i.e. values giving a higher risk were chosen. Thus, results include maximum risks, which is a way to apply to the precautionary principle. *Campylobacter jejuni*, *Cryptosporidium parvum* and rotavirus were chosen as representatives for various microbial groups, i.e. bacteria, protozoa and viruses.

The transmission pathways investigated included accidental ingestion of unstored urine, either by cleaning blocked urine pipes or from urine in the collection tank; accidental ingestion of stored urine; inhalation of aerosols while spreading the urine; and ingestion of crops contaminated by urine (Figure 12) (Höglund *et al.* 2002). Persons at risk include inhabitants in the housing area, workers handling the urine, including farmers applying the urine to arable land, persons in the surroundings of the field and persons consuming fertilised crops. The volume accidentally ingested was assumed to be 1 ml based on assumptions by Asano *et al.* (1992) and pathogens ingested through contaminated crops corresponded to 10 ml of urine per 100 g of crop (Asano *et al.* 1992). Risk from the aerosol exposure was estimated for a person 100 m away inhaling 0.83 m^3 during an hour (Dowd *et al*. 2000). A spray type fertilising technique was assumed.



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

Figure 12. *Exposure pathways in the urine-diverting system investigated in the microbial risk assessment.*

The average faecal contamination based on the faecal sterol analysis was used as an estimate of faeces entering the urine tank. The collection of urine was assumed to take place for a year, and reported or estimated cases of infection per year (incidence) were used to calculate the concentration of pathogens in the faeces, i.e. in the urine. Two different scenarios were investigated:

- *worst-case* or epidemic, where all infections were assumed to occur during the same time period, just before the collection tank was emptied. Thus no inactivation took place in the collection tank;
- *normal* case or sporadic, where infections in the population were assumed to be evenly spread out over a year. Collection of urine either occurred at 4°C or 20°C.

The inactivation results from previous studies were used to estimate the concentration of pathogens in the urine after storage at 4°C or 20°C.

7.3 Quantitative risks (Sweden)

Risks were calculated per exposure, which corresponded to a yearly risk for some of the exposures. Blockage of pipes is likely to occur about once a year per household and the tank was assumed to be emptied after a year. Fertilising with urine usually also takes place once a year in Sweden. Consumption of crop on the other hand might result in repeated exposures.

The risks for the exposure pathways in the worst-case scenario are summarised in Table 5. The risks in the normal scenario where infections occurred sporadically were generally around one $\log_{10}$ lower. Except for rotavirus, calculated risks were all below 10^{-3} (1:1 000).

Due to the persistence of rotavirus at low temperatures (≤5°C) and a low infectious dose (median infectious dose, N_{50} = 5.6) risks for rotavirus infection were up to 0.56 by ingestion of unstored and stored (4°C) urine (Table 5). If stored at a higher temperature (20°C) for six months, risk for rotavirus infection decreased to below 10^{-3} (Table 5). The risk for *Campylobacter* infection was negligible ($<10^{-15}$) except if unstored urine was handled or used for fertilising. *Cryptosporidium* constituted a lower risk in unstored urine than *Campylobacter* but six months storage at 20°C was needed for risks to be negligible.

Table 5. *Calculated risks, mean and (standard deviation), for a single exposure by accidental ingestion of urine and inhalation of aerosols in the worst-case scenario*

Pathway	Storage conditions	*C. jejuni*	*C. parvum*	Rotavirus
accidental ingestion	unstored	4.8×10^{-4} (3.7×10^{-3})	8.7×10^{-5} (8.4×10^{-4})	5.6×10^{-1} (2.2×10^{-1})
	1 month 4°C	nr	1.6×10^{-5} (1.8×10^{-4})	5.6×10^{-1} (2.2×10^{-1})
	6 months 4°C	nr	2.6×10^{-8} (5.5×10^{-7})	5.6×10^{-1} (2.2×10^{-1})
	1 month 20°C	nr	6.9×10^{-11} (6.8×10^{-10})	3.3×10^{-1} (2.4×10^{-1})
	6 months 20°C	nr	nr	5.4×10^{-4} (5.7×10^{-3})
aerosol inhalation	unstored	1.2×10^{-4} (9.6×10^{-4})	2.0×10^{-5} (2.0×10^{-4})	4.2×10^{-1} (2.4×10^{-1})
	1 month 4°C	nr	3.6×10^{-6} (4.3×10^{-5})	4.2×10^{-1} (2.4×10^{-1})
	6 months 4°C	nr	6.0×10^{-9} (1.3×10^{-7})	4.2×10^{-1} (2.4×10^{-1})
	1 month 20°C	nr	1.6×10^{-11} (1.6×10^{-10})	2.0×10^{-1} (2.0×10^{-1})
	6 months 20°C	nr	nr	1.4×10^{-4} (2.2×10^{-3})

nr = negligible risk ($<10^{-15}$)

Aerosol inhalation involved similar risks as direct ingestion of urine. This was calculated for the case when a fine nozzle spray-type fertilising technique was used, and a spray-type fertilising technique can thus be considered inappropriate. The risk from ingestion of contaminated crops will be dependent on the time that passes between fertilisation and harvest of the crop, i.e. consumption, since pathogen inactivation will continue on the crop due to UV-radiation, desiccation etc. In Figure 13, the risks from consumption of crops one to four weeks after fertilising with unstored urine are presented.

The risk for bacterial or protozoan infection was $<10^{-5}$ after one week, whereas three weeks were needed for the risk of viral infection to be of the same magnitude. The rate of inactivation on crop was estimated from previous studies (Asano *et al.* 1992; Petterson *et al.* 1999), but will vary due to weather conditions and the estimate is thus uncertain. Still, the risks were low ($<10^{-7}$ after 4 weeks) even when unstored urine and the worst-case scenario was used, and risks may be acceptable even if a significantly slower inactivation occurs and the exposure occurs repeatedly.

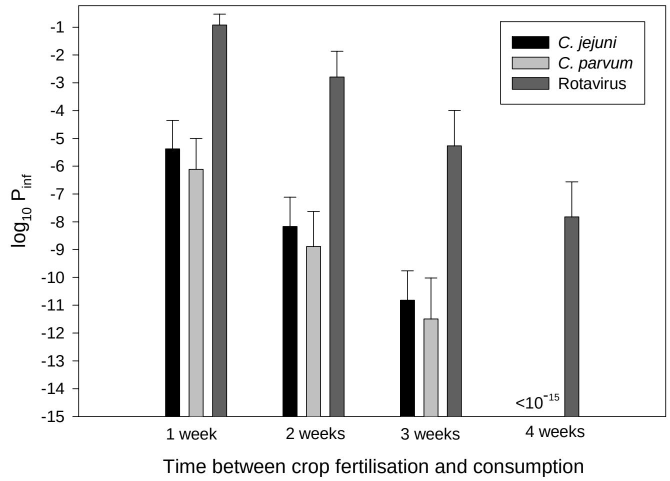


Figure 13. *Mean probability of infection by pathogens following ingestion of 100 g crop fertilised with unstored urine with varying time between fertilisation and consumption. Error bars indicate one standard deviation.*

7.4 Exposure scenarios – examples from a developing country

The above example is taken from a large or medium scale urine diverting system. In urban areas significantly larger systems may be implemented and on the other side we have much smaller scale systems, e.g. single households. The scale probably have a large impact on the risks related to the handling and reuse of urine, as do the environmental setting. Compared to a developed country, specific conditions in developing countries may be assumed to influence the risks.

These factors include:

- a higher prevalence of infectious diseases in the population
- shorter storage times due to lower capacity, e.g. only small containers like jerricans available and affordable
- climate – often tropical climate with higher temperatures that may increase the inactivation rate of pathogens
- more frequent exposure to urine due to manual emptying of storage vessels
- manual application of urine to crops
- more frequent use of urine depending on longer/all year around growing season

Many of these assumptions actually adapt more to scale, e.g. small scale and manual handling assumed, than to type of country. Urban systems in developing countries may also include long time storage of large volumes and handling by trained personnel. Thus specific factors determining the risk that can not be altered would be health status of the population, i.e. number of infected persons, and climate.

A lot of the data needed to make quantitative assessments for systems in a developing country is currently lacking. Surveillance systems, for example, need to be developed and more reliable, which often is true also for developed countries. Qualitative risk assessments may however together with rough assumptions ("best guestimates") enable the comparison of different systems and help in decision making. Independent on the existing sanitary system, the reuse of urine can be assumed to constitute a low additional risk and the use can be promoted in most settings.

7.5 Discussion

The uncertainties of assumptions need to be considered when interpreting the calculated risks. Using worst-case scenarios may avoid underestimation of risks, even though sometimes being less realistic. Dose-response models are obtained from trials with healthy adults. A large part of the population (20%) may however be referred to as immunocompromised (Gerba *et al.* 1996). To adequately assess risks of an infectious disease in a population, issues including secondary spread and short- and long-term immunity need to be considered (Eisenberg *et al.* 1996). In this study only primary infection on an individual level was considered. More sophisticated risk assessments require further assumptions and more complex mathematical models. Due to concentration of sedimented pathogens the sludge formed at the bottom of urine tanks may involve a higher risk than the urine (liquid phase).

Risks for transmission of zoonotic diseases were not specifically investigated even though *Campylobacter* and *Cryptosporidium* may be transmitted from humans to animals. The rapid inactivation of *Campylobacter* in urine implies that there is usually no risk of animals getting infected. Human rotavirus, like other human enteric viruses, is not considered to be transmitted to animals. The risk for transportation of pathogens from urine to groundwater or recreational water (due to run-off) was considered negligible due to the limited amount of liquid (corresponding to <5 mm of rain) that is applied when fertilising with urine.

Assessing the risk may also include a comparison with alternative situations. In most developed countries excreta are collected as sewage and treated. Depending on the efficiency of the treatment and location of the outlet the treated sewage may constitute a risk for transmission of infectious agents. In addition, use of sludge and (partly) treated wastewater involves hygienic risks. In developing countries the option to reuse may be collection and disposal of urine and faeces which may involve problems with groundwater contamination as further discussed in Section 10.2. Even though the precautionary principle could be interpreted as to avoid all risks, an activity may be encouraged if other risks greatly outweighs the added risk. In the example with reuse of urine risks related to the faecal fraction (including sewage containing toilet waste) probably are significantly larger. For some of the infections person to person transmission is the major route as well, thus outweighing the added risk from urine quantified above.

7.5 Acceptable risk and risk minimisation

The acceptable risk is a key point in risk management. If a risk is considered to be too high preventive measures can be taken to decrease the risk to the acceptable level or the practice may not be approved, e.g. the reuse of wastewater or human urine in agriculture. The US EPA, however, has proposed a level of 1:10 000 per year for the consumption of drinking water (Regli *et al.* 1991). This limit has been debated and Haas (1996) argued that it should be lowered to 1:1 000 per year. The proposal of an acceptable risk limit needs to involve representatives from various parts of society and the proposal may vary depending on the present health status of the population concerned (Blumenthal *et al.* 2000).

Assuming that the acceptable risk for infection is 1:1 000 per year then all practices would be considered safe if occurring once a year, except for viruses. For viral risks to be less than 1:1 000 a storage time of six months at 20°C or a period of three weeks between fertilisation and consumption would be needed (Figure 13). Furthermore, several of the exposures will be partly on a voluntary basis that may allow for higher risks compared to involuntary exposure. If individuals are aware of the exposure they also have the possibility to protect themselves for example by wearing gloves and mouth protection when handling urine.

8. GUIDELINES FOR THE REUSE OF HUMAN URINE

Guidelines are tools for regulatory agencies with the purpose of protecting public health. If they are enforceable by law they are generally called regulations. Since urine-diverting systems are being implemented in Sweden, it was decided to set reuse conditions based on the parameters urine storage time and temperature (Table 6). Guidelines may in this context be seen as recommendations on how to use urine in agriculture in order to minimise the risks for transmission of infectious diseases and as a part of risk management. Regulatory standards or guidelines have yet to be determined by the agency responsible.

Table 6. *Relationship between storage conditions, pathogen content[a] of the urine mixture and recommended crop for larger systems[b]. It is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l*

Storage temperature	Storage time	Possible pathogens in the urine mixture	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[c]
20°C	≥1 month	viruses	food crops that are to be processed, fodder crops[c]
20°C	≥6 months	probably none	all crops[d]

[a] Gram-positive bacteria and spore-forming bacteria are not included.
[b] A larger system in this case is a system where the urine mixture is used to fertilise crops that will be consumed by individuals other than members of the household from which the urine was collected.
[c] Not grasslands for production of fodder. Use of straw is also discouraged, further discussed below.
[d] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

These guidelines were set based on the inactivation of microorganisms in urine and the results from the risk assessment do not imply that the recommendations need to be modified. Under conditions (i.e. regarding temperature, pH and nitrogen concentration) other than those given, the inactivation may be different. The Gram-negative bacteria are the major bacterial group causing gastrointestinal infections. Gram-positive bacteria (faecal streptococci) have a slower inactivation rate than Gram-negative bacteria and may be present after one month’s storage at 4°C. Bacteria belonging to this group are, however, considered to be less of a health concern in the urine-diverting systems. If initially present in high concentrations, faecal streptococci may be used as an indicator of the effects of storage. Bacterial spores will be present since they were persistent in urine. This group of bacteria is also of less health concern in relation to urine-diversion.

Processing of crops, using e.g. heat, will inactivate all pathogens potentially present except bacterial spores. Fertilising grasslands used for fodder to cattle with urine is not recommended since grazing animals may consume substantial amounts of soil. Similarly the use of urine on straw to be used as bedding material is discouraged since animals may consume part of the material and since the lower parts of the plant are more exposed to microorganisms in urine and contaminated soil than the upper parts, e.g. grain.

For single households the urine mixture is recommended for all type of crops, provided that the crop is intended for the household's own consumption and that one month passes between fertilising and harvesting, i.e. consumption. Incorporating the urine into the ground is also recommended, but only for crops where the edible parts grow above the soil surface. For crops growing under the surface it is, from a hygiene point of view, more beneficial not to work the urine into the ground since inactivation of potential pathogens by heat, UV-radiation and desiccation is faster on the surface. This approach can probably be used for any smaller system in developing countries, whereas larger (urban) systems may be adopted to the above guidelines (Table 6). One reason for more relaxed guidelines for single housholds is that person to person transmission will outweigh the risk from urine as discussed in Section 7.4. Another aspect is the possibility of controlling and steering the behaviour of individuals.

For diverted urine it is recommended to use a fertilising technique that applies the urine close to the ground, not creating aerosols, since spray application implies quite high risks for viral infections and also leads to high nitrogen losses. Harrowing directly after spreading would further decrease the exposure for both humans and animals. Relying on treatment (in this case storage) is a simpler method than monitoring by the analysis of microbiological parameters. Furthermore, collection and reuse of urine from hospitals, homes for the elderly and also from day-care centres could be avoided since the prevalence of enteric diseases is often higher at such institutions than in the normal population.

9. SOCIAL ASPECTS ON URINE-DIVERTING SYSTEMS AND THE REUSE OF HUMAN URINE

Socio-cultural aspects on sanitation comprise norms and attitudes among the general public as well as perceptions among professional groups. Material on perceptions pertaining to various aspects of sanitation was gathered from scattered joournals, books, and documents from national and international organisations.

9.1 Perceptions of urine and faeces

Attitudes and perceptions about health hazards and/or revulsion from faeces and urine vary between cultures and often people´s ideas about urine differ from those of faeces. Tanner (1995) writes that every social group has a social policy for excreting; some norms of conduct which will vary with age, marital status, sex, education, class, religion, locality, employment and physical capacity. Only some of these aspects will be commented on in this short account. Attitudes and norms are often under pressure of change i.e. due to what is being considered modern or fashionable or what customs are possible to retain in new environments. A process of social conditioning is involved in the identification of bad smells and other nuisances that may be categorised as disgusting in particular sub-cultures. However, as noted by Loudon (1977:168), it is a matter of common observation that among individuals accustomed to the smells of putrefaction, such as those involved in specialised occupations, conditioning modifies or suppresses a response which may well have a biochemical basis, even though reinforced by socio-psychological factors.

More generally, Mary Douglas (1978:34) argues that it is difficult to think of dirt except in the context of pathogenicity within contemporary European ideas, and that makes it, according to her, more demanding to understand dirt-avoidance before the perception was transformed by bacteriology. The following material is presented in this context.

Urine has been thought to have disinfective properties and in many, perhaps most societies, urine has been used to smear wounds (Frode-Kristensen, 1966:18, pers. com). Today urine therapy is widely used in Japan and Germany, and the practice is promoted through international conferences i.e. in India (1996) and Germany (1999). People´s perceptions of urine have hardly been studied, but it seems as if most people entertain a fairly relaxed attitude towards urine. Urination is done rather indiscriminately in towns in the evenings, possibly because the urine seeps away or dries and may leave some smell only. Hansen (1928:88) reported that urine was stored and used as a detergent for washing clothes and dyeing in the Danish countryside in the 19th century. A century earlier, European artisans collected urine and canine excrement for industrial purposes (Reid 1991:10).

Faeces are perceived quite differently, and most people regard them as offensive and unpleasant to handle (Fortes 1945:8 on the Tallensi; Malinowski 1929:378 on the Trobriand; Hamlin 1990 on the British; Reid 1991 on the French). We have found no evidence of how cultures where farmers apply fresh excreta to their fields perceive faeces per se. Koranic edict demands that Muslims minimise contact with human excreta (Hanafi, 1985). A general exception seems to be how women perceive cleansing a child´s bottom, which fits Loudon´s comment above on conditioning.

One may expect to find huge differences between male and female perceptions due to the varying roles and exposure to adult excreta when caring for elderly and incapacitated persons. The development and management of urban areas indicate that towns are men´s projects; men use their political influence to organise the community, while women have little impact on the broad outline of urbanisation.[i] In the process, however, men are increasingly taking over the task of bringing water to the household and disposing of excreta. They do this as engineers, administrators and daily labourers employed by the municipal council or water utility[ii]. They readily accept taking over these tasks from women since men are paid for doing this job, unlike women. Society has tended to view the shift in these gendered tasks as a technical development that has little or nothing to do with gender or norms. Ordinary urban men, moreover, lose their traditional task of digging pits for wells and latrines, since these are expected to be provided by the landlord and paid for through the rent, like in the case of inner-city dwellings.

At the same time, urban women living in places with water in the home have lost a task that gives rural women a crucial function for the livelihood of their families. Female urban dwellers have to find other ways to meet with fellow-women than at the well - a female workplace and meeting point in villages, but they remain with much of the sanitary tasks. The women usually cleans the toilets or latrine in the home, she handles most of the grey water, she often does the gardening, and she is responsible for feeding the family. Therefore, the potential use of urine and grey water in watering and fertilising the garden - be it a lawn, trees or vegetables - does not require a change of responsibilities between men and women in the household. The woman does not have to wait for her husband to perform, but is in control of all the aspects of urine-based biomass production.

In poor periurban settlements piped solutions are rare. Here, actual relationships between the sexes have not changed as above, but mental pictures may have emerged which influence people´s perception of the environmental sanitation. A test survey in 1998 in Cuernavaca in Mexico pointed to differences between men and women as to what is important in the newly acquired plot in periurban settings. Wives tended to favour keeping flowers and a small garden fertilised by composted faecal material, whereas husbands (who are responsible for the emptying of dry latrines) seemed more interested in the modern project of sewerage and a lawn on the plot.

Another case relates to the placing of the urine-diverting toilet inside the house or in the backyard. Towards the end of a ten-day course on ecological sanitation the participants were given the task to suggest practical solutions. Each of five work groups selected one participant as head of household, while the other group-members were consultants to the head on the issue of installing a urine-diverting toilet in his/her home. The three groups with a male head of household all opted to have the toilet in the yard, while the two groups with female heads suggested the toilet to be indoors. This outcome is not a random one, but reflects that women clearly see that the indoor toilet would facilitate her present household chores, while men tend to discard female benefits and they talk about the risk of bad smell.

Gender analysis deals with such roles and relations between the sexes.[iii] From the above account it is clear that the supply of piped water and sewerage changes many roles for both men and women. According to Steven Smith´s schemata for “critical gender thinking” the mainstream approach belongs to the ‘asymmetry thesis’, i.e. a power differential where the core of the discriminated gender (female) is its power disadvantage[iv]. He continues, ”Social science wants value to be a neutral category, but critical study of gender runs into the double problem that its object is a deep fissure in the realm of valuing and that the criteria of study might themselves be gendered”.[v]

Our gender analysis in the proposed study tries to see not just one, but a number of spheres where the sexes may have varying hierarchical positions.[vi] In Smith´s ‘arbitrary theory’, we can “just as well” choose different gender schemes than the one we inhabit. Then ”men and women are capable of being moulded to a single pattern as easily as to a diverse one”, as Margret Mead concludes in Sex and Temperament in Three Primitive Societies. At one level this refers to practical possibility and facility. This more open approach will, for example, allow for an analysis of what takes place when people move from rural to urban neighbourhoods where the couple´s gender relations are less fixed and up for negotiation.

If the two examples from Mexico and Kenya represent a general pattern and men in decision-making positions entertain such “masculine perception”, it becomes highly interesting to analyse where and how the negotiation takes place, if at all. Decision-making in the household may be treated as a negotiation between its members.[vii] This is in line with Amartya Sen´s “cooperative conflict model”, which allows for a distribution of benefits and costs accruing among the members.[viii] The parties have values to guide them to perceived ends in any negotiation, but these may be incompatible. Each person knows that the choice between a cooperative arrangement and a breakdown position is a matter of co-operation, since the former is better for both.[ix] Important factors influencing negotiation results include power, socially accepted behaviour (norms),[x] time-use[xi], threats, perceived contributions, etc.

A different indirect way of approaching people´s attitudes to excreta is to find out how sewermen and excreta collectors are viewed. Read (1991) writes about the professional pride shown by Parisian sewermen. Another example from South Africa tells that the ethnic group Bhaca are eagerly sought after in the whole of the Republic as attendants at sewage treatment works (Mbambisa and Selkirk, 1990). A possibly contrasting example is given by Tanner who notes about the social position of lavatory cleaners ”In Hinduism it is done by out-castes but much the same status applies to cleaners in western societies.” (1995:90). In ancient Rome the cleaning of the Cloaca Maxima was performed by prisoners of war (Hösel 1987:22). We may infer from this information that the general perception of human waste was one of disgust. At the same time, however, the organisation of the disposal of human waste was highly regarded and led by one of the most prestigious officials in the Roman Empire.

The concierges of Japanese terraced houses had the right to the waste of the tenants that was collected in the common toilet. Japanese farmers paid the manure collectors cash for their treasures up to the mid-twentieth century (Ishikawa, 1998). The commercialisation of human excreta led the Japanese to grade its quality; that derived from feudal lords and people who worked for the government being the best, while that from jails was graded the poorest quality. It is of interest to note that a greater portion of urine in the human waste was regarded as of poorer quality. In England most of the excrements were collected in well-constructed watertight cesspools, which were emptied twice a year by market gardeners, and they paid for it in proportion to its solidity. In Milan in Italy there were but few water closets in the mid-19th century because the farmers refused to buy excrements diluted by water (Krepp 1867:59).

Keeping in mind that all these examples from various periods and parts of the world exclusively deal with mixed excreta. The author´s interpretation is that both professionals and laymen may still consider plain urine harmless and inoffensive. A reason for this may be the fact that urine is indistinguishable from water on the ground, and stepping into it is quite different from stepping into human faeces. The important question now is how people match these basic ideas about urine and faeces with various kinds of toilet systems.

9.2 Perceptions and sanitation options

The water closet (WC) as we know it today, was introduced a century an a half ago in Britain, and later in other countries in the North and elsewhere. This technology reached hegemony in the 20th century and other systems were - in the minds of sanitation engineers and health professionals - considered inferior. At the same time, high investment costs delayed a wide-spread introduction of wc. Therefore, cheaper alternatives have been competing for all of the last century.

International organisations started to promote various types of dug latrines to replace the use the bush or water bodies for defecation. The role of pigs, dogs and chicken diminished as human excreta was buried in the soil. In the following decades various modifications of the simple dug latrines evolved; ventilated improved latrines (VIP), the Blair latrine, pour-flush toilets connected to a pit or cesspit. The main idea seems to have been to break transmission routes for pathogens, at the expense of reuse of nutrients in human excreta in agriculture.

The thought of using water to flush the excreta seems to have been favoured by professionals also for rural areas and small communities (Wagner and Lanoix, 1958). This may explain the surprised reactions to the book Water without Sanitation first published in 1978 (Winblad and Kilama, 1978). The battle for hegemony among alternatives continued. In the 1990s the old idea to keep urine and faeces apart was revived (Drangert 1996, Esrey et al. 1998).

Norms and perceptions are related to technical devices and management. Three fundamentally different technical toilet systems will be dealt with in this paper: the flush toilet, the dug latrine system, and dry urine-diverting toilets. The three systems under scrutiny are not singular in character, but each of them display a range of variations.

The flush toilet can be attached to a cesspool or a larger grid of sewers. However, inside the bathroom flush toilets show few variations. The dug latrine, on the other hand, may look very different. It can be a very simple construction and superstructure. The floor may be a slab of cement or just logs put across the pit. The pit may be lined or not. It may reach the groundwater part of the year. Often the pit needs to be emptied or replaced every couple of years.

The third system is the modern urine-diverting toilet. The principle is simple: urine and faecal matter are never mixed. Urine is collected in a bowl or container, stored for some time, and then applied on agricultural land. The faecal matter is stored for at least six months in a dry place, after which it can be used as soil conditioner or just be burnt. The management may involve only a single household, or may comprise several households and for instance connected to a communal sewer for urine.

9.3 Management of systems and social sustainability

Social and management factors influence the sustainability of any sanitary system. In Table 1 we compare the WC and dug latrines with the modern urine-diverting toilet which is a technical development of the simpler version from the 1860s. The selection of explicit features to be compared is always under discussion, and depends on historical and other contexts. However, a selection has to be done of a number of important requirements associated with users, society and nature. The degree of fulfilment of requirements by the WC, dug latrine, and urine-diverting toilet systems is assessed.

Table 7. *Fulfilment of various user and sustainability requirements on toilet systems*

Features:	**WC, septic tank**	**Urine-diversion**	**Dug latrine**
In the home or homestead:			
- smell, flies, and maggots?	No	No, if well managed	Yes
- indoor for control and security?	Yes	Yes	No
- easy and safe to clean and maintain?	Yes, if properly built	Yes, if properly built	No
- handwashing facility?	Yes	Yes	No
- hygienic handling of urine & faeces?	Yes	Yes, but can be unpleasant	Yes, except for emptying
- affordable to most residents?	rarely	Yes, an alternative for every pocket	Yes
- space?	Yes	Yes	No
In the community and natural environment:			
- degradation of the environment?	leaks to ground-water/overflow, eutrofication if no treatment plant	No	overflows and leaks to the groundwater at heavy rains
- resource saving?	wasteful use of water	Yes	Yes
- reuse of nutrients?	hazardous heavy metals in sludge	Yes	Yes, if pit is emptied
- flexible system?	No	Yes, moveable and can be improved	Yes, can be improved

Source: Drangert 2001

The judgements made in the table are commented briefly.

a) In the home.

Some of the positive features of the WC include that it is easy to clean, is odourless, is indoors, and it benefits health. These are features that pit latrines do not have, and therefore make them substandard in comparison with the flush toilet.

Urine-diverting toilets are odourless too and therefore possible to install indoors. Thereby the household can control its use and keep it as clean as they want. These benefits will occur only where the toilet has its entrance inside the house or flat. The urine-diverting toilet would require a change of a few practices, however, such as collecting the urine and composting faecal material. The frequency of hand-washing after defecation will increase substantially if indoors, thanks to easy access to water and soap. It turns out that a urine-diverting toilet has the same positive features as the WC when it comes to convenience and hygienic safety. However, if the toilet is mismanaged, only the household members are those who suffer.

In case the urine-diverting toilet is found in the yard, the toilet has some important features similar to those of the dug latrine. Each time ash or water is missing in the toilet room, someone has to walk out of the house to bring it. Since the toilet is away from the house, a certain level of smell may be viewed as acceptable. If a child has diarrhoea, the caretaker has to walk it to the toilet outside and also to come back afterwards to clean the slab. Female users encounter a security problem when visiting the toilet after dark. Also, if the toilet room is not locked, anyone may use or misuse the toilet, and it is a less inspiring chore to clean after unknown visitors. These examples show that it is likely that (any) toilet in the yard face operational and social problems.

b) In society and the natural environment
The WC requires water for flushing and treatment of the produced blackwater. If the water supply is intermittent users are forced to store water for flushing. The blackwater either goes into a septic tank or into the sewer system, both of which tend to leak. If groundwater levels are shallow, this leakage will result in contamination of the groundwater. If the septic tank is well built it must be emptied regularly. However, it often happens that the collection is delayed or non-operational and therefore the household has to empty the tank in unhygienic ways. As in the case of pit latrines, a heavy rain may do the job of emptying the pit or cesspool to the detriment of the environment.

In case sewers and emptying of septic tanks function well, there is a need to treat the wastewater before being discharged into a river or lake. Wastewater treatment plants require large investments and qualified management. The running cost may be prohibitive, and collection of tariffs often falls short of what is needed for O&M. Ensuing management failures make the community suffer.

Today´s urine-diverting toilet provides various possibilities to recover and reuse the nutrients in human waste. Due to its transparency, users will not unknowingly throw alien objects into the urine-diverting toilet. They know that the content will be used for their own food production or in the vicinity. The urine-diverting toilet encourages, in contrast to the WC and dug latrine, good user behaviour and thus provides a fertiliser of higher quality, ready for (re)use in the nutrient cycle.

10. GENERAL DISCUSSION

10.1 Health risks

Whether urine-diversion and the reuse of urine can be recommended depends on whether the associated health risks are considered to be acceptable. These risks can be balanced against benefits like the fertiliser value of human urine. Higher risks from reuse of waste products may be acceptable in areas where enteric disease is endemic and where it is more often transmitted through poor hygiene and sanitation (Blumenthal *et al.* 2000). In areas where food is scarce, benefits from larger harvests may reduce other risks such as malnutrition, which otherwise causes immunosuppression and makes the individual more susceptible to infections. The awareness of risks and the voluntary aspect are issues that also need to be considered when establishing an acceptable risk.

Hygienisation or sanitation may refer to a treatment that reduces the number of microorganisms in a waste product to prevent negative impacts on humans and the environment. For diverted urine the only sanitising treatment that has been discussed is storage. This is a simple means of controlling pathogen spread, and a non-complex system is often preferable. Temperatures above 20°C would probably increase the inactivation of microorganisms, and further investigations at higher temperatures could also be of interest for systems in tropical climates.

The risk for infection depends on the abundance of various pathogens in the urine mixture (i.e. in faeces) and the infectious dose. All Gram-negative bacteria investigated were found to be rapidly inactivated, which resulted in the conclusion that pathogens belonging to this group constitute a low risk. *Vibrio* species are, however, known to be persistent at alkaline pH-values and may have a longer survival in urine. The main concern is *Vibrio cholerae*, especially in communities with low sanitary standards. Further investigations may be justified for evaluation of sanitary systems in developing countries even though short survival times were reported in faeces and sewage (Feachem *et al.* 1983). *Cryptosporidium* was considered to be the most resistant of all the protozoa. Thus *Giardia*, *Entamoeba*, microsporidia and *Cyclospora* do not imply a higher risk than *Cryptosporidium*. The Gram-positive faecal streptococci had a similar inactivation rate to the protozoa but other Gram-positives would, if pathogenic, result in a lower risk than for *Cryptosporidium*, since infectious doses for bacteria are generally higher than those for protozoa. At low temperatures there was no reduction of the viruses investigated. With the high excretion and low infectious dose of rotavirus, there is probably no other enteric virus that constitutes a higher risk. However at 20°C, phage 28B was more resistant than rotavirus and other viruses could be equally persistent in urine. Rotavirus has been reported to be as resistant or more resistant than several other enteric viruses (Ward *et al.* 1989; Pesaro *et al.*1995). Hepatitis A viruses are also known to be resistant, e.g. to heat and UV-radiation, and have been recognised to be of potential concern when applying wastes to land (Yates and Gerba 1998). Since virus survival has been recognised as highly influencing health risks in reuse further investigations in urine as well as in other waste products may be relevant. Helminth eggs are very persistent in the environment. Due to the lifecycles of helminths often including development to the infectious stage outside the host, the transmission routes and risks for infections need to be evaluated separately, especially in relation to conditions prevailing in areas where the infections are endemic.

Certainly, the inactivation of pathogens will continue after the urine has been applied to the soil. Inactivation in soil and on crops is hard to predict since local conditions always will vary regarding climate (e.g. temperature, sunlight, moisture), type of soil (e.g. particle size, water holding capacity) and type of crop (e.g. cereals, leafy/root vegetables). Inactivation on crops is generally considered to be faster, with a total inactivation ranging from days to weeks, than inactivation in soil and on the soil surface, which ranges from weeks to months (Feachem *et al.* 1983). According to a review by Yates and Gerba (1998) enteric viruses are likely to survive less than two weeks on crops during the summer and less than six weeks during spring and fall. As in other environments bacteria are probably less persistent than viruses whereas parasitic cysts may remain viable for long periods if not desiccated. Regarding the risk for pathogen transmission, there is a choice of whether to store the urine at conditions that virtually eliminates pathogens or to account for further inactivation in the field. If applied to non-food crops the foodborne route of transmission is eliminated, but there is still an infection risk for people involved in the production and processing of crops as well as for humans and animals in the surroundings.

Epidemiological studies on people in contact with diverted urine would be a reliable way to investigate whether the practice of reusing urine affects public health. This type of study would hardly be feasible with the small numbers of people who handle urine at present. Several investigations regarding the impact of wastewater reuse on the health of people in the immediate vicinity have been conducted. Clear evidence of increased infection rates was found in several of the investigations, some of them involving irrigation with untreated or poorly treated wastewater (Katzenelson *et al.* 1976; Fattal *et al.* 1986). According to Cooper and Olivieri (1998) there are no recorded incidents of infectious disease transmission associated with reuse of appropriately treated wastewater, possibly because the risk is too low for detection by epidemiological methods. In the risk assessment method, used as an alternative in predicting risks for infection, viruses constituted the highest risk. The transmission of e.g. rotavirus commonly occurs person-to-person, which implies that handling of waste products would only marginally affect the prevalence of such diseases in a society (Lewis-Jones and Winkler 1991). Even though individual cases of viral infections theoretically could arise from handling urine, they would probably not be recognised by any surveillance system. The risk for an outbreak caused by direct contact with urine is low, since few persons are exposed, e.g. compared to a drinking water supply or recreational water. The risk for foodborne outbreaks could be minimised by following the guidelines for storage in combination with choice of crop and risks for infections caused by unsafe handling of food produce should be similarly considered (Yates and Gerba 1998).

10.2 The present situation in developing countries

The most common sanitation system in the world is the pit latrine, which provides on-site sanitation for 20% of the population in developing countries (WHO 1997). Even though these latrines protect the population from infectious diseases compared to on-the-ground excretion, the excreta collected in the pits may contaminate the groundwater due to transport of pathogens and nitrate leaching (Lagerstedt *et al.* 1994; Stenström 1996). Exclusion of the urine would significantly decrease the leaching, and urine-diversion has been suggested for preventing transmission of disease, as well as for avoiding nitrate contamination. Further research on pathogens common to developing countries, especially in tropical areas, would be valuable. The risks from handling and reusing the faecal fraction are probably in more acute need of control than the risks related to urine. If the faecal fraction is kept dry and the pH is raised by adding lime or ash, enteric pathogens may be inactivated (Lewis-Jones and Winkler 1991). Education is also crucial in order to get the systems to function hygienically. Apart from decreasing diarrhoeal diseases, the management of water and sanitation is also important for reducing cases of e.g. malaria and schistosomiasis (WCED 1987).

Much can also be gained if a cheap fertiliser is available. For sustainable agriculture in developing countries it is important to increase the use of organic fertilisers as a complement to mineral fertilisers (WCED 1987). Only animal manure and crop residues were mentioned earlier, whereas later reports have emphasised human urine and faeces as being important resources as well (WSSCC 2000). Compared to developed countries, agriculture in developing countries may obtain an even larger benefit from utilising the plant nutrients found within human excreta, since this contributes a larger proportion of plant nutrients than animal manure, due to the lower intake of animal protein in developing countries. It would be especially beneficial to use human excreta in urban agriculture (FAO 1999). In combination, improved sanitation and higher nutritional status could significantly improve public health in developing countries (WCED 1987). The low risks for transmission of infections through urine further support the implementation of urine-diversion. The higher temperature in many of the developing regions would probably be beneficial for the inactivation of enteric pathogens in the urine. In addition, the more concentrated urine obtained from toilets or latrines that do not use flushwater would probably increase the inactivation rate.

11. CONCLUSIONS

The risk for transmission of infectious diseases in relation to diverted human urine is largely dependent on the cross-contamination by faeces.

- Human urine does not generally contain pathogens that will be transmitted through the environment.
- By analysis of faecal sterols, faecal contamination corresponding to a mean of 10 ppm was detected in approximately half of the sampled systems on at least one occasion and in 28% of all urine samples.
- Indicator bacteria are not suitable for determining faecal contamination of diverted urine due to a rapid inactivation of *E. coli* in urine mixtures and to growth of faecal streptococci within the systems.
- To avoid faecal contamination, special precautions may be considered during instances of diarrhoea and when children or unaccustomed adults use the toilet.

The risk for transmission of infectious diseases is dependent on the storage temperature and duration of storage of the urine mixture before it is used as a fertiliser.

- The enteric bacteria of main concern (Gram-negative bacteria) were rapidly inactivated in diverted urine at both 4°C and 20°C (T_{90} <5 days).
- The inactivation rate of *Cryptosporidium* oocysts at 4°C corresponded to a T_{90} of 29 days and was estimated to 5 days at 20°C. These rates are expected to be higher for other protozoa.
- Viruses were, with the exception of clostridia spores, the most persistent microbial group investigated. During six months of storage, the numbers of rotavirus and a bacteriophage were not reduced in urine at a low temperature (5°C). At 20°C T_{90}-values were 35 and 71 days, respectively.
- The elevated pH (pH 9) caused by the conversion of urea to ammonium is beneficial for the inactivation of microorganisms in the urine.
- A shorter storage time at a lower temperature will involve higher risks for individuals handling the urine and for those in contact with the fertilised field or crop, including animals. Further inactivation of pathogens is expected in the field and the risk for infection by ingestion of crop will be reduced during the time between fertilisation and consumption.

Guidelines including reuse conditions and other recommendations may ensure a minimal risk for exposure to pathogens in diverted urine.

- Protection (e.g. wearing gloves) and awareness of risks is important, especially for those handling unstored urine.
- Using suitable fertilising techniques and working the urine into the soil, as well as letting some time pass between fertilisation and harvesting, will decrease the exposure of humans and animals to potential pathogens.
- If urine is used on crops that are to be commercially processed, e.g. cereal crops, the risk for infection through food consumption is negligible.
- Urine collected from individual households and used for the household's own consumption involves less risk than large-scale systems and is suitable for fertilising all types of crops if one month is allowed between fertilisation and consumption.

Urine-diverting wastewater systems may contribute to sustainable development in both developed and developing countries and in both rural and urban areas.

- Health criteria for wastewater systems will be fulfilled if urine is handled and reused according to recommended guidelines. The microbial health risks from urine-diverting systems are considered to be low, also if compared to conventional systems. For small-scale wastewater systems, comparisons of risks are further dependent on local conditions.
- In Sweden, systems analyses of urine-diverting systems have resulted in decreased emissions of eutrophying nitrogen and phosphorous and energy consumption compared to the conventional system. Small-scale treatment systems may be especially suitable for supplementation with urine-diversion since their treatment efficiency is often low and their contribution to eutrophication significant.
- As a fertiliser, urine would probably be of best use in organic farming, but its fertilising effect is comparable also to that of mineral fertilisers.
- In developing countries there is an urgent need for safer handling of excreta as well as for fertilisers. International organisations promote dry sanitation and the concept of regarding human excreta as a resource. The survival in urine of pathogens common to these areas might require further investigations even though the reuse of urine is a safe alternative compared to the reuse of faeces or poorly treated wastewater.

How health risks and acceptable risks are to be managed will probably be one of the main issues that decides the future of urine-diverting and other recycling wastewater systems:

- Acceptable risks of 1:1 000 - 1:10 000 per year have been discussed in relation to drinking water. According to the Quantitative Microbial Risk Assessment (QMRA) results presented in this report, the risk for infections through urine mixtures will often be in this range or lower. Furthermore, higher risks may be more acceptable for a wastewater system since the exposed population is smaller and is also aware of the risks associated with waste products.
- Reuse of human excreta and wastewater in developing countries, especially in tropical areas, may involve higher risks due to the higher prevalence of enteric diseases. However, the risks need to be balanced against possible soil fertilisation benefits and the risks from current sanitary systems.

12. REFERENCES

Adamsson, M. 2000. Potential use of human urine by greenhouse culturing of microalgae (*Scenedesmus acuminatus*), zooplankton (*Daphnia magna*) and tomatoes (*Lycopersicon*). *Ecological Engineering* **16**(2):243-254.

Asano, T. and Levine, A.D. 1998. Wastewater reclamation, recycling, and reuse: An introduction. In: Asano, T. (ed.) Wastewater reclamation and reuse. Technomic Publishing Company, Inc., Lancaster, PA, USA. p. 1-56.

Asano, T., Leong, L.Y.C., Rigby, M.G. and Sakaji, R.H. 1992. Evaluation of the California wastewater reclamation criteria using enteric virus monitoring data. *Water Science and Technology* **26**(7-8):1513-1524.

Beaglehole, R., Bonita, R. and Kjellström, T. 1993. Basic Epidemiology. World Health Organization, Geneva, Switzerland.

Berglund, M. 2001. The food sector's view on plant nutrients from urban to rural areas. (Livsmedelssektorns syn på växtnäring från stad till land). Masters' thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden. (In Swedish, English summary).

Blumenthal, U.J., Mara, D.D., Peasey, A., Ruiz-Palacios, G. and Stott, R. 2000. Guidelines for the microbiological quality of treated wastewater used in agriculture: Recommendations for revising WHO guidelines. *Bulletin of the World Health Organization* **78**(9):1104-1116.

Campbell, A.T., Robertson, L.J. and Smith, H.V. 1992. Viability of *Cryptosporidium parvum* oocysts: Correlation of *in vitro* excystation with inclusion or exclusion of fluorogenic vital dyes. *Applied and Environmental Microbiology* **58**(11):3488-3493.

CDC. 2000a. Leptospirosis. Centers for Disease Control and Prevention.

http://www.cdc.gov/ncidod/dbmd/diseaseinfo/leptospirosis_g.htm. Last updated 31 March 2000.

CDC. 2000b. Schistosomiasis. Centers for Disease Control and Prevention. http://www.cdc.gov/ncidod/dpd/parasites/schistosomiasis/factsht_schistosomiasis.htm. Last updated 7 June 2000.

Cifuentes, E. 1998. The epidemiology of enteric infections in agricultural communities exposed to wastewater irrigation: Perspectives for risk control. *International Journal of Environmental Health Research* **8**:203-213.

Cooper, R.C. and Olivieri, A.W. 1998. Infectious disease concerns in wastewater reuse. In: Asano, T. (ed.) Wastewater reclamation and reuse. Technomic Publishing Company, Inc., Lancaster, PA, USA. p. 489-520.

Crook, J. 1998. Water reclamation and reuse criteria. In: Asano, T. (ed.) Wastewater reclamation and reuse. Technomic Publishing Company, Inc., Lancaster, PA, USA. p. 627-703.

Devaux, I., Gerbaud, L., Planchon, C., Bontoux, J. and Glanddier, P.Y. 2000. Infectious risk study associated with wastewater reuse: An epidemiological approach applied to the case of Clermont-Ferrand, France. In: Conference preprint, Book 7, Health-related water microbiology, 1st World Water Congress of the International Water Association (IWA), 3-7 July 2000, Paris, France. p. 41-42.

Dowd, S.E., Gerba, C.P., Pepper, I.L. and Pillai, S.D. 2000. Bioaerosol transport modeling and risk assessment in relation to biosolid placement. *Journal of Environmental Quality* **29**:343-348.

Dumontet, S., Dinel, H. and Baloda, S.B. 1999. Pathogen reduction in sewage sludge by composting and other biological treatments: A review. *Biological Agriculture and Horticulture* **16**:409-430.

DuPont, H., Chappell, C., Sterling, C., Okhuysen, P., Rose, J. and Jakubowski, W. 1995. Infectivity of *Cryptosporidium parvum* in healthy volunteers. *New England Journal of Medicine* **332**(13):855.

Eisenberg, J.N., Seto, E.Y.W., Olivieri, A.W. and Spear, R.C. 1996. Quantifying water pathogen risk in an epidemiological framework. *Risk Analysis* **16**(4):549-563.

Esrey, S.A., Gough, J., Rapaport, D., Sawyer, R., Simpson-Hébert, M., Vargas, J. and Winblad, U. 1998. Ecological Sanitation. Swedish International Development Cooperation Agency, Stockholm, Sweden.

FAO. 1999. Issues in urban agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/magazine/9901sp2.htm. Accessed 14 November 2000.

Fattal, B., Wax, Y., Davies, M. and Shuval, H.I. 1986. Health risks associated with wastewater irrigation: An epidemiological study. *American Journal of Public Health* **76**(8):977-979.

Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. Sanitation and Disease - Health aspects of excreta and wastewater management. John Wiley and Sons, Chichester, UK.

Gagliardi, J.V. and Karns, J.S. 2000. Leaching of *Escherichia coli* O157:H7 in diverse soils under various agricultural management practices. *Applied and Environmental Microbiology* **66**(3):877-883.

Gerba, C.P., Rose, J.B. and Singh, S.N. 1985. Waterborne gastroenteritis and viral hepatitis. *CRC Critical Reviews in Environmental Control* **15**:213-236.

Gerba, C.P., Rose, J.B., Haas, C.N. and Crabtree, K.D. 1996. Waterborne rotavirus: A risk assessment. *Water Research* **30**(12): 2929-2940.

Ghiglietti, R., Genchi, C., Di Matteo, L., Calcaterra, E. and Colombi, A. Survival of *Ascaris suum* eggs in ammonia-treated wastewater sludges. *Bioresource Technology* **59**:195-198.

Gopinath, R. and Keystone, J.S. 1995. Ascariasis, Trichuriasis, and Enterobiasis. In: Blaser, M.J., Smith, P.D., Ravdin, J.I. and Greenberg, H.B. (eds.) Infections of the gastrointestinal tract. Raven Press, Ltd., New York, NY, USA. p. 1167-1177.

Haas, C.N. 1996. Acceptable Microbial Risk. *Journal of the American Water Works Association* **88**(12):8.

Haas, C.N., Rose, J.B. and Gerba, C.P. 1999. Quantitative Microbial Risk Assessment. John Wiley and Sons, Inc., New York, NY, USA.

Hamdy, E.I. 1970. Urine as an *Ascaris lumbricoides* ovicide. *Journal of the EgyptianMedical Association* **53**:261-264. In: Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. Sanitation and Disease - Health aspects of excreta and wastewater management. John Wiley and Sons, Chichester, UK.

Höglund, C. E. and Stenström, T. A. B. 1999. Survival of *Cryptosporidium parvum* oocysts in source separated human urine. *Canadian Journal of Microbiology* **45**(9), 740-746.

Höglund, C., Stenström, T. A., Jönsson, H. and Sundin, A. 1998. Evaluation of faecal contamination and microbial die-off in urine separating sewage systems. *Water Science and Technology* **38**(6), 17-25.

Höglund, C., Ashbolt, N., Stenström, T. A. and Svensson, L. In press. Viral persistence in source separated human urine. Accepted for publication in *Advances in Environmental Research.*

Höglund, C., Ashbolt, N. and Stenström, T. A.2002. Microbial risk assessment of source-separated urine used n agriculture. *Waste Management and Research* **20**:162-171.

IFOAM. 2000. Basic standards for organic production and processing decided by the IFOAM General Assembly in Basel, Switzerland, September 2000. International Federation of Organic Agriculture Movements. http://www.ifoam.org/standard/index_neu.html. Accessed 3 January 2001.

Jawetz, E., Melnick, J.L. and Adelberg, E.A. 1987. Review of medical microbiology, 17th ed. Appleton & Lange, East Norwalk, CT, USA.

Jenkins, M.B., Bowman, D.D. and Ghiorse, W.C. 1998. Inactivation of *Cryptosporidium parvum* oocysts by ammonia. *Applied and Environmental Microbiology* **64**(2):784-788.

Jönsson, H., Vinnerås, B., Höglund, C., Stenström, T.A., Dalhammar, G. and Kirchmann, H. 2000. Recycling source separated human urine. (Källsorterad humanurin). VA-Forsk Report 2000-1, VAV AB, Stockholm, Sweden. (In Swedish, English summary).

Katzenelson, E., Buium, I. and Shuval, H.I. 1976. Risk of communicable disease infection associated with wastewater irrigation in agricultural settlements. *Science* **26**:944-946.

Kirchmann, H. and Pettersson, S. 1995. Human urine - chemical composition and fertilizer use efficiency. *Fertilizer Research* **40**:149-154.

Kärrman, E., Jönsson, H., Gruvberger, C., Dalemo, M., Sonesson, U. and Stenström, T.A. 1999. Environmental systems analysis of wastewater and solid organic waste from households - synthesis of handling systems studied in the R&D programme "Organic waste as a plant nutrient resource". (Miljösystemanalys av hushållens avlopp och organiska avfall - syntes av hanteringssystem undersökta inom FoU-programmet "Organiskt avfall som växtnäringsresurs"). VA-Forsk Report 1999-5, VAV AB, Stockholm, Sweden. (In Swedish, English summary).

Lagerstedt, E., Jacks, G. and Sefe, F. 1994. Nitrate in groundwater and N circulation in eastern Botswana. *Environmental Geology* **23**:60-64.

Lewis-Jones, R. and Winkler, M. 1991. Sludge parasites and other pathogens. Ellis Horwood Limited, Chichester, UK.

Lind, B.-B., Ban, Z. and Bydén, S. 2000. Nutrient recovery from human urine by struvite crystallization with ammonia adsorption on zeolite and wollastonite. *Bioresource Technology* **73**:169-174.

Mead, P.S., Slutsker, L., Dietz, V., McCaig, L.F., Bresee, J.S., Shapiro, C., Griffin, P.M. and Tauxe, R.V. 1999. Food-related illness and death in the United States. *Emerging Infectious Diseases* **5**(5):607-625.

Meinhardt, P.L., Casemore, D.P., Miller, K.B. 1996. Epidemiologic aspects of human cryptosporidiosis and the role of waterborne transmission. *Epidemiologic Reviews* **18**(2):118-136.

Morgan, P. 1999. Ecological sanitation in Zimbabwe - A compilation of manuals and experiences. Conlon Printers, Harare, Zimbabwe.

Murray, C.J.L and Lopez, A.D. 1996. The Global Burden of Disease: A comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 projected to 2020, summary. Harvard School of Public Health, Cambridge, MA, USA.

Olsson, A. 1995. Source separated human urine - occurrence and survival of faecal microorganisms and chemical composition. (Källsorterad humanurin - förekomst och överlevnad av fekala mikroorganismer samt kemisk sammansättning). Report 208, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala, Sweden. (In Swedish, English summary).

Olsson Engvall, E. and Gustavsson, O. 2001. Leptospirosis (Leptospiros). In: Källenius, G and Svenson, S.B. Zoonoser (Zoonoses). Studentlitteratur, Lund, Sweden. (In Swedish).

Pesaro, F., Sorg, I. and Metzler, A. 1995. *In situ* inactivation of animal viruses and a coliphage in nonaerated liquid and semiliquid animal wastes. *Applied and Environmental Microbiology* **61**(1):92-97.

Petterson, S.R., Ashbolt, N.J. and Sharma, A. 1999. Microbial risks from wastewater irrigation of salad crops: Are risks dictated by rare virus events? Proceedings from the 4th International Conference, Managing the Wastewater Resource - Ecological Engineering for Wastewater Treatment, June 7-11, 1999, Ås, Norway.

Porter, A. 1938. The larval Trematoda found in certain South African Mollusca with special reference to schistosomiasis (bilharziasis). *Publications of the South African Institute for Medical Research* **8**:1-492. In: Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. Sanitation and Disease - Health aspects of excreta and wastewater management. John Wiley and Sons, Chichester, UK.

Regli, S., Rose, J.B., Haas, C.N. and Gerba, C.P. 1991. Modeling the risk from *Giardia* and viruses in drinking water. *Journal of the American Water Works Association* **83**:76-84.

Richert Stintzing, A., Rodhe, L. and Åkerhielm, H. 2001. Human urine as a fertiliser - Spreading technique and effects on plant nutrition and environment. (Humanurin som gödselmedel - Spridningsteknik, växtnärings- och miljöeffekter). JTI report Agriculture and Industry no. 278. , Swedish Institute for Agricultural and Environmental Engineering, Uppsala, Sweden. (In Swedish, English summary).

Robertson, L.J., Campbell, A.T. and Smith, H.V. 1993. *In vitro* excystation of *Cryptosporidium parvum*. *Parasitology* **106**:13-19.

Rodhe, L. and Johansson, S. 1996. Ammonia emission and nutrient utilization from urine using different techniques for application. (Urin – spridningsteknik, ammoniakavgång och växtnäringsutnyttjande). JTI Report Agriculture and Industry no. 217, Swedish Institute for Agricultural and Environmental Engineering, Uppsala, Sweden. (In Swedish, English summary).

Schönning, C., Leeming, R. and Stenström, T.A. In press. Faecal contamination of source-separated human urine based on the content of faecal sterols. Accepted for publication in *Water Research.*

SMI. 2000. Infectious Diseases 1999. (Smittsamma sjukdomar 1999). Swedish Institute for Infectious Disease Control, Stockholm, Sweden. (In Swedish).

Snowdon, J.A., Cliver, D.O. and Converse, J.C. 1989a. Land disposal of mixed human and animal wastes: A review. *Waste Management and Research* **7**:121-134.

Stenström, T.A. 1996. Pathogenic microrganisms in wastewater systems - Risk assessment of traditional and alternative wastewater systems. (Sjukdomsframkallande mikroorganismer i avloppssystem - Riskvärdering av traditionella och alternativa avloppslösningar). Report 4683, Swedish Environmental Protection Agency and National Board of Health and Welfare, Stockholm, Sweden. (In Swedish).

SUDEA. 2000. Ecosan - economy, ecology, sanitation. Society for Urban Development in East Africa. http://user.tninet.se/~gyt516c/ECOSAN.html. Last updated 11 March 2000.

Swedish EPA. 1995. Environmentally compatible water and wastewater systems - a proposal for criteria. (Miljöanpassade vatten- och avloppssystem - förslag till bedömningsgrunder). Report 4429, Swedish Environmental Protection Agency, Stockholm, Sweden. (In Swedish).

Söderberg, H. 1999. Recycling municipalities - the change of sewage treatment from reduction to resource management. (Kommunerna och kretsloppet - avloppssektorns förändring från rening till resurshantering). PhD thesis, Water and Environmental Studies, Linköping University, Linköping, Sweden. (In Swedish, English summary).

Tauxe, R.V. and Cohen, M.L. 1995. Epidemiology of diarrheal diseases in developed countries. In: Blaser, M.J., Smith, P.D., Ravdin, J.I. and Greenberg, H.B. (eds.) Infections of the gastrointestinal tract. Raven Press, Ltd., New York, NY, USA. p. 37-51.

Tortora, G.J., Funke, B.R. and Case, C.L. 1992. Microbiology: An introduction. The Benjamin/Cummings Publishing Company, Inc., Redwood City, California, USA.

UNFPA. 1999. The state of the World population 1999, summary. United Nations Population Fund. http://www.unfpa.org/swp/1999/thestate.htm. Accessed 11 January 2001.

Vivian, C.M.G. 1986. Tracers of sewage sludge in the marine environment: A review. *The Science of the Total Environment* **53**:5-40.

Walker, R.W., Wun, C.K. and Litsky, W. 1982. Coprostanol as an indicator of fecal pollution. *CRC Critical Reviews in Environmental Control* **10**:91-112.

Ward, R.L., Knowlton, D.R., Stober, J., Jakubowski, W., Mills, T., Graham, P. and Camann, D.E. 1989. Effect of wastewater spray irrigation on rotavirus infection rates in an exposed population. *Water Research* **23**(12):1503-1509.

WCED. 1987. Our common future. World Comission on Environment and Development, Oxford University Press, Oxford, UK.

Weslien, P., Klemedtsson, L., Svensson, L., Galle, B., Kasimir-Klemedtsson, Å. and Gustafson, A., 1998. Nitrogen losses following application of pig slurry to arable land. *Soil Use and Management* **14**:200-208.

Wheeler, D. and Carroll, R.F. 1989. The minimisation of microbiological hazards associated with latrine wastes. *Water Science and Technology* **21**(3):35-42.

WHO. 1989. Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture. World Health Organization, Geneva, Switzerland.

WHO. 1997. Environmental Health Newsletter, No 27, October 1997. World Health Organization. www.who.int/peh/ehn/ehn27.htm. Accessed 14 November 2000.

WHO. 2002. 2.4 billion report for 2000.

Winblad U. 1996. Towards an ecological approach to sanitation. In: Simpson-Hébert, M. and Wood, S. (eds.) Sanitation promotion. World Health Organization, Geneva, Switzerland. p. 203-214.

Winblad, U. and Kilama, W. 1978. Sanitation without water, Sida, Stockholm.

WRI. 1996. World Resources Report 1996-97. World Resources Institute in collaboration with the United Nations Environment Programme, the United Nations Development Programme and the World Bank. Oxford University Press, New York, USA.

WSSCC. 2000. VISION 21: A shared vision for hygiene, sanitation and water supply and a framework for action. Water Supply and Sanitation Collaborative Council. http://www.wsscc.org/vision21/wwf/index.html. Accessed 27 September 2000.

Yates, M.V. and Gerba, C.P. 1998. Microbial considerations in wastewater reclamation and reuse. In: Asano, T. (ed.) Wastewater reclamation and reuse. Technomic Publishing Company, Inc., Lancaster, PA, USA. p. 437-488.

[i] Vaa, M. 1995. Gender relations and the environment of urban poverty. In proceedings from research seminar *Tropical Diseases, Society and the Environment*, Aug. 31-Sept. 2. 1993. SAREC. Stockholm.

[ii] Sommerstad, L. 1992. Från mejerska till mejerist. En studie av mejeriyrkets feminiseringsprocess. Arkiv. Lund. and _Drangert, J-O 1996, Stockholm Water Symposium Proceedings.
[iii] Murdoch, G.P. and C. Provos., 1980. Factors in the division oflabour by sex: A cross-cultural analysis. In Berry, H. III and A. Schegel (eds). *Crosscultural Samples and Codes*. pp. 289-312. Pittsburg. University of Pittsburg Press. p. 293.
[iv] Smith, S.G. 1992. *Gender Thinking*. Philadelphia. Temple University Press. p.17.
[v] Smith, 1992:19.
[vi] Connell, Robert W. 1987. Gender and power. Society, the person and sexual politics. Oxford. Polity Press and Blackwells.
[vii] Drangert, J.O. 1993. *Who cares about water? Household water development in Sukumaland, Tanzania*. Linköping university. Linköping Studies in Arts and Sciences. No. 85.
[viii] Sen, A. 1990. Gender and Cooperative Conflicts. In: I. Tinker (ed*). Persistent Inequalities: Women and World Development*. pp. 123-149. New York. Oxford University Press. p. 129.
[ix] Sen, 1990:132
[x] Nyberg, A. 1989. *Tekniken - Kvinnornas befriare?* (Technology- A liberator of women?) Linköping university, Sweden. Linköping Studies in Arts and Science. No. 45.
[xi] Godás, M.G. 1992. *Mujeres mayas. Trabajo, nutrición y fecundidad*. Mexico City. Institute of Anthropological Studies.

Skräp

The question of putting more pressure on overburdened women should be addressed since it may become an obstacle to this application of human-derived nutrients into food production. Only the individual woman will decide in the end whether it is a worthwhile effort. However, women who are already involved in gardening may find it easier to use grey water and urine than fetching water from a well for watering their gardens.

The proposed study will investigate whether a similar process is taking place in the sanitation sector and how urban agriculture affects the spouses.

The present discussion among people engaged in water-related gender issues has been concerned only marginally with changing relations and is often limited to easily observed or measurable facts like who fetches water and to what extent women are engaging in the planning and decision-making processes in water committees or in the formal water sector.[xixi]