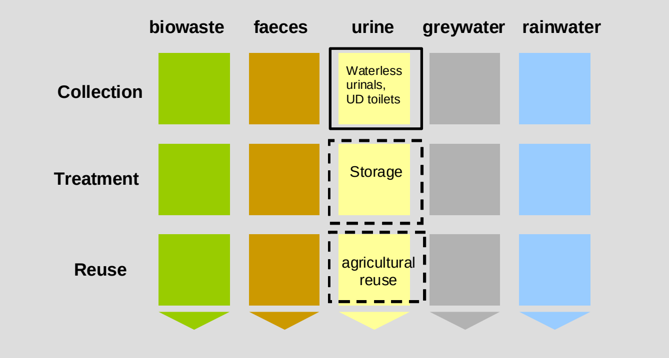
Basic overview of urine diversion components (waterless urinals, UD toilet bowls and pans, piping and storage)

DRAFT 2, June 2009



Preface and acknowledgements

Dear readers,

This document is a revised version of four separate documents (technical datasheets) on “urine diversion” which were published on the GTZ ecosan website in 2005. Authors of those four documents were Nathasith Chiarawatchai, Florian Klingel, Christine Werner and Patrick Bracken (in 2005 they were all working for the GTZ ecosan team). This revision has become necessary to include new findings obtained from research projects and practical experiences, and to update the information about suppliers of waterless urinals and urine diversion toilets.

The following colleagues provided substantial input to the text: Dr. Hakan Jönsson (especially to Section 3 to 6) and Dr. Elisabeth Kvarnström (for Section 3) (both from Stockholm Environment Institute (SEI), Sweden), and Dr. Martina Winker who contributed to Section 3.3, together with Dr. Arno Rosemarin (SEI, Sweden). The GTZ ecosan team is deeply grateful for their advice and contributions. We also thank all the suppliers who have provided information on their products which is shown in Appendix A.

Information was also taken from postings on the very useful Ecosanres discussion forum in 2008 and 2009 (to join: http://www.ecosanres.org/discussion_group.htm).

If you spot omissions, errors or confusing text, please e-mail us your feedback at ecosan@gtz.de.

We from the GTZ ecosan team hope that you find this publication useful for your own ecosan projects and dissemination activities.

Kind regards,

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Please send feedback and comments to the e-mail address given below. We look forward to hearing from you.

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1 Summary and target audience

The target audience for this publication are people who are new to the topic of urine diversion (or new to the topic of ecosan), with little technical background and who:

- need to obtain an overview of the main issues for urine diversion and the main technical components;
- want to know which are the main important documents in this field for further reading;
- may have a particular interest in the developing countries, pro-poor perspective;
- need information on available suppliers worldwide and on costs for waterless urinals and urine-diversion toilet pedestals and squatting pans.

This publication explains the purposes of urine diversion, its advantages and disadvantages, urine precipitation, urine treatment and reuse in agriculture. It provides an overview on design and operational aspects for equipment needed, such as waterless urinals and urine-diversion toilets including supplier information and indicative costs. The publication also provides basic design information for urine piping and storage tanks (including tank sizing, odour control and ventilation issues).

Urine diversion is the term used to describe keeping urine and faeces separate at the point of discharge from the producer. The four main purposes of implementing systems with urine diversion (UD) are: to reduce odour, to prevent production of wet faecal sludge, to reduce water consumption and to collect urine pure for use as fertiliser in agriculture.

Further potential advantages include minimised excreta-related groundwater pollution, the fact that the toilet can be indoors (as opposed to a pit latrine) and better control over micro-pollutants discharged to the environment. The associated disadvantages are mainly to do with having to "re-train" the users, and operational aspects related to urine precipitation and odour control.

Equipment needed for urine diversion includes waterless urinals (optional), urine diversion toilets (either dry or water-flushed), urine piping and urine storage tanks (optional). The most common and cheapest method to treat urine (for pathogen removal) is by extended storage.

Urine can safely be used in gardening and agriculture as a nutrient-rich fertiliser, provided relevant guidelines (WHO, 2006) are followed. If there be no use for the urine, it can be discharged to a sewer or infiltrated in the ground (if local soil and groundwater conditions permit this without adverse impacts on groundwater quality).

Waterless urinals would allow the collection of undiluted urine and are widely used, e.g. in Western Europe and USA, in public or communal buildings (less common at household level). But so far, they are usually just connected to the sewer system and the urine is not reused.

Odour control in waterless urinals is crucial for user acceptance, and is achieved by (i) various designs available for an odour blocking mechanism (most notably with a flat rubber tube, silicon curtain valve or sealant liquid), and (ii) by ensuring correct maintenance procedures.

Urine-diversion dehydration toilets (UDDTs) collect faeces dry in vaults located under the UD pedestal or squatting pan. For pro-poor approaches in developing countries, UDD toilets are more suitable than UD flush toilets, as the latter still require a sewer system and treatment for brownwater.

Recommendations for odour control and pressure equalisation from urine pipes and urine storage tanks (for indoor multi-toilet systems) are provided in this publication.

Waterless urinals and UDD toilets are a proven and promising step forward towards implementing water saving, more sustainable sanitation and reduced dependency on costly artificial fertiliser, thus contributing to poverty reduction.

2 Introduction to urine diversion (UD)

2.1 Definition of UD

The major difference between urine diversion (UD) and other sanitation systems is that a urine-diverting toilet has two outlets and two collection systems: one for urine and one for faeces, in order to keep these excreta fractions separate. UD toilets may, or may not, mix water and faeces, or water and urine, but they never mix urine and faeces. Urinals – widely used by men at public toilets, restaurants, schools, etc. – act *per se* as a urine-diversion device because urine is collected separately from faeces. When urinals are of the waterless version, they can collect the urine pure, i.e. without dilution with water.

Urine diversion <u>may</u> be used in ecological sanitation (ecosan) concepts, but <u>not all</u> ecosan projects use urine diversion. Ecosan is an approach to sanitation which focusses on options for reuse of nutrients and organic matter contained in excreta and wastewater, and emphasises sustainability in all aspects[1].

2.2 Purposes of UD

The purpose of UD installations (as opposed to conventional, non-UD systems) is usually one, or several of the following:

1. to reduce **odour** (in dry toilets): when urine and faeces are not mixed, the odour from a dry (or waterless) UD toilet is much, much less than when urine and faeces are mixed together (as in a pit latrine). Therefore, a dry toilet with UD can even be placed indoors without causing odour problems.
2. to **avoid production of wet, odorous faecal sludge**, which has to be removed by someone when the pit latrine is full. Faeces collected dry, separately from urine and water, are hardly offensive, especially after an extended drying period in a faeces vault); this is particularly relevant for hilly or crowded areas with difficult access for vacuum trucks to pit latrines.
3. to **reduce water consumption** – in the case where UD devices are of the waterless type (i.e. waterless urinals; UD toilets without flush water) or of the water-saving type (UD toilets where the urine is flushed with a smaller amount than the faeces).
4. to be able to **collect urine pure** so that it can – after sanitisation by storage – be safely used as fertiliser in agriculture. This is particularly important for small-scale farmers in developing countries who cannot afford costly artificial fertilisers.

[1] For definition of sustainable sanitation, please refer to the Vision Document of the Sustainable Sanitation Alliance (http://www.susana.org/index.php/lang-en/intro/vision/42-vision/76-vision-document)

2.3 Advantages of UD

The advantages of UD are closely linked to the purposes of UD, which were outlined in the previous section. The advantages are always case-specific and may include:

- Significantly **less odour** when compared to pit latrines (but odour is the same when comparing UD flush toilets with conventional flush toilets)
- Toilet can be **indoors** (when comparing UDD toilet to pit latrine), which leads to higher security, privacy and user comfort. In UDD toilets, the faeces dry out unlike in a pit latrine. Consequently, less odour is produced compared to pit latrines. Hence, the toilet can be indoors. This aspect is very important for women and girls, who may fear to go to the toilet outside in darkness if security levels in the community are low.
- **No production of wet faecal sludge** when comparing UDD toilets with pit latrines (but no difference in brownwater (faeces plus water) production for UD flush toilet and conventional flush toilets).
- **Water savings**: Even the urine diversion flush toilets can reduce water consumption for flushing compared to conventional water-flushed toilets: this is because after urination, the amount of flush water can be set to a low volume to flush away some remaining urine and the toilet paper. If urine-soiled toilet paper is collected in a bin, rather than flushed away, water savings can be even higher. Obviously, the potential savings from UDD toilets (without flush water) are even greater. Waterless urinals use no water for flushing, whereas conventional urinals use around 4 L per flush.
- **Recycling of phosphorus from urine** is easier if urine is collected pure, rather than mixing it with other wastewater. The element phosphorus is a finite resource, which will eventually run out - and up to that point, it will become increasingly expensive to produce phosphorus from phosphate rock. Phosphorus is an essential element in fertilisers. But at current rates of exploitation (increasing about 3% per year), the economic reserves of P will last no more than 50 years, and the US economically viable reserves will be depleted within 25 to 30 years (Rosemarin et al., 2008). Hence, in the future increased efforts to recycle the P content in human excreta are in fact unavoidable (EcoSanRes, 2008).
- Ability to use collected urine as **fertiliser**, which can lead to higher food security for poor farmers. As explained further in Section 3, urine is a liquid fertiliser rich in nitrogen and phosphorus and can thus be an important resource for people growing food or non-food crops.
- Environmental benefit (1): **No toilet wastewater production** (in the case of UDD toilets compared to flush toilets) since UDD toilets are not connected to a sewer. In the case of UD flush toilets, this advantage does not apply as the faeces and water mixture is still discharged to the sewer. In cases where untreated wastewater is discharged to surface water, then another advantage of a UDD toilet is the reduced pollution of surface water with nutrients (nitrogen and phosphorus) and pathogens; note however, that greywater is being produced in the same manner as before.
- Environmental benefit (2): **Minimised toilet-related groundwater pollution with nitrate and pathogens** (in the case of UDD toilets compared to pit latrines and septic tanks). Pit latrines and septic tanks are designed to infiltrate liquid into the soil, which can lead to groundwater pollution if the population density is high and the groundwater level is high as well. UDD toilets on the other hand collect the urine and faeces above-ground and therefore achieve groundwater protection[2]. Note that onsite greywater disposal can also lead to groundwater pollution and this issue is not addressed by urine diversion systems.
- If there is concern about **hormones and pharmaceutical residues** entering drinking water sources via sewage, then the separate collection of urine has the advantage that these substances can be eliminated from a concentrated source (urine), rather than from a dilute source (sewage). Treatment options are further discussed in Section 2.8. For industrialised countries, this can be a major driving force in favour of UD systems (e.g. in the Netherlands, where the concept is now better known under the title "new sanitation systems").
- Urine diversion may also create **business opportunities** for the private sector via the sale of the new UD technology, implementation, management, and marketing of the product (urine) to farmers.

Cost savings: whether or not there will be cost savings when implementing UD systems, cannot be answered universally, but is context specific (see Section 2.9).

2.4 Disadvantages and challenges of UD

2.4.1 Overview

Urine diversion may also have disadvantages and challenges, which are case dependent: They depend on what the situation was like before (e.g. did the users have pit latrines before? Or did the users have conventional flush toilets before?), and what is compared with what. Possible disadvantages include:

- Users have to "think a bit" when they use the toilets especially if they use them for the first time (this point does not apply to waterless urinals, which are used in the same way as water-flushed urinals). Thus urine diversion needs a certain level of **awareness raising** to achieve social acceptance.
- If users do not cooperate, the resulting abuse can result in odour (if users urinate in the faeces compartment of a UDD toilet) or a "messy" toilet (e.g. if users defecate into the urine compartment of a UD flush toilet).
- Anal washwater has to be collected separately (in the case of UDD toilets), which requires a basic level of understanding/cooperation from the user.
- In the case of UD flush toilets, maintenance requirements of urine diversion systems may be higher in comparison with conventional sewer-based systems. Users' commitment to the proper use of these facilities is very important:
    - o Cleaning of UD flush toilets is more time consuming than cleaning of conventional flush toilets, due to the separate urine compartment.
    - o Blockages of urine pipework due to precipitates can occur (see Section 2.4.3).
- If urine diversion is applied in cities, urine needs to be transported to the reuse areas by truck, leading to increased truck movements (and related CO_2 emissions).

[2] See Section 3.1.4 regarding possible risks of groundwater pollution when urine is reused in agriculture.

- When urine is used in gardening and agriculture, there are some aspects which the farmers need to consider – as with other fertilisers (see Section 3).
- If urine is not reused, but infiltrated, this could lead to groundwater pollution with nitrate (depending on the amount of urine infiltrated, soil properties, groundwater table).

2.4.2 Social acceptance

Regarding social acceptance, successful adoption of urine diversion is closely linked to:

- political will, messages from the media and local "champions"
- users' motivation and willingness to change existing habits and behaviours
- supportive attitudes of all stakeholders involved (i.e. users, maintenance staff, planners, farmers, politicians)
- demand for urine as a fertiliser (or some other reuse/disposal option for collected urine if agricultural reuse is not possible).

Hence, careful planning with stakeholder participation is crucial.

Odour nuisance is a potential obstacle to social acceptance, but with the correct design and operation, odours from waterless urinals and UD toilets are the same or less than conventional urinals and toilets. Also, UDD toilets can be expected to have significantly less odour than pit toilets, and can therefore be placed indoors which can be a significant driver for social acceptance.

Social acceptance also depends to a high degree on:

- What people are currently using (are they used to "flying toilets" (plastic bags) or to water-flush toilets?) and what they are expecting to get.
    - o UDD toilets may be perceived as a sub-standard, unhygienic solution, compared to flush toilets which the wealthy people have. It is important that UDD toilets are not seen as a solution for the poor only.
- Whether their culture has a tradition of reusing human excreta? Are there taboos surrounding faeces? If yes, these taboos need to be addressed.

2.4.3 Urine precipitation

The information given in this section has mainly been taken from Larsen and Lienert (2007), where further more detailed information is available.

Precipitation in urine pipes and storage tanks occurs in both water flushed and waterless systems. The solid precipitates consist of mineral compounds originating from urine ingredients such as calcium, magnesium, ammonium and phosphate.

In fresh urine, the main nitrogen compound is urea. During storage, urea is hydrolysed to ammonia/ammonium and hydrocarbonate by urease enzymes present in the urine storage container, soil and in aquatic systems (see also Table 1). This process is accompanied by an increase in pH. The increased pH value results in precipitation of struvite and calcium phosphate crystals.

This may occur as hard precipitates (incrustations) or soft, viscous, paste-like precipitates (deposits). While incrustations tend to occur on the inner walls of pipes and pipe bends (e.g. in water-flushed urinals), soft deposits occur in storage tanks (where they form a sludge at the bottom of the tank) and in near-horizontal urine pipes (e.g. outlet pipes from waterless urinals).

The incrustations, widely called "urine stone", consist of various crystals – mainly struvite and calcium phosphates.

The following factors reduce the extent of precipitation:

- **Short retention time**: precipitation often occurs at locations where the urine flow velocity is low or even stagnant (e.g. siphons, pipes with a small slope) and at the U-bend of the toilet.
- **Smooth surfaces and hydrophobic materials** should be used. Scratching of surfaces by mechanical cleaning should be avoided. Plastic PVC pipes are commonly used for urine pipes.
- Relatively **large diameter pipes** (at least 2.5 cm), as they are less likely to become blocked.
- If flushing with water: **Flushing with soft water**, such as rainwater, is preferred compared to flushing with hard water (soft water has a lower content of calcium and magnesium which can react with the ammonium and phosphate in the urine to form precipitates).

Using no flush water at all (e.g. in waterless urinals) does not eliminate the problem, since urine also contains calcium and magnesium to cause precipitation with ammonium and phosphate.

More information about maintenance tasks to prevent or remove blockages in urine pipes is provided in Section 6.2.

2.5 Quantity of urine

The quantity of urine produced by an adult is commonly quoted as 0.8-1.5 L per adult per day (WHO, 2006, Volume 4, section 1.5.3) – it mainly depends on the amount of liquid a person drinks. Children produce approx. half as much urine compared to adults. A widely used design figure, based on Swedish data, is **1.5 L/cap/d (or 550 L/cap/year)**[3].

2.6 Quality of urine

2.6.1 Pathogens

It is important to know that urine in the bladder of a healthy individual is sterile (meaning it contains no pathogens)[4]. Only very few diseases are transmitted via pathogens in urine. The only disease which needs to be considered from a risk perspective when urine is used is *Schistosoma haematobium* - in areas where this disease is endemic (WHO, 2006, Section 3.2.2).

In contrast, the amount of pathogens in *faeces* (such as eggs of intestinal worms) can be very high, depending on the prevalence of diseases in a given population.

2.6.2 Nutrients

With regards to nutrients contained in urine, the following design figures are generally used:

- Mass of nutrients excreted with urine: 4 kgN/cap/yr and 0.36 kgP/cap/yr

[3] Cap = capita = person

[4] However, cross-contamination of urine with faeces may occur during toilet use, see also Section 2.8.

- Concentrations of nutrients in urine (design figure): 7300 mg/L N; 654 mg/L P
- Concentration figures vary depending on a person's diet, (see Jönsson et al. (2004) for calculations on this) and should preferably be verified onsite.
- Other parameters of <u>fresh and old urine</u> are listed in Table 1.
  - o Fresh urine contains nitrogen mainly in the form of urea; old urine contains nitrogen mainly in the form of ammonium/ammonia (the transformation process is described in Section 2.8.2)
  - o The lower phosphate, magnesium and calcium concentration in old urine compared to fresh urine is due to precipitation processes.
- 80% of the nitrogen excreted by a person is excreted with the urine, and the rest with the faeces. Hence, in terms of nitrogen as fertiliser, urine is more important than faeces. For phosphorus, the figure is: 55% excreted with the urine, the rest in faeces.

Adults excrete the same mass of nutrients as taken up in their diet, i.e. there is no retention of nitrogen and phosphorus in the human body, except for children where a small amount is retained for bone growth.

Table 1. Chemical composition of fresh and old (stored) urine[5]

Parameter	Fresh urine (literature)	Stored, old urine (from an office building)
pH	6.2	9.1
Total nitrogen (mg/L)	8830	9200
Ammonium/ammonia $NH_4^+ + NH_3$ (mg/L)	**463**	**8100**
Nitrate/nitrite NO_3 + NO_2 (mg/L)	0.06	0
Chemical oxygen demand (COD), a measure of the organic components (mg/L)	-	10,000
Potassium K (mg/L)	2737	2200
Total P (mg/L)	800 – 2000	540
Sodium Na (mg/L)	3450	2600
Magnesium Mg (mg/L)	119	0
Chloride Cl (mg/L)	4970	3800
Calcium Ca (mg/L)	233	0

2.6.3 Micro-pollutants

Micro-pollutants in urine could include the following types of substances:

1. Heavy metals
2. Organic compounds
3. Natural hormones
4. Pharmaceutical residues, including e.g. hormones from contraceptive pill

The first two types of micro-pollutants – heavy metals and organic compounds - are virtually non-existent in urine as they would originate from the food a person eats (this is an advantage when using urine as a fertiliser compared to some artificial fertilisers which have elevated heavy metal contents).

The other two types of micro-pollutants - the natural hormones and pharmaceutical residues - do occur in urine. They represent however a low risk in urine reuse practices (see Section 2.8 and 3.3).

2.7 Technical components used for achieving UD

To achieve urine diversion, the following technical components are used: waterless urinals, urine diversion (UD) toilets, urine piping to a urine storage tank (or to a sewer) and a reuse system for the urine. UD toilets do not mix urine and faeces at the point of collection in the toilet.

There are two main variants of UD toilets: UDD toilets (urine-diversion dehydration toilets - no flush water is used at all) and UD flush toilets (water is used to flush the faeces away and to rinse the urine compartment). Further information is provided in the following chapters.

2.8 Urine treatment options

2.8.1 Treatment objectives

Urine treatment has the following objectives:

- **Pathogen kill** (this is the main objective): Collected urine may be contaminated with pathogens if careless or inexperienced users deposit faeces in the urine compartment of a UD toilet (this is termed "cross-contamination" of urine with faecal material). As mentioned above, pure urine is virtually pathogen-free.
- Other possible treatment objectives (these are not usually of relevance in the developing country context, as they are not crucial from a public health point of view):
  - o Volume reduction
  - o Conversion into solid form (struvite)
  - o Extraction (further concentration) of nutrients
  - o Elimination of micro-pollutants, such as pharmaceutical residues and hormones

2.8.2 Treatment by storage

The simplest, cheapest and most common method to treat urine is by **storage** (Section 6.1 provides design details).

Storage of urine in a closed tank or container (not gas tight) is an efficient treatment method for reducing pathogens in urine: The decomposition of urea into ammonia/ammonium and hydrocarbonate – which is facilitated by the natural enzyme urease - leads to an **increased pH value** which has a sanitising effect (meaning it kills pathogens), so that bacteria, protozoa and viruses die off over time. An environment with a high temperature and low dilution with water enhances this effect.

Pathogen content can be reduced to a level at which safe reuse of urine in agriculture is ensured, if the following recommended storage times are respected (for full details see WHO (2006), Section 4.4.4):

- Urine originating from larger systems (community level) – where cross-contamination with faeces cannot be ruled out - should be stored for at least one month if it is used on food or fodder crops which are processed. For a higher safety margin, 6 months of storage can be used (in which case the urine can be used on all crops).
- For urine which originates from small systems (household level) or from systems where cross-contamination with

[5] Source: Maurer, M. (2007) Urine treatment – absolute flexibility, Eawag News, March 2007, results from Novaquatis research project, Dübendorf, Switzerland http://www.eawag.ch/services/publikationen/eanews/news_63/en63e_maurer.pdf

faeces is definitely not occurring[6], no storage is needed when using such urine for crops grown for own consumption. This is because disease transmission within the family or within small communities via the urine-oral route is much less likely compared to the faecal-oral route.

2.8.3 Other treatment options

More advanced urine treatment – other than storage – can be via biological processes (nitrification), chemical processes (struvite precipitation; ozonation) or physical processes (membrane-based). Some of these "high-tech" methods (such as ozonation and membrane-based processes) can remove micro-pollutants from urine. This is useful to know if there is concern about micro-pollutants in urine (this is a theoretical risk for urine reuse, see Section 3.3)

These "high-tech" processes are well researched and documented e.g. in Larsen and Lienert (2007) and Tettenborn (2007).

2.9 Cost considerations

Possible cost savings of urine-diversion systems may be related to the following considerations (in each case, one needs to consider what system is being compared with what system):

- If a centralised sewer system and wastewater treatment plant can be avoided by using UD toilets, then cost savings may be considerable. However, the collection and treatment of greywater, industrial wastewater and rainwater, still requires a sewer system of some sort (separate, decentralised systems may often be preferable). Note that the remaining greywater contains a far lower concentration of pathogens and nutrients compared to conventional domestic wastewater.
- Farmers can use urine as a fertiliser instead of buying artificial fertiliser.
- Reduced water and energy demand may be possible, but this depends on the baseline scenario.

Regarding potential **energy** savings, this needs to be analysed on a case by case basis. Energy savings may be possible with UD systems in three areas:

1. If the system is set up to use less water, energy savings are possible with respect to pumping, processing and distribution of the tap water.
2. Energy savings may be possible at the wastewater treatment plant, which would receive a lower load of nitrogen in the sewage if urine was collected separately (hence less oxygen required for nitrification process).
3. If urine replaces artificial mineral fertiliser, then energy savings are possible for fertiliser production.

On the basis of a life cycle analysis, a study comparing the energy demands for nutrient removal and mineral fertiliser production versus nutrient recovery identified a considerable energy saving potential with urine diversion nutrient recovery (Maurer et al., 2003).

On the other side, the following aspects can lead to UD systems having higher costs than conventional systems:

- In comparison with conventional sewer-based sanitation systems, urine diversion systems which use UD flush toilets tend to have a higher initial investment cost as they require additional components for the separate collection, transport and treatment of the urine and faeces.
- A UDD toilet may have a higher capital cost than a simple pit latrine or – of course - the do-nothing option of open defecation.

Adequate financing and operating schemes have to be found that ensure financial sustainability. These have to be adjusted to what the users are willing and able to pay so that their financial burden stays affordable.

Further information is available in the fact sheet of the SuSanA working group on "costs and economics" (http://www.susana.org/index.php/lang-en/working-groups/wg02/documents-wg02).

3 Reuse of urine as fertiliser in agriculture

3.1 How to use urine as a fertiliser

When sanitation projects are set up where collected urine is to be used as fertiliser, consultation with farmers and soil fertility experts is essential, as the engineers and urban planners setting up the sanitation projects may lack the necessary agricultural expertise.

3.1.1 Basic guidelines

The benefits of urine as a fertiliser have been well documented. These benefits and the application methods for urine as a fertiliser in agriculture are detailed for example in SuSanA (2008), PuVeP (2008), Morgan (2007), WHO (2006) and Jönsson et al. (2004). Some highlights from these documents are summarised below.

Urine is a quick acting fertiliser that can be used for any crops which require N, P, K or S (nitrogen, phosphorus, potassium or sulphur[7]). The fertilising effects of the nutrients in urine are essentially the same as those of artificial mineral fertiliser if the same amount of N, P and K is applied. Hence, reuse of urine in agriculture has the potential to reduce demand for artificial mineral fertiliser.

Below are some rules of thumb for the use of urine as a fertiliser with respect to its nutrient content (e.g. taken from Jönsson et al. (2004)):

- Urine is a nitrogen rich complete fertilizer, containing also sodium and chloride. This makes it well suited as fertiliser for crops thriving on nitrogen, e.g. maize, and especially for crops also enjoying sodium, e.g. Swiss Chard (spinach), while care should be taken when applying for crops sensitive to chloride, e.g. Irish potatoes and tomatoes, even though yields of these crops can also be much improved by appropriate urine application.
- If all urine is collected, it will suffice to fertilize **300-400 m^2** of crop per person per year with N at a reasonable rate.
- For crop production, apply the amount of urine that one person excretes in one day on **one square metre** per cropping season. That means 1.5 L undiluted urine per square metre. If we assume that there is 7 gN/L in the urine (typical value for Swedish conditions), then 1.5 L urine/m^2 will correspond to 105 kg N/ha, which is a low to

[6] E.g.: urine collected from waterless urinals only (not from toilets).

[7] Sulphur is an important macro-nutrient, needed in approximately the same amount as phosphorus, and often lacking.

normal dose for cereals (depending on the country, soil and expected harvest from the field).

- The crop yield also depends very much on the soil, too. Urine will always work better in living soils compared to barren sandy soils. The nitrogen converting bacteria must be present. Compost helps enormously[8].

Some selected recommendations for the methods on *how* urine should be applied as a fertiliser are:

- Between fertilisation and harvest a withholding period of at least 1 month should always be applied (large and small scale systems).
- The person applying the urine to the fields should follow good personal hygiene practices (thorough hand washing, and when suitable also using gloves, see WHO (2006)).
- The best nitrogen fertilising effect is obtained when urine is applied close to the ground and directly incorporated or watered into the soil so as to minimize ammonia losses to the air. In order to avoid leaching, and for climates with heavy rainfall or very sandy soils, frequent application of small amounts of urine is favourable but not essential. It may be necessary to balance maximum crop yield with what is practical in real life.
- Urine should always be applied to the soil next to the plant (e.g. in furrows) but not onto the plant, especially when it is not diluted with water. *"We fertilise the soil, not the plant!"* (quoted from Linus Dagerskog at CREPA in Burkina Faso).

3.1.2 Specific advantages of urine fertiliser compared to other manufactured fertilisers

As pointed out by Eliabeth Kvarnström (Stockholm Environment Institute), one of the great advantages of urine is that the content of heavy metals and organic compounds is really very low, since these only come from the food which you have once considered having a high enough quality to ingest. Artifical mineral fertilisers can have a relatively high content of heavy metals.

Secondly, when farmers are able to use the urine from their households in their own fields, this fertiliser is essentially for free (where urine has to be transported over a distance from production to use, then there are transport costs).

3.1.3 Should urine be applied pure or diluted with water?

Urine can be applied either undiluted or diluted with water, depending on the soil and the gardener's or farmer's preferences.

Some gardeners dilute urine with water in a ratio of 1:3, 1:5 or even up to 1:15, and this dilution has the following advantages:

1. Reduces risk of plant "fertiliser burn" (see next section);
2. Enables irrigation and fertilisation in one step and with one piece of equipment or irrigation systems. But nozzles of drip irrigation may clog when a urine-water mixture is used for "fertigation" (irrigation and fertiliser application together).
3. Reduces odour during application, especially if a high dilution ratio is used (1:5 or greater).
4. Minimises the risk of applying too much fertiliser to potted plants, as the pot will overflow before too much nitrogen is applied.

On the other hand, applying urine undiluted has the advantage that a smaller volume of an odorous liquid has to be handled. Furthermore, existing drip irrigation systems would not get clogged with urine precipitates as in this case urine would be applied separately from the irrigation system.

When applying urine undiluted, fertiliser burn of the roots is avoided by adding urine in furrows, somewhat to the side of the plants. Odour nuisance is minimised by immediately covering the urine with soil after it has been added to the furrows. Usually, irrigation water is added directly *after* the urine application.

An explanation for this issue Peter Morgan (Aquamor, Zimbabwe – Ecosanres discussion forum in 2008): "*Whatever methods works and suits the "gardener" - by applying urine in holes or furrow and adding water later – or diluting - very fine. The point is that urine is getting into the soil. I am not sure whether the conversion of the urine nitrogen which cannot be used by plants into plant nitrogen (nitrate) by the soil bacteria takes place more efficiently in urine which is diluted and therefore spread out further into the soil or in undiluted urine which is concentrated more in one place first, then is diluted from the central spot. My guess this is academic!*"

3.1.4 Disadvantages of urine compared to other mineral fertilisers

Whilst urine is a proven fertiliser with many advantages, it is important to be aware of some drawbacks compared to artificially manufactured chemical fertilisers:

- Urine is, compared to artificial fertilisers, a diluted fertiliser: The N, P, K and S concentration in pure urine is much lower than in artificially manufactured fertiliser. Urine's nutrient content as a fertiliser is: $N:P_2O_5:K_2O$ is approximately 0.7 : 0.15 : 0.22 : 0.05 - compared to diammonium-phosphate (DAP) or $(NH_4)_2HPO_4$ with the composition: $N:P_2O_5:K_2O$ of 21:46:0:0.
  - This means that in terms of transport, a large mass of water is transported whenever urine-fertiliser is transported.
- Urine contains traces of pharmaceutical residues and hormones – this may stop buyers of crops fertilised with urine even if the actual risk of health impacts is very, very low (see Section 3.3).
- Urine is a multi-component fertiliser, containing N, P, K and S in a fixed (but slightly variable) ratio, which may or may not be the right fertiliser for a given soil and crop (Winker et al., 2008)
- The macronutrient concentrations in urine may vary somewhat (although in relatively narrow ranges), depending on people's diet and whether toilet users add some flush water to the toilet.
- Urine is a liquid fertiliser, whilst farmers may prefer a solid fertiliser (unless urine is converted to struvite, by addition of magnesium and raising pH, which is also a proven process).
- Urine adds salinity to the soil and therefore its use as fertiliser to pot plants is only recommended when the soil can easily be exchanged. Peter Morgan (Aquamor, Zimbabwe) explains: "*In pot soils (small volumes of soil) the salts will build up more quickly than in the garden, and*

[8] Source: Peter Morgan, Aquamor, Zimbabwe in 2008

may need replacing from time to time and perhaps put back into the compost pile, with fresh soil being added back to the pot. Use the pots and get the crop. Toss out the soil and introduce it back into the mound of soil and compost. Put new soil in the pot. But I guess you can't so easily do that in a flat without a garden" (Ecosanres discussion forum, 2008).

The following disadvantages are not specific to urine as a fertiliser but still need to be kept in mind:

- Like other fertilisers, urine can cause plant fertiliser burn if not applied correctly. Fertiliser burn is the visible symptom of insufficient water in a plant associated with an over application of fertiliser salts (i.e. those dissolved in urine)[9].
- Also like other fertilisers, urine can lead to groundwater pollution (with nitrate) and nutrient run-off (resulting in eutrophication in water bodies) if excess amounts are applied.

3.2 Is urine an "organic" or a mineral fertiliser?

The term "organic fertiliser" is widely used, but its definition may be according to two different categories:

1. Organic in the analytical chemistry sense (a compound which contains carbon, and may contain other elements such as hydrogen, oxygen, nitrogen etc.)
2. Organic in a "green", "eco" or "natural" sense.

Fresh urine contains urea, and can thus classify as an organic fertiliser in the analytical chemistry sense. Old urine contains ammonia and no urea (see Section 2.6.2), and is therefore *not organic* in the analytical chemistry sense.

In other words: Urine is both a natural mineralised or mineral fertiliser, and an organic or ecological or natural fertiliser[10]. More explanations on this double-definition is available in the archive of the Ecosanres discussion forum[11].

The "organic farming"[12] regulations differ between countries with regards to which type of fertiliser is allowable (and is in this context called "organic fertiliser"). For example, countries in the European Union are subject to the EU organic farming legislation, where urine is not considered an allowed fertiliser. In China on the other hand, urine is considered a natural fertiliser and thus allowed in organic farming.

Making urine allowed for organic farmers in the EU remains an important challenge. It should be possible as urine is a natural fertiliser with similar composition to e.g. pig urine.

3.3 Are hormones and pharmaceutical residues in urine problematic for reuse?

The information in this section is mostly based on Winker (2009). The publication of Larsen and Lienert (2007) is also recommended in this context.

Hormones and pharmaceutical residues are two types of micro-pollutants which occur in urine (concentration levels are available in Winker (2009)), as human beings excrete them with their urine and faeces (as a rule of thumb: two thirds of pharmaceutical residue substances are excreted with the urine, one third with faeces, although the figures can vary widely for individual substances[13]).

There is the possibility that if urine is reused in agriculture, these micro-pollutants can be taken up by plants and thereby enter the human food chain. This is a risk, but a small one: A full evaluation of the potential toxic effects of pharmaceuticals ingested by humans with crops is very difficult and has not yet been done. The risks needs to be put in perspective compared to pharmaceutical residues contained in animal manure, or the risks resulting from pesticide use.

With present sewer-based sanitation systems, these types of micro-pollutants are not removed in conventional sewage treatment plants either and are thus discharged into surface water bodies and can reach the groundwater in the long run (e.g. detected concentrations of pharmaceutial residues in groundwater lay in the range of 50 ng/L in Germany).

Apart from urine, already today animal manures and sewage sludge are brought to our agricultural fields containing such substances. It was shown that the load of hormones and antibiotics in urine is in fact much lower than in animal manure (however not all groups of substances can be compared in that way as they are not all present in animal manure).

When comparing the two approaches (mixing urine with water in sewer-based sanitation versus urine application to soil), it is safer to discharge urine to soil, rather than water, as the micro-pollutants can be degraded better in the aerobic, biologically active soil layers (high concentration of micro-organisms per cm^3) with long residence times than in water bodies whose ecosystem is much more sensitive. This has previously been proven in the case of hormones[14].

Soil is a more suitable medium for natural degradation of pharmaceuticals than water because:

- The oxygen levels are around 50,000 times higher than in water
- Exposure to UV light also helps to degrade pharmaceuticals, although this only applies to the surface (1-2 cm soil depth) and crops can shade the ground.
- Terrestrial systems are much better equipped to degrade organic compounds than aquatic ones. The high specific surface of soil particles maximises the exposure of adsorbed chemicals, maximising the kinetics of degradation such as oxidation, reduction, enzyme-enhanced diagenesis, etc.

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[9] Root cells actively absorb fertiliser salts from soil solution, and under normal conditions, maintain a higher osmotic pressure. If excess fertiliser salts are applied (i.e. concentrated urine which is not diluted), the osmotic pressure of the soil solution is raised. This means, water cannot enter the cell and may actively move out of it. The resulting injury is known as fertiliser burn or physiological drought (Robert Holmer, Ecosanres discussion forum, 2008)

[10] Source: Håkan Jönsson (Ecosanres discussion forum, 2008)

[11] See: http://www.ecosanres.org/discussion_group.htm, debate in December 2008.

[12] A possible definition of "organic farming/agriculture": Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (source: International Federation of Organic Farming Movement, http://www.ifoam.org/)

[13] To be more precise: around 70 % are excreted via urine accounting for 50 % of the overall ecotoxicological risk (see publications listed in Larsen and Lienert (2007)). The ecotoxicological risk of the fraction of pharmaceutical residues contained in urine and in faeces is the same regardless of the higher number of substances excreted via urine.

[14] This finding is of relevance for the artificial hormones which are excreted in urine from women taken the contraceptive pill.

- The wide biodiversity of the fungal and bacterial flora of soil are also adapted to degrade various sorts of organic molecules, both complex and simple.

Ultimately, the potential risks from consuming crops fertilised with urine need to be compared with the risks related to pesticide use on crops, as well as antiobiotics and hormones given to farm animals (poultry and cattle) which can be traced e.g. in milk and eggs.

Also, "*drug residues in sustainable sanitation products used to supply plant nutrients can hardly be a serious issue in regions where malnutrition, ground and surface water pollution due to inappropriate sanitation and irrigation with untreated waste water is reality*"[15].

Further thoughts of experts on this matter are summarised in the Appendix.

4 Waterless urinals

This chapter draws on the publication v. Münch and Dahm (2009). Note: "waterless" means "no water" in the English language. Some people also use the term "waterfree".

4.1 Definition and purpose

A urinal is a specialised toilet for urinating only, which is used while standing up, and is designed for male users. Urinals are widely used around the world, primarily in public facilities being frequented by a large number of people, because they save space and costs compared to toilets (simpler design; no separate cubicles needed, although in many cases separation panels are installed). Urinals are not commonly used in private households due to their additional space requirements.

A limited number of urinals for females (to be used while standing up, rather than squatting) are on the market but they are not generally accepted for various reasons, e.g. females have greater need for privacy as they have to partially undress. Squatting-type urinals (i.e. squatting pans without an outlet for faeces) are sometimes used for girls in e.g. African or Asian primary schools to save on space and costs compared to toilets.

Conventional urinals are flushed with approx. 4 L of water either after each use or based on a timer, whereas waterless urinals use no water for flushing. The main motivation for using waterless urinals (example shown in Figure 1) is to:

1. Save water (and energy) and hence costs – these urinals are simply connected to the sewer system.
2. Allow collection of pure, undiluted urine for use in agriculture as a nitrogen and phosphorus-rich fertiliser – these urinals are connected to a urine storage tank.

As has been pointed out previously, urine diversion can be a first step towards ecological sanitation (Kvarnström et al., 2006). And waterless urinals are the <u>first and easiest step</u> towards urine diversion.

[15] Quoted from Jörn Germer on Ecosanres discussion forum, April 2009.

Figure 1. Waterless urinals for men (left: Centaurus model of Keramag company; right: Plastic urinal from Addicom, South Africa, with Eco-Smellstop device). Sources: left: E. v. Münch, Delft, 2006; right: Addicom).

4.2 Historical development of waterless urinals

In 1894, Mr. Beetz from Austria patented a drainage device (trap) which allowed urinals to be made "flushless". The trap used a sealant liquid (the mechanism is explained later in this paper). This patent was then commercially exploited by the company F. Ernst Engineer in Zürich, Switzerland who was the sole supplier of waterless urinals worldwide for approximately 100 years.

In the early 1990s, water saving came into fashion and several companies appeared on the market using derivatives of the Beetz patent. At more or less the same time Hepworth, a UK plumbing manufacturer, patented a drainage device (one way valve) which was in fact a flat tube. A similar device is used in small boats to drain spray water from the bilge. Derivative patents of the flat tube elements are today used in waterless urinals and marketed by various sanitary ware companies, for example Keramag (model Centaurus).

In 2002, a Swiss engineer (Peter Dahm) patented a one way valve similar to the flat tube design but using a "curtain" mechanism in order to reduce maintenance requirements. This unit, which is now used in waterless urinals of several suppliers, is sold under the name of EcoSmellstop (ESS). Even the 100-year old company F. Ernst Ingenieur AG is since October 2006 using the ESS unit instead of its sealant liquid system.

At present, Germany may well be the country with the highest number of waterless urinals per capita, as the price of municipal tap water in Germany is one of the highest in the world, and Germans are consequently very interested in all water-saving opportunities (e.g. 1200 waterless urinals of Keramag are in use in the public toilets of Hamburg in Germany).

Waterless urinals are commonly used in industrialised countries for public toilets which are not connected to the sewer (e.g. rest stops along highways). Now it is time for this technology – in a low-cost derivate – to also take off in developing countries.

4.3 Odour control methods (general)

To guarantee a success, waterless urinals must meet the accepted standards applicable for conventional waterborne installations. Their odour emission must be less or at worst equal to the old system. To achieve this odour-free performance four aspects are absolutely crucial for waterless urinals:

1. Suitable mechanism to block the odour coming back from the sewer or urine storage tank, for example (discussed in detail in the sections below):
   - rubber tube seal
   - curtain valve seal
   - sealant liquid (blocking fluid)
   - old light bulb or plastic table tennis ball placed in a funnel which is inserted in the opening of a jerrican; or
   - place urinal in a well ventilated area (located outside of houses), and put up with some odour (may be possible for rural areas).
2. Appropriate surface of the urinal bowl (smooth, non-stick, e.g. with wax coating)
3. Correctly designed interrelation between urinal bowl and the drain fitting to minimise crevices where urine can accumulate
4. On operational level: a thorough maintenance regarding the bowl and the odour blocking device. The surface of the urinal bowl is usually wiped clean once, twice or several times per day with a moist sponge. For the odour blocking device, the maintenance depends on the specifications by the urinal supplier (see below).

4.4 Odour control for connection urinal to sewer or storage tank

4.4.1 Rubber tube seal

For this method, a flat rubber tube is used (Figure 2). This rubber tube is flat at the bottom when not in use (and hence blocks odour from the sewer or urine storage tank) but opens up when urine is flowing through. This one-way valve allows passage of grit up to 2 mm.

Urine precipitates ("urine stone"), which stick to the rubber tube need to be cleaned off with water regularly (otherwise the flat rubber tube does not close properly anymore). The cleaning frequency depends directly on the number of uses per day (e.g. cleaning once per month under average circumstances may be sufficient). The rubber tube needs to be replaced approx. once a year. The rubber material is sensitive to solvents, acids, and deodorising tablets often used in urinals. The use of acids or aggressive cleaning agents must therefore be avoided. This system is used for example by the German company Keramag in their Centaurus model.

4.4.2 Curtain valve seal

The curtain valve seal is similar to the rubber tube seal, but was designed to reduce maintenance requirements. It was designed to hydrodynamic laws quantified by Bernoulli (relation between flow speed of a medium and its pressure). This type of "one-way valve" has "self cleaning properties" as a small pressure difference forces the urine to wet the whole inner surface between the "curtains", therefore flushing them clean. The element is designed in a manner to minimise build up of urine precipitates or urine sludge and thus keeping the sealing surfaces clean. Like the flat rubber tube seal, this one-way valve also allows passage of grit up to 2 mm.

The silicon curtain element is integrated into a plastic casing (Figure 3). The placing of the EcoSmellstop (ESS) element into a plastic sleeve has a twin purpose, firstly to guarantee that no odour from the sewer or urine storage tanks escapes into the room, and secondly to allow an easy removal of the ESS unit for maintenance purposes. For replacement of the curtain, the entire plastic casing is removed with a small plastic extractor tool (Figure 4), then discarded and replaced with a new ESS. This replacement process takes only a few seconds and can be performed without having to touch the ESS element by hand.

The ESS manufacturing process is "high tech" as the injection moulds are of extreme complexity, and the mixing and injection requires very sophisticated machinery (for this reason, it is not yet possible to manufacture the ESS locally in developing countries, but it can easily be imported as it is small, light-weight and low-cost).

This patented ESS unit is used by the companies Addicom, Kellerinvent AG and F. Ernst Ingenieur AG since 2006.

Figure 2. Two types of odour seals for waterless urinals: Left: flat rubber tube (Keramag Centaurus) and right: Transparent EcoSmellstop (ESS) unit showing the blue silicon curtain one-way valve inside (source: Addicom).

Figure 3. EcoSmellstop (ESS) fitting with extractor. Inside the ESS is the silicon curtain valve (source: Addicom).

4.4.3 Sealant liquid (blocking fluid)

This system works with a sealant liquid (also called blocking fluid) which is made of vegetable oils or aliphatic alcohols – they are biodegradable if released to the sewer or urine storage tank. The sealant liquid, with a specific gravity of around 0.8, floats on top of the urine contained in the trap and thus constitutes an effective odour barrier. Urine immediately penetrates the sealant liquid and flows to the drain. Urine precipitates are collected in the cartridge (e.g. for Falcon Waterfree urinals) or inner cylinder of the trap (e.g. for Uridan urinals).

The maintenance program of waterless urinals with a sealant liquid calls for the cleaning of the urinal bowl and the exchange of the cartridge (or the sealant liquid, see Figure 4). Again, the required exchange frequency depends on the number of uses. With each use and in between uses, some urine precipitates accumulate which eventually renders the trap inoperative. Foreign objects, such as cigarette stubs, accelerate the process. At this point the cartridge has to be cleaned or replaced.

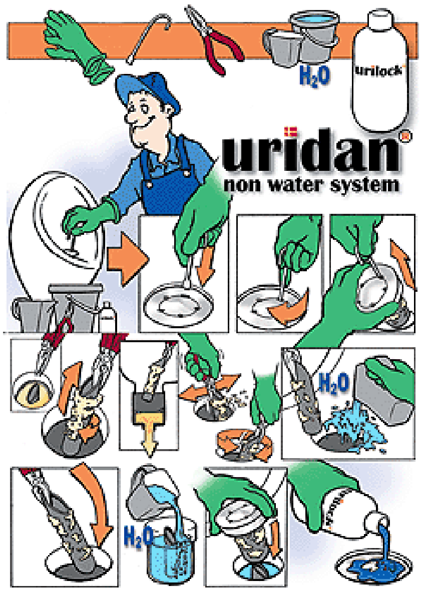

Figure 4. Example instruction sheet, showing replacement of sealant liquid for Uridan urinals (other urinals with sealant liquid have a similar maintenance routine). Source: Uridan.

If the trap commences to smell, while it is still freely passing urine, merely a refill with the sealant liquid can resolve the problem for some designs.

In the USA, this type of waterless urinal is currently the most common type of waterless urinal, as under current legislation only liquid filled traps are approved, but not waterless urinals that use the rubber tube or silicon curtain system.

Possible advantages of liquid sealant systems in the context of developing countries may include:

1. Does not need to be exchanged when full with precipitates, but can instead easily be cleaned out.
2. Not patented in developing countries, which means that they can be copied locally.
3. After being cleaned out, they can be refilled with some thick cooking oil e.g. a cheap olive oil[16] (this does not last as long as the recommended liquid, but is available almost for free anywhere).

There is no clear evidence yet which system is better for low-cost, low-maintenance applications, and this may depend on the preference of the individuals or companies responsible for the urinals' maintenance[17].

[16] Hakan Jönsson: "the important properties of oil for this use are density lower than water - most oils have a density around 0.7 kg/L - this way it floats on urine; hydrophobic - maintains a lid above the urine and its content; and both of these are shared by cooking oils. Cooking oils are partly unsaturated and will thus oxidise faster and need replacement, but this is secondary to them being generally available".

[17] The company F. Ernst Ingenieur AG which used the sealant liquid system (in its waterless urinals installed mostly in Switzerland and Germany), changed over to the EcoSmellstop system in October 2006, and is now retrofitting all of its approx. 100,000 urinals which were installed prior to that date (F. Ernst AG operates its urinals under a maintenance contract should the client not decide otherwise). The reason, according to Addicom, is the lower maintenance requirement of the ESS unit.

4.4.4 Other methods for the odour seal

Other methods for odour control are on the market (see also suppliers listing in Appendix A). One example is the system by Urimat[18] where the sealant liquid is replaced by a float (hydrostatic float barrier) which is magnetically activated thus opening the channel to the overflow chamber. For low-cost applications in developing countries, this system has the disadvantage of a higher complexity compared to the systems described above.

Small-scale simple systems may utilise just a pipe or hose (without any odour trap) connecting the urinal with the tank. Here, the odour can be controlled by having the urine pipe (filling hose) going down to almost the bottom of the collection vessel, thus creating a liquid seal in the collection vessel. Another option is to pour some cooking oil into the collection vessel, thus getting a thin sealant film in the collection vessel itself.

Another very simple option for a waterless urinal is the "eco-lily" (term invented by the NGO SUDEA in Addis Ababa), where a plastic funnel is inserted into the opening of a plastic jerrican. Into the funnel, an old light bulb or a table tennis ball is placed to act as odour seal (it floats up when urine enters the funnel). The disadvantage of the light bulb over the plastic ball is that the solder and metal cap on the light bulb contains heavy metals which can contaminate the urine.

4.5 Design information

The space requirement of a urinal is less than that of a toilet, which makes them popular for any venue where many people need to urinate (soccer stadiums, restaurants, schools, etc.). Waterless urinals are usually wall hung and do not require piping for fresh water nor flushing devices, thus allowing a considerable cost saving.

The flushing devices as well as the traditional water traps in the outlet piping (U, P or "bottle" shaped) of conventional urinals tend to attract a considerable amount of vandalism (hence waterless urinals can further reduce maintenance costs). Waterless urinals allow some additional advantages as they need not necessarily be connected to a sewer but can also be connected to a urine storage tank instead (important for remote locations not connected to sewers).

Obviously, water for hand wash basins and water-flushed toilets (if not replaced by waterless toilets) is of course still required in ablution facilities.

Materials:

Urinal bowls are typically made of acrylic, ceramics, stainless steel or glass-fibre reinforced polyester, but can also be made of simple low-cost plastic or concrete, provided that it has a smooth surface (for odour control). Self-construction of inexpensive waterless urinals is also possible. When using plastic urinal bowls, one option is to use linear low density polypropylene as it is among the most inert plastics (non stick surfaces). The hot production process at 180°C guarantees a smooth, non porous surface, therefore minimising bacterial biofilm growth.

Procurement options:

The following procurement options exist for waterless urinals in developing countries:

[18] Hans Keller used to run the company Urimat and has the patents. But he now runs Keller Invent which bought F Ernst AG (hence Mr. Keller moved from hydrostatic float barrier to ESS).

- Imported waterless urinals with or without patented odour control mechanisms;
- Plastic waterless urinals manufactured locally (mould for urinal bowl can be imported if needed), and locally manufactured liquid seal or imported ESS element inserted for odour control; or
- Self-constructed waterless urinals made from plastic containers.

For low cost applications, plastic urinals may be a good option. These can be produced in a "rotation moulding" process. This is a cheap and simple process to make a single-skin type unit, which can be replicated in any country.

Converting water-flushed urinals to waterless urinals

It is in principle also possible to convert conventional water-flushed urinals to waterless urinals (depending on the bowl design), for example by using the ESS, which is also sold as a "stand alone" unit. It is very important to get a snug fit of the ESS into the urinal drain.

4.6 Use and maintenance of waterless urinals

The instructions given below are not for urinals at households but for **installations at institutions or public places**. At household level in industrialised countries, waterless urinals for indoor use are rarely used – whereas for outdoor use in developing countries, waterless urinals are often installed in conjunction with urine-diversion dehydration toilets. At household level, different maintenance routines apply than those described below due to much lower frequency of use.

The urinal bowl should be cleaned daily, just like any other (water-flushed) urinal. There are 100% organic cleaning solutions on the market that are simply sprayed onto the urinal bowl, and not wiped off. For the waterless urinals in the GTZ headquarters in Eschborn, Germany, URIMAT MB-AktivReiniger with anionic and non-ionic tensides is used – this is a biologically active and biodegradable cleaning agent.

Any type of odour seal (be it flat rubber tube, curtain seal or sealant liquid) needs to be cleaned (or replaced if cleaning is no longer possible) in regular intervals to keep it fully functional in terms of odour control. The frequency of cleaning or replacement of the odour seal system depends on the number of uses per day, user and cleaning staff behaviour (e.g. in terms of foreign objects discarded in urinal), etc. It can therefore vary widely, e.g. ranging from once per week to once per month or once every six months.

The flat rubber tube and ESS units can be cleaned many times before having to be replaced. Some sealant liquid cartridges cannot be cleaned but need to be replaced when they fail, whilst for example the Uridan type system can be cleaned, and the sealant liquid replaced, any number of times.

To give an example: According to information given by Addicom, the expected 16-month life time of an ESS element can be achieved with careful maintenance, e.g. spraying the urinal bowl regularly with the cleaning agent “DestroySmell”, and removing the ESS element and rinsing with diluted citric acid to slow down the formation of urine precipitates on the curtains.

Empirical evidence gathered in low-income settings in South Africa (e.g. public parks and taxi ranks in Johannesburg) since 2004 suggests that the curtain seal (ESS system) can perform its functionality with *less maintenance* than the flat rubber tube. In regions where diligent maintenance of urinals cannot be guaranteed (e.g. public toilets in informal settlements in sub-Saharan Africa), the ESS system may therefore be a better choice of the two.

More side-by-side comparisons between different waterless urinal types (e.g. flat rubber tube versus liquid sealant type) are required, particularly for urban, low-income areas in developing countries with a potentially high level of abuse and neglect.

4.7 User acceptance of waterless urinals

Experience worldwide has shown that waterless urinals enjoy the same level of user acceptance as water-flushed urinals do, since for the male users there is no change required in behaviour (many users do not even notice that they are using a waterless urinal). - For those men who are “shy” and do not like using urinals in public places (for lack of privacy), it makes no difference whether the urinal is water-flushed or not.

When planning the use of urinals in cultures where anal washing with water is practiced, each urinal can be installed in a cubicle to guarantee privacy. For example, many Muslim males wash their penis with water after urinating, which requires water supply and separate drainage facilities. Prior to providing waterless ablutions, one has to establish whether the community in question is willing to accept such facilities.

In some instances, there may be a psychological barrier of users or cleaning staff (“if a urinal is not flushed it cannot be hygienic”) - the thought that water is always equal to hygiene is an understandable misconception. However, when faced with a well-functioning, odourless waterless urinal, those fears are quickly alleviated, which is why demonstration projects can be useful. Today’s waterless urinals are designed to be odourless and simple to maintain.

As waterless urinals are a novelty for many communities, any smell emitted from a waterless urinal gets blamed on the new system. However a smelly water-flushed urinal is accepted as “normal” as they have a longstanding odorous history. It is a fact that any type of urinal (water-flushed or waterless) will not smell if well maintained. The extent of maintenance required for waterless urinals can be higher or lower compared to water-flushed urinals, depending on the type of waterless urinal used (as explained above).

4.8 Suppliers and costs of waterless urinals

Suppliers lists for waterless urinals are provided in Appendix A.

For reference installations either contact the manufactures directly or see the case study descriptions of sustainable sanitation projects on www.susana.org: many of these projects incorporate waterless urinals. Photos of waterless urinals are available here: http://www.flickr.com/photos/gtzecosan/sets/72157613881735035/.

4.9 How to choose the right type of waterless urinal

When choosing a waterless urinal from the large range of suppliers and models, the following guide questions can be used (for waterless urinals in institutions and public places[19]):

[19] Note: For waterless urinals at households, the maintenance considerations are quite different. Househols want to be able to do the maintenance using materials that can be found in the general store at a minimal cost.

1. Do the urinals need to be as cheap as possible?
2. Do the users prefer ceramic urinals and can they pay for the higher costs compared to plastic urinals?
3. Are the urinals available locally (local distributor) or do they have to be imported?
4. Is there likely to be any vandalism in the location where the urinals will be installed?
5. Who will do the maintenance, and will they be diligent or rather unreliable?
6. After how many uses does the odour seal need replacement (or after what time period)?
7. How long does each event of odour seal replacement take?
8. How "messy" is the odour seal replacement routine?
9. Does the supplier offer you to get in contact with the suppliers' existing clients?
10. Does the supplier have reference letters?
11. How many units has the supplier sold already and can you go and see them?
12. Do the urinals need specific spare parts, and can they be obtained locally and with minimal waiting times?

5 UD Toilets (UDD or water-flushed)

5.1 Definition

Urine diversion (UD) toilets are designed to not mix urine and faeces at the point of collection in the toilet. There are two main variants with UD toilets:

1. **UDD toilets** (urine-diversion dehydration toilets or UDDTs) - no flushwater at all is used. These toilets are often called "ecosan toilets" – something which GTZ does not support, since it wrongly labels one particular toilet type as *the toilet* to be used in ecosan projects.

2. **UD flush toilets**: Water is used to flush the faeces away, and to rinse the urine compartment.

These toilets may be implemented within new sanitation systems or may complement existing systems. In any case, additional pipework such as a second pipe from the toilets to the holding tanks becomes necessary (see Section 6).

5.2 Design information for UD toilets in general

Careful planning and appropriate design is essential for successful application of UD toilets. They should be designed or chosen based on the needs and the customes of the intended users. The preference of the user can be distinguished between:

- **Sitting toilets** (with pedestals): these can be wall-hung or floor mounted. Specific connection parts may be necessary for proper installation. Easily accessible and removable connections can help in case of required replacement.
- **Squatting toilets** (with squatting pans): many people are used to toilets which are used in a squatting position so that no part of the body has to touch the toilet.

Further design considerations which need to be considered for all UD toilets (these will be described in the following sections):

1. Do the users intend to wash their anal area with water after using the toilets instead of using toilet paper ("washers" as opposed to "wipers"). This is customary in many Muslim cultures but is not 1:1 linked to religion, e.g. in parts of India also Christians practise this. It is therefore also linked to cultural norms, climate, availability of water, habits, etc.
2. Consideration on how the toilets can be used by disabled people, elderly, children (just like for other toilets).
3. Specific needs of females (menstrual hygiene considerations; privacy needs).
4. Odour control methods for the urine pipe.
5. Will the toilet be an indoor or an outdoor toilet (indoor is likely to become the norm in the future and is possible with UD toilets).

5.3 Urine-diversion dehydration toilets (UDD toilets)

5.3.1 Basic design information for UDDTs

UDD toilets do not use water for flushing. They use a very simple system where the urine is captured in a bowl which is integrated in the front of the toilet pedestal or squatting pan. From here, the urine is drained off to a storage container (or leaching pit if the urine is not collected – beware of possible groundwater contamination with nitrate).

For the faeces, a straight drop (or chute if toilets are on several levels in the house) is provided from the toilet pedestal or squatting pan to a collection chamber (faeces vault) below. The faeces vault can also be in the form of a large bin.

A vent pipe is provided to ventilate the faeces chamber, remove odour from the room and to speed up the drying process.

UDD toilets are not designed for composting to take place in the faeces chamber (on the other hand, composting toilets can be designed with urine diversion).

In regions where people practise anal cleansing with water (e.g. many Asian countries, West-African, Muslim-dominated countries), a third hole and pipe is used, to collect the anal washwater separately from urine and faeces – it is best not to mix it with the urine to keep pathogen levels in the urine to a minimum, if it is to be used as a fertiliser.

Figure 5. UDDT toilet (pedestal type) in Johannesburg, South Africa at the house of Richard Holden (ecosan pioneer). Source: E. v. Münch, 2006.

Figure 6. UDD toilet (squatting type) in Ouagadougou, Burkina Faso, installed by NGO CREPA. Source: E. v. Münch, 2006.

5.3.2 Odour control for UDDTs

For the urine pipe, an odour seal may be used if the toilet is indoors, especially in systems with many toilets (the same types of seals as for waterless urinals can be used, including the ESS (see Section 4.3)).

Some UDDTs have an integrated fan (e.g. the toilet of Separett), which removes odour from both the faeces bucket and the urine pipe. No separate odour blocking device is necessary in this case.

For outdoor UDD toilets with individual urine storage tanks, the connection to the urine storage tank is usually direct, without any odour trapping device.

The vent pipe from the faeces chamber removes odour from the faeces chamber.

5.3.3 Construction methods and materials for UDDTs

Possible materials for the toilet bowl or squatting pan are: ceramic, concrete, acrylic, glass-fibre reinforced plastic. The construction can either be self-constructed or prefabricated.

Metal components (except for stainless steel) cannot be used since urine is corrosive.

See Appendix A for further details on available products.

5.3.4 Use and maintenance of UDD toilets

The main operational requirements when using UDD toilets is that the faeces vault is kept as dry as possible (no addition of urine or water; also anal washwater cannot be added to faeces vault, but needs to be collected separately)

Covering material should be added to the faeces vault after each defecation. Covering material can be ash, sand, soil, lime, leaves, compost. The cover material should be as dry as possible. The purpose of adding covering material is to:

- Reduce odour
- Assist in drying of the faeces (soak up excess moisture)
- Prevent access for flies to faeces
- Improve aethetics of the faeces pile (for next user)
- Increase pH value (achieved when lime or ash is used)

5.3.5 Examples of projects which use UDD toilets

UDD toilets are used in sustainable sanitation projects worldwide, mainly in rural and peri-urban areas, and they have also been implemented in urban areas. They have been installed at household level, at schools and for public toilets, and are especially popular wherever there is a demand for cheap fertiliser. As mentioned above, they can be built indoors or outdoors.

Projects which are using UDD toilets are described in the case studies of SuSanA (http://www.susana.org/index.php/lang-en/case-studies), particularly in the Philippines, India, China, Uganda. They can also be found via the Google-Earth based tool Sanimap (www.sanimap.net).

5.3.6 Further information for UDD toilets

Further information for UDD toilets can for example be found in:

- Winblad and Simpson-Hebert (2004)
- A detailed study from 2005 on the use of UDD toilets in a sewered area, in Stockholm, can also be downloaded from www.urbanwater.org (Urban Water rapport 2005:8, in Swedish only).
- Austin (2006)
- Morgan (2007)
- Berger (2008)
- Technology reviews of GTZ on dehydration toilets and on composting toilets (publications are currently being revised): http://www.gtz.de/en/themen/umwelt-infrastruktur/wasser/9397.htm

5.4 UD flush toilets

5.4.1 Overview on historical development

UD flush toilets were invented in Sweden in the 1990's (Kvarnström et al., 2006). Their application was first adopted in eco-villages and holiday homes. Today, they are also used in some housing projects and public buildings in several countries in Europe, although still only at a pilot scale.

A detailed study – NOVAQUATIS - on the use of UD flush toilets was conducted by EAWAG, Switzerland (Larsen and Lienert, 2007).

5.4.2 Basic design information of UD flush toilets

The UD flush toilet has a partition in the toilet bowl isolating a bowl for urine in the front, and a bowl for faeces in the back. The bowl is similar to bowls used for UDD toilets, except that for the UD flush toilet, water is used to flush the faeces away.

The flushing mechanism for the urine part is designed in one of two ways:

1. The urine pipe stays open and therefore receives a certain amount of flushing water when the bowel is flushed (see Figure 7); or

2. The urine pipe is closed by a valve and therefore receives no flushing water (this is the case for the Roediger NoMix toilets, see Figure 8).

UD flush toilets can also be combind with the concept of vacuum toilets (realised for example by the company Roediger for a pilot project in Berlin Stahnsdorf and by the Swedish company Wost Man Ecology, see Appendix A). This type of toilets allows separate collection of urine and a small, concentrated amount of "brownwater" (faeces with about 1 L of flush water).

Vacuum systems are the subject of another technology review (see: http://www.gtz.de/en/themen/umwelt-infrastruktur/wasser/9397.htm).

Figure 7. UD flush toilets (left: Gustavsberg (in Meppel, the Netherlands); right: Dubbletten (in Stockholm, Sweden)). Source: E. v. Münch, 2007.

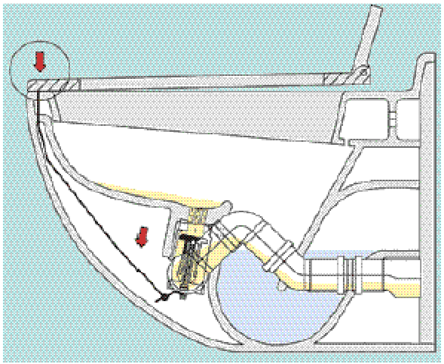

Figure 8. Schematic showing the valve on the urine pipe to collect urine without flushing water in the Roediger "NoMix toilet" – valve opens when the user is seated (source: Roediger).

5.4.3 Odour control for UD flush toilets

For the faeces part, odour control is achieved by the common water seal in a U-bend (as for conventional flush toilets).

For the urine pipe, several types of odour seal are used by the toilet manufacturers, e.g. a valve (Roediger NoMix toilets), a urine/water seal (Gustavsberg toilets) or a novel silicon seal (Dubbletten toilets)[20].

Odour locks in the UD toilet and urinal are required to prevent back flow of odour into the air space above the drain opening and into the toilet room; but these are not necessary in the cases of short pipe systems of 3-4 meters or less.

5.4.4 Materials for UD flush toilets

As UD flush toilets have been designed for users in high-income countries, they have so far been manufactured only in ceramic – the same material which the users are used to from conventional flush toilets.

5.4.5 Use and maintenance of UD flush toilets

The faeces section of UD flush toilets is cleaned in the same way as for conventional flush toilets (using a brush directly after use).

Toilet paper is flushed away together with the faeces. A particular problem found with the Roediger NoMix toilets is that toilet paper thrown into the urinal bowl is not flushed away with the small urine flush; and hence more than one flush become necessary – reducing the water saving effect of this toilet.

A particular problem for the Roediger NoMix toilets is also that the valve on the urine pipe can get blocked over time (in this case, urine is no longer collected in the storage tank but flows to the faeces compartment of the toilet).

One potential problem is blockages of the urine pipe leading from the toilet to the storage tank (for causes and solutions see Section 2.4.3 and Section 6.2).

5.4.6 Examples of projects which use UD flush toilets

UD flush toilets are used rather in industrialised countries (not a low cost option). So far they are mainly used in Sweden with some isolated projects in Germany, the Netherlands, Switzerland and Austria.

Two project examples for which detailed descriptions are available are (both on http://www.susana.org/index.php/lang-en/case-studies/europe):

- Urine and brownwater separation at the GTZ main building, Eschborn, Germany
- Urban urine diversion & greywater treatment system, Linz, Austria

5.5 Suppliers and costs for UD toilets

Information on models and suppliers can be found in Appendix A.

The costs for these toilets which are not yet sold in very high numbers is relatively high, as there is not enough economy of scale yet. If the market for these types of toilets grows and more suppliers enter the market, then the unit costs will decline.

5.6 How to choose between a UDD toilet and UD flush toilet

A general guideline on how to choose between a UDD toilet and a UD flush toilet is presented in Table 2.

For pro-poor approaches in developing countries, UDD toilets are more suitable than UD flush toilets, as the latter still require a sewer system and a safe treatment of the faecal water ("brown water") to achieve good hygienic conditions.

[20] Hakan Jönsson (March 2008): "*the only part which needs replacement for the new Dubbletten system, probably after about some 8-16 months, is a small oval sheet made out of silicon. It should be fairly cheap, cheap to ship and it seemed easy to replace, as it is fixed only with a knob, close to one edge.*"

Table 2. Comparison of UDD toilets and UD water-flush toilets

	UDD toilet	UD water-flush toilet
Advantages	• Does not require connection to water supply nor to sewer and treatment plant • Collects urine undiluted • Can be home-built, low cost, simple design • Results in easy-to-handle, dried faeces	• Requires hardly any change in user behaviour (for people used to flush toilets) • No significant odour risk if not used right • Has similar "appeal" for users as flush toilet • Allows collection of urine pure or with little flush water (depending on the model) • Can have lower water consumption compared to conventional flush toilet (since less water used to flush after urination), but the actual water use depends mainly on user habits.
Disadvantages	• Is prone to odour if users are not sensitised or unwilling to use correctly • Requires paradigm shift for those who are used to flush toilets or who aspire to have flush toilets	• Requires to be connected to reliable water supply and to sewer system (for faeces-water mixture) • Requires treatment step for faeces-water mixture (not manageable by user) • More expensive than conventional flush toilets and than pit latrines • Possible blockages in urine pipe and valve (if valve is used, e.g. Roediger NoMix toilet)
Applicable for developing countries?	• Yes - rural, peri-urban, public toilets, slums, cities	• Partially – only for wealthier segment of society (similar to application range as for conventional flush toilets)

6 Urine storage tanks and piping

A comprehensive description of the technical details for urine pipes and tanks is available in Appendix 2 of Kvarnström et al. (2006). Below, some key considerations are provided.

6.1 Urine storage

6.1.1 Functional principles

The urine which is collected by means of a waterless urinal (or by a urine-diversion toilet), can be collected undiluted in a urine storage tank. These tanks are either emptied by the users themselves (small-scale systems) or emptied by a pump and truck arrangement (vacuum tanker are also possible). The urine is then transported to the point of agricultural reuse (or to further storage or treatment if desired).

As explained in Section 3, urine is well suited as a fertiliser in agriculture.

Urine storage tanks are used for one or several of the following three main purposes:

1. To bridge the time in between collection/emptying events by transport vehicle or by the users themselves.
2. To sanitise the urine: over time, pathogens in the urine tanks are killed off (increased pH due to urea conversion to ammonia; time itself also results in pathogen kill – see Section 2.8).
3. To bridge periods where plants are not fertilised: The plants' needs for urine fertiliser is not constant all year round, but mostly just before sowing and in the beginning of the growth period (see Section 3).

At the bottom of the urine storage tank a layer of sludge forms over time (containing precipitates and crystals – see Section 2.4.3), with high levels of nitrogen, phosphorus, calcium and magnesium. If the full nutrient value of urine is to be used for fertiliser purposes, then it needs to be ensured that also the bottom sludge layer is emptied and reused.

6.1.2 Locations for the urine storage tank

The location of the urine storage tanks can be:

1. At toilet level: If the urine is to be used in the household garden, a simple construction is possible (example: Figure 9).
2. At household/building level (several toilets together).
3. At community level (several houses together) – this is possible if distances between houses are short (see Figure 10).

As the urine tanks must be emptied regularly, suitable access for trucks is required.

The tanks can be located either in the cellar of the building or next to the building or below ground. Urine tanks below ground have the disadvantage that leaks from the urine tank are difficult to detect (a leaking urine storage tank can lead to groundwater pollution with ammonia and nitrate or to the tank being filled up with groundwater). Underground tanks have the significant advantage however that they are usually much cheaper and the access to the manhole is usually also easier.

Whilst the tanks are designed to minimise odour, some odour could still occur. Hence, the tanks should be in a well-ventilated area and away from kitchen, office and bedroom areas etc. to minimise odour complaints from users.

A secondary urine storage tank at the point of reuse (agricultural fields) is often used to enable the farmers to use the urine when they need it (Figure 11). As a side benefit further sanitisation of the urine takes place during this second storage period.

6.1.3 Materials for urine storage tanks

Urine storage tanks need to be 100% watertight to avoid loss of valuable nitrogen fertiliser, groundwater contamination and groundwater entering.

Urine storage containers are most commonly made of glass fibre reinforced plastic, PE, PP or PVC, but they can also be made of rubber bladders or reinforced concrete. There are a fair number of concrete urine tanks in Sweden. They are cheaper for small tanks and so heavy that they do not float if the groundwater is high.

Metal components cannot be used since urine is corrosive (except for stainless steel, which can be used but is expensive).

Plastic tanks which are used for rainwater harvesting are also suitable tanks for urine storage tanks.

6.1.4 Urine tank size

The required urine tank volume ($V_{storage}$) can be estimated as follows:

$$V_{storage} = N_{users} \cdot p_{urine} \cdot t_{emptying} \cdot f_{timefraction}$$

with:

N_{users} = number of users

p_{urine} = specific urine production per person (~ 1.5 L/cap/d of urine if the user was at the premises 24 hours per day[21])

$t_{emptying}$ = desired time between emptying events

$f_{timefraction}$= fraction of the time that the users stays in the premises where the toilet is.

The required storage time ($t_{emptying}$) was already discussed in Section 2.8.2).

For example, typical design criteria for a storage tank is 360 L of urine per person per year (if they spend 2/3 of their time at the premises) and a storage time of two months.

It is obvious from this equation that if urine is flushed away with water, then a larger urine storage tank is required compared to a toilet where urine is collected undiluted.

When designing the size of the urine storage tank, consideration needs to be given to the capacity of the emptying vehicle to be used so that there is a good match. Details on tank sizes and possible emptying vehicles in the low-cost context are provided in Slob (2006).

If several tanks are installed, they should be placed in parallel, rather than in series, so that they can be filled alternately. For large installations, the use of several urine storage tanks is advisable so that one can be taken out of service if necessary.

6.1.5 Ventilation or pressure equalisation

The holding tank should not be ventilated but have a mechanism for pressure equalisation in order to equalise pressure to allow for the replacement of headspace air by urine flowing into the tank and vice versa, when emptying the tank.

[21] Plus flushing water if UD flush toilets are used, unless they have a valve like the Roediger NoMix toilet model

The urine tank should not be opened more often than necessary in order to prevent odour development and ammonia-nitrogen losses. Important points concerning the tank's ventilation system are:

- Normally no vent pipe is needed, provided that the main opening is not very tightly sealed.
- In places where odour control is essential, a small diameter vent pipe can be used for pressure equalising of the tank.
- If the tank is emptied by suction truck, provisions should be made for sufficient flow of air into the tank to prevent undue vacuum in the tank, which can cause tank implosion.

The urine pipe system shall also, quite opposed to other wastewater pipes, *not* be ventilated. The pipe system shall only be pressure equalised which is best done by a small hole in the tank for equalisation with the urine tank pressure.

The reasons why the pipe system shall not be ventilated are:

- ammonia emissions are decreased
- ammonia smell in neigbourhood is eliminated
- risk of blockage in vertical urine pipes are largely reduced
- risk of sucking the liquid out of the liquid urine seals is largely reduced.

A one-way valve or air admittance valve placed at the top of the pipe stack can also be a good option. Advantages are[22]:

1. that ammonia is not emitted
2. internal pressure is equalised ensuring proper drainage downwards to the tank (emptied urine pipes mean no standing urine and less build up of struvite)
3. the installation can be done inside the building just above the top floor urinal or UD toilet in the building so the top of the pipe stack does not need to penetrate the roof like old-fashioned ventilation pipes always have
4. saves on construction costs
5. eliminates problems caused by condensation ice and UV weathering of plastic pipes.

The product is popular in Sweden for greywater and urine systems and many new houses do not have protruding ventpipes anymore[23].

6.1.6 Urine overflow pipe

Installation of a urine overflow pipe is not recommended, as this increases cost, introduces a risk of contamination of the urine when there is an overflow or blockage in the ordinary wastewater system and as an overflow easily leads to the urine just overflowing instead of being emptied. It is better that the urine is pumped to an acceptable disposal point with a portable wastewater pump, if the collection tank becomes too full.

6.1.7 Examples for urine storage tanks

Examples for different urine storage tanks of different sizes are shown below.

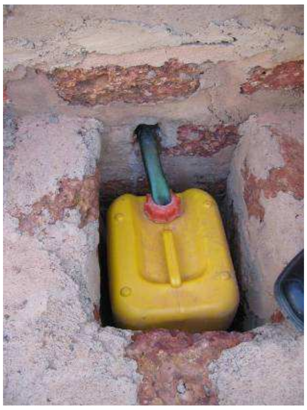

Figure 9. Low-cost solution: 20 L plastic jerrican for urine storage at individual toilet level in Ouagadougou, Burkina Faso (source: E. v. Münch, 2006).

Figure 10. Below-ground plastic urine storage tanks at Kullön, Sweden during the construction process. The tanks will be covered with soil. Photo: Mats Johansson (source: Kvarnström *et al.* (2006), page 36).

Figure 11. Urine storage tank made of a plastic bladder (3 x 150 m^3) at Lake Bornsjön near Stockholm (Sweden). Photo commissioned by: E. v. Münch (2007).

[22] Posting by Arno Rosemarin (SEI, Sweden) on Ecosanres discussion forum, August 2008.

[23] Link to website of an American supplier: http://www.accentshopping.com/product.asp/P_ID/150518#tabtop

Figure 12. Above-ground plastic urine storage tank in Ouagadougou, Burkina Faso as part of EU-funded CREPA project ECOSAN_UE (source: S. Rüd, 2008).

6.2 Urine piping

6.2.1 Functional principles

The urine piping system connects the waterless urinals or the urine compartment of a UD toilet with the urine storage tank.

As urine generates a considerable amount of urine precipitates or sludge, special attention has to be given to the design and maintenance of the urine piping system.

It is important that the incoming pipe to the urine storage tank goes down almost to the bottom, so that a liquid seal is formed preventing undue gas movement through the piping system. But it is not recommend to place a bucket here, as it might fill with the heavy sludge, and thus introduce an undue flow restriction.

6.2.2 Materials for urine pipes

Urine pipework is normally made of durable plastics such as polyethylene (PE) or polyvinyl chloride (PVC).

6.2.3 Pipe size and layout

To maximise the flowrate of the urine (and any resulting sediment), the insides of the pipes should be smooth. Flow restrictions, e.g. sharp 90º bends, should be avoided as much as possible.

The minimum recommended diameter of the piping or sewer is 50 mm, but the optimum range is from 75 mm to preferably 110 mm.

For larger systems (several toilets connected to one urine tank), the slope of the pipe should be at least 1% to minimise urine precipitation. For individual toilet systems, the slope should be at least 4%, but can be built with smaller diameter pipes, down to about 15 mm.

For inspection and cleaning, the pipes should be made accessible (by the provision of inspection openings).

As a rule of thumb: keep urine pipes as **short** as possible and with the highest possible slope (having long, horizontal pipes can cause blockage problems). Horizontal delivery pipes from the pipe stack to the underground tanks should not exceed 200 m because of the problems of sludge accumulation in the continuously wetted side of the pipe[24].

Over time crystals and sludge may accumulate in the slow flowing horizontal parts of the pipe system, so periodic flushing may be necessary (once every few years in the best cases; more frequent in the worse cases) – although this is minimised if the slope is at least 1% and pipe diameter is at least 75 mm[25].

6.2.4 Odour control

To prevent odours, the piping system should be *only sparingly* ventilated, pressure equalisation is enough (see Section 6.1.5 for more details on ventilation).

To prevent odour from the urine pipe and storage tank, the pipe opening needs to be immersed in the liquid in the storage vessel; this is especially important in long pipe stacks that can act as chimneys with upward flow of air[26].

For individual toilet systems, the urine pipe can be without any odour seal.

6.2.5 Maintenance of urine pipes

It is difficult to predict how often pre-emptive maintenance should be carried out, as this will depend on local circumstances – trial and error will lead to an optimised cleaning schedule. Experience has shown that correctly installed pipes generally need no cleaning, except for the odour seal or 90-degree bends (which should be avoided).

Detailed instructions for clearing and preventing blockages in U-bend odour seals are provided in Kvarnström et al. (2006) in Appendix 2, from where the following paragraphs are taken:

"In all installations there is a risk of blockages occurring mainly in the seal. It is a result of fibres and other particles entering the piping system and of chemical precipitation of struvite ($MgNH_4PO_4$) *and calcium phosphates* ($Ca_{10}(PO_4)_6(OH)_2$) *from the urine caused by the increase in pH which occurs when its urea is degraded. The precipitation also forms a viscous sludge, which will slowly flow towards the tank provided that the slope of the pipes is correct.*

Most blockages that occur in urine-diverting toilets are "soft" blockages caused by precipitation on hair and paper fibre. The other type is hard "blockages", caused by precipitation directly on the on the pipe wall[27]*. The blockages are removed either mechanically by a drain auger or chemically by use of strong solutions of caustic soda (2 parts of water to 1 part of soda) or acetic acid (>24%)."*

It is important that the cleaning is carried out in a way so that the quality of the urine in the urine storage tanks is not negatively affected.

But if the urine can flow freely and immediately in its fresh state without additions of water directly from the urinary

[24] Source: Arno Rosemarin (March 2009)

[25] Hakan Jönsson (March 2009): *My fairly extensive experience is that as long as there is at least a slope of 1% and the diameter is 75 mm or more, then the sludge will flow out at the rate of generation, flushing is not necessary. And the reason extensive pipes should be avoided is that frequently there has been problems with groundwater leaking into the pipes, diluting the urine!*

[26] Source: Arno Rosemarin, March 2009, based on experiences with large-scale urine diversion system with indoor toilets in Erdos, China.

[27] Hard blockages tend to occur when water is mixed with urine, whereas soft blockages tend to occur in pure urine systems.

bladder to the storage tank, no blockage in the pipe will occur.

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7.2 Video clips on YouTube.com

The following video clips are available on www.youtube.com:

- Many videos on waterless urinals can be found by entering the keyword "waterless urinal" in the search field of YouTube.
- Waterless urinal at UNESCO-IHE in Delft, the Netherlands (2006 and 2007): www.youtube.com/watch?v=z0GKD3JAUOY, www.youtube.com/watch?v=ywp4YPDeBEc,
- Waterless urinal maintenance at University of Witwatersrand, Johannesburg, South Africa (Addicom): http://www.youtube.com/watch?v=nTa4yerQL1o
- Videos on UDD and UD flush toilets (find video clips by entering the keywords "ecosan toilet" in the search field).

7.3 Photos on Flickr.com

The GTZ ecosan team and partners have uploaded a large number of ecosan-related photos to the photo sharing website Flickr.com:

- Worldwide: waterless urinals: http://www.flickr.com/photos/gtzecosan/sets/72157613881735035/
- Worldwide: Urine diversion toilet seats and squatting pans: http://www.flickr.com/photos/gtzecosan/sets/72157612793192986/

8 Appendix A: Worldwide listing of suppliers for waterless urinals, urine diversion pedestals and squatting pans

This Appendix is provided as a separate file to keep the file size low.
Please see: http://www.gtz.de/en/dokumente/en-urine-diversion-appendix-suppliers-lists-2009-14-May.pdf

9 Appendix B: Further thoughts regarding risks of pharmaceutical residues in urine

Arno Rosemarin (March 2009):

- The whole discussion of exposure/dose level and risk assessment needs to be evaluated with regard to the occurrence of pharmaceuticals in foodstuffs. The levels found in soil systems originating from urine application would be in the ppb and ppt level - only detectable using advanced atomic absorption spectroscopy. Antibiotics and hormones given to farm animals (poultry and cattle) result in high exposure levels to consumers (e.g. via milk) that can produce lethal reactions in for example penicillin-allergic individuals. Agro-pesticides applied to vegetables also overshadow the trace levels of hormones, antibiotics and anti-inflammatory substances that could be theoretically occuring due to reuse of human urine. Finally if this is still perceived to be a problem, urine can be treated with sulphuric acid to drop the pH to 2-3 which will degrade most of these trace compounds prior to the natural degradation in soil.
- Sick people taking lots of persistent drugs should not be adding their excreta to the general sewer systems. At least their urine should be bottled up and incinerated. This is a much cheaper way of dealing with at least part of the problem ie managing it at source. One question however is general use of antibiotics, antiinflammatories, birth control pills, hormones, behaviourial modification drugs, etc. Here we cannot isolate such a large number of people. It is therefore the responsibility of the drug manufacturers that have developed these persitent drugs to do environmental impact assessments in addition to all the other advanced testing they do to get the drugs licensed. If the drugs can be destroyed or rendered inactive through sewage treatment additives, super oxidation or acid treatment of urine this is their responsibility.
- The psychological aspect in this debate and (lack of) risk assessment is however huge. People will not drink tap water if they know there are ppt or any levels of hormones or anti-inflammatories in it. And the bottled water industry will take up the slack and make more profits.
- Realistic risk assessment is thus a necessity here since there is no pristine system on earth other than a few mountain streams. By drinking the theoretical picogram levels in drinking water that are probably rendered inactive in the gastric acid of the stomach (pH 2) the dose level will be insignificant. Remember these pills are always coated to make it through the stomach before they are absorbed into the intestine where the pH conditions are neutral.

Martin Regelsberger (March 2009):

- Is there any significant difference in hazardous substance content in food prepared from crops fertilised with urine or with industrial fertiliser or animal manure, taking into consideration potential use of pest control substances, too?
- Finally, like with organic farming, the final endeavour may have to be to avoid altogether substances that we don't want to find in our environment and food. Releasing these substances into the aquatic environment together with the nutrients from excreta is certainly no viable alternative. Applying the cradle to cradle concept to food and drugs and wastewater we wouldn't want to place anything in our cradle we don't want to find there after a first use. If waste=food really is our chance to survive then it is clear we have to avoid any waste we don't want to become food.