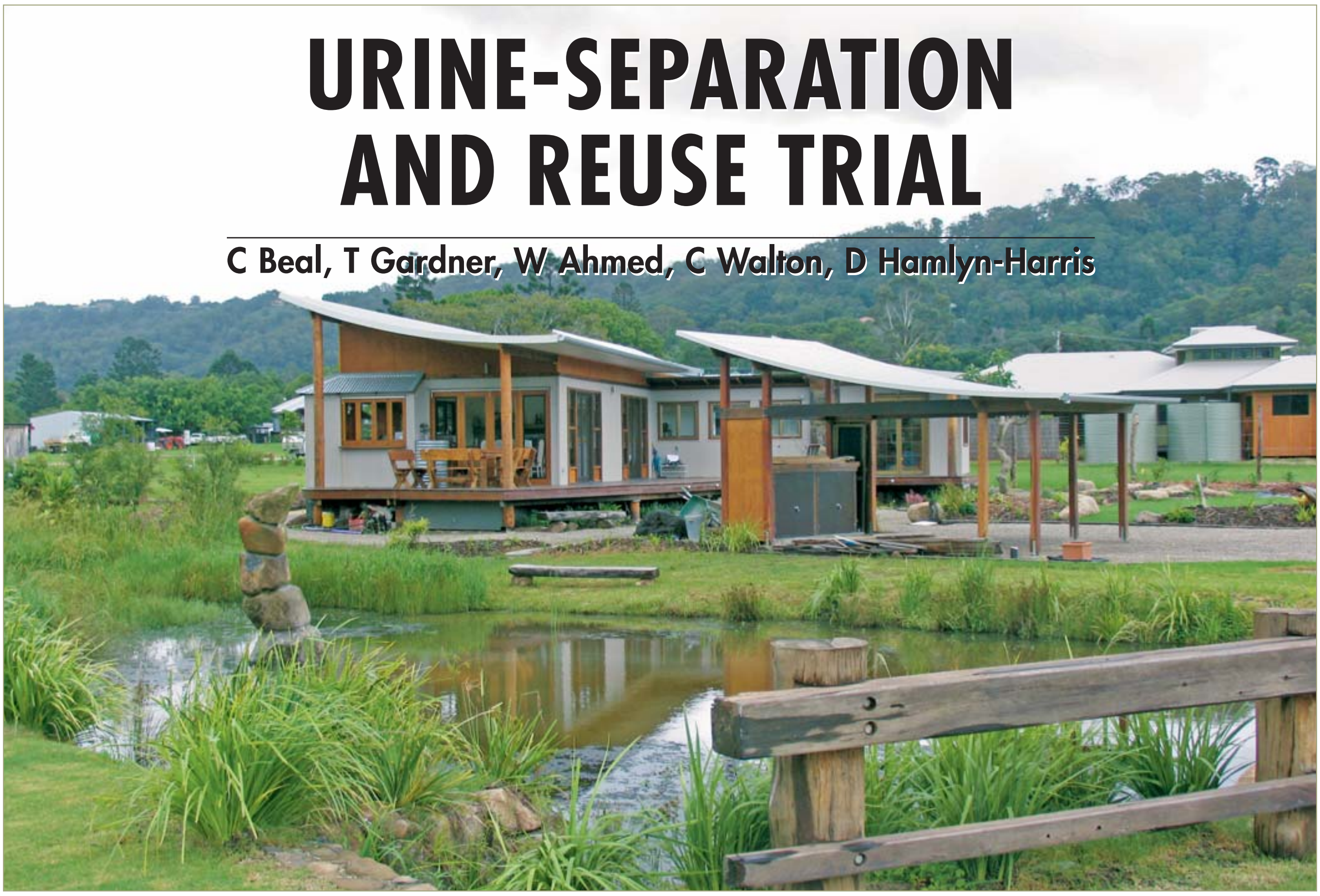
URINE-SEPARATION AND REUSE TRIAL

C Beal, T Gardner, W Ahmed, C Walton, D Hamlyn-Harris



Abstract

Urine-separating toilets (UST) have been used as an effective source control measure in many parts of Europe for years. The purpose of UST is to separate nutrients (N, P, K) at source to avoid mixing with faecal matter. Urine separation reduces water use and nutrient discharges to sewage treatment systems and the receiving environment, and increases the potential for closing the nutrient loop since the stored urine can be used as a fertiliser. UST technology ranges from single and dual flush systems to dry (composting) toilets. This paper will firstly provide a brief background on UST and the reuse of urine in Europe, and then describe its application to 20 homes at The Ecovillage at Currumbin.

Urine collection as in Northern Europe: is it feasible here?

This article has been reduced from "Closing the Nutrient Loop: A Urine Separation and Reuse Trial in the Currumbin Ecovillage, Queensland" in Patterson, RA and Jones, MJ (Eds) Innovation and Technology for On-site Systems. Proceedings of On-site '07 Conference 25-27 September 2007. Lanfax Laboratories, Armidale ISBN 978-0-9579438-3-4

I. Background on Urine-Separation

Advantages of source separation

Although up to about 80% of nitrogen (N), 50% of phosphorus (P) and 60% of potassium (K) excreted by humans are contained in the urine, its fraction of total volumetric wastewater flow is only around 1% (Johansson *et al* 2002) (Figure 1). By separating the urine, nutrients can be captured and used without the intensive, expensive and time-consuming process of

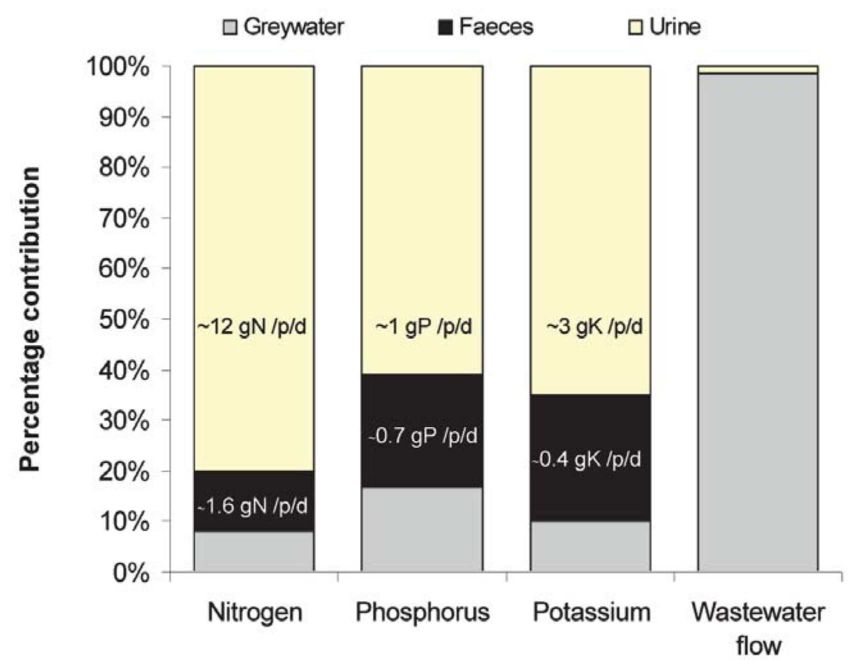


Figure 1. The percentage of nutrients and their daily excreted mass in various wastewater components (Johansson *et al.* 2003).

treatment that is traditionally required when urine is mixed with faeces. Urine separation can also reduce the peak flows of ammonia in sewage treatment plants (STP) by 30% and reduce the impact of sewer overflows on the aquatic environment (Wilsenach and Loosdrecht 2006).

Reduced water use

An advantage of urine separating toilets is their lower water use. Johansson *et al.* (2002) report about 0.1 to 0.3 L of water is required to flush the urine. This is a reduction of over 90% per flush compared with a half flush from a standard 3/6 dual toilet. For a solids flush, the volume ranges from 2 to 6 L.

Closing the loop

Manufacture of nitrogenous fertilisers is energy intensive (see below). Our deposits of economically recoverable phosphate rock are reducing, as are our sources of potassium. Experience in Europe has shown that it is feasible to use collected urine as a concentrated fertiliser to replace at least some of the agriculture demand.

Energy reduction

Life cycle analyses of different removal and recovery technologies for nutrients indicated source-separation can be energetically more efficient than their removal at the STP and their new production from natural sources (Maurer *et al.* 2003). Indeed one study reported that removing more than 60% of urine results in the STP having a net production of energy (Wilsenach and Losdrecht 2006).

The specific energy requirements for denitrification and phosphorus precipitation at a STP are 13 kWh/kg N and 14 kWh/kg P, respectively (Maurer *et al.* 2003) whilst traditional fertiliser production requires specific energies of 13 kWh/kg N and 8 kWh/kg P (Maurer *et al.* 2003). In comparison the *thermal reduction of urine consumes about 10 kWh/kg N (Maurer et al. 2003)whilst Struvite production (producing available P for separate fertiliser use) from separated urine, uses only 6 kWh/kg P* (Maurer *et al.* 2003)

Health Considerations

Pathogens

In healthy humans, urine is a pathogenically sterile in the bladder (Johansson *et al.* 2002; Kvarnström *et al.* 2006). Freshly excreted urine normally contains different dermal bacteria. The most commonly observed pathogens excreted in urine of INFECTED patients are *Salmonella typhi, Salmonella paratyphi, Mycobacterium tuberculosis,* polyomaviruses, hepatitis B viruses and adenoviruses. If cross-contamination with faecal matter occurs during the use of a UST, bacteria and enteric viruses are likely to be present in the urine. However, such pathogenic microorganisms transported through urine are not considered a public health risk as research on separated urine demonstrates that storage conditions of high pH and high temperature (e.g. >20°C) for ≥6 months will effectively render the urine solution sterile (Johansson *et al.* 2002). The typical concentrations of *E. coli* in collected urine can reduce by > 6 $\log_{10}$ within a week of storage. Considerable research has been performed in Europe on bacterial regrowth and faecal indicators (Schonning *et al* 2002).

Figure 1. The Gustavsberg toilet selected for the trials.

Heavy metals

Heavy metals have also been shown to be low in urine solutions from UST (Jönsson *et al.* 1997; Vinnerås *et al.* 2002). Heavy metal contamination of urine can also occur from the corrosion of metal pipes and storage tanks due to the high pH and high ammonia content. Therefore standard metal should be avoided anywhere in the urine collection and transport system.

Pharmaceuticals

Hormones and pharmaceuticals are excreted in urine. There is currently a knowledge gap regarding the risk of exposure from land application of urine, although Johansson *et al.* (2002) suggest that the environmental risk is less than that from traditional STPs (where discharge to waters is common). Kvarnström *et al.* (2006) also point out that urine and fertilisers are mixed into the active topsoil, which has a microbial community comparable to that in STPs where substantial removal or inactivation of residues can occur (e.g. Watkinson *et al* 2007). Additionally, the residues can be retained and degraded for months in the topsoil, further reducing the likelihood of transmission into plant material via plant uptake.

Notwithstanding the above, in complex chemical mixtures such as urine, threshold values are very problematic to set and research indicates that environmental and human toxicological effects of pharmaceuticals may be additive (Maurer *et al.* 2006). Lienert *et al.* (2007) report a > 50% removal of pharmaceuticals from the wastewater stream by separating urine from faeces, thereby reducing the ecotoxicological risks in the aquatic environment. However, the risks from urine application to soil for use as a fertiliser on food crops remain under review.

II. Urine Separation and Reuse Demonstration Project

Site description and project overview

The Ecovillage at Currumbin (the Ecovillage) is a 144 lot development on a former 110 ha grazing property in the Currumbin Valley, in the Gold Coast region of south-east Queensland (http://www.theecovillage.com.au). A core philosophy of The Ecovillage is one of sustainable living where minimal impact on the environment and maximum conservation and/or recycling of resources is achieved. Each house must be constructed to achieve high thermal efficiency, self sufficiency in potable water, and partial self sufficiency in energy generation/use. A communal STP/ advanced water reclamation plant treats sewage and reticulates Class A+ water for household toilet flushing and external water use.In line with this, a demonstration project, managed by the Queensland Department of Natural Resources and Water (DNRW), is trialling the use of urine-separating toilets as a sustainable and achievable method of nutrient capture and water conservation and on-site reuse. The DNRW will manage the project with close liaison with developers Landmatters Currumbin Valley Pty Ltd and design engineers Bligh Tanner Pty Ltd. There are two stages to the project: STAGE I –

Demonstrating the practicality of the UST principle and STAGE II – Beneficial reuse of urine.

The objectives of the project will be to (1) demonstrate the advantages of separating nutrients such as N, P and K at the source for subsequent reuse as a concentrated form of fertiliser; (2) quantify the water savings and recovery / person of nutrients that are achieved by UST; and (3) demonstrate to the urban development, local authority, and state regulatory sectors that urine-separation and reuse can provide a safe, socially acceptable and sustainable alternative to traditional wastewater treatment management solutions.

System selection

Based on expert advice (e.g. Prof Nick Ashbolt, Prof Ralf Otterpohl, Dr Håkan Jönsson), cost, cleansing capability and the ability for men to stand up while using this unit without splashing, the UST chosen for the project was the Gustavsberg unit (Figure 2), They were shipped from Germany through the supplier Berger Biotechnik (www.berger-biotechnik.de).

Figure 2. The 500 L storage bladder located under the house.

Urine collection and storage

At each of the 20 households involved in the project at the Ecovillage the diverted urine will be collected from the UST into a 300 to 500 L flexible polyethylene bladder tank using a combination of stainless steel pipe (see Fig 2) and plastic hosing. The volume of urine solution generated will equate to about 350 L per month, assuming 3 people per household and 1.5 L urine plus 2.5 L of flush water per person per day.

Each bladder will be emptied monthly by a pump-out truck and transferred to a 23,000 L polyethylene rainwater tank giving a capacity of at least 2 months urine storage assuming 20 USTs at full operational capacity. During Stage I of the project urine will be trucked offsite to a local STP. Based on the lessons learnt from Swedish demonstration trials (e.g. Johansson *et al.* 2002) the following points are considered in the design of the collection and storage of urine:

- Watertight pipes and tanks and no metal used for pipes and tanks in contact with urine;
- Horizontal pipes should have a slope of ≥ 1% as sludge continuously precipitates from the urine mixture (although easy to flush away);
- Pipes should be able to be easily inspected; and
- System should not be ventilated (to minimise ammonia loss and odour).

Odour problems have occurred due to poor design and where installations are not watertight. In projects where the UST are properly connected to the pipe system, these problems have not occurred. When connected and operating properly, residents from Swedish studies report that the odour problems in connection with UST do not appear to be greater than with other toilets.

Monitoring program

It is expected that monitoring results collected during this project will provide a baseline database for future urine separation trials. There will be two main elements : biophysical parameters and survey of participant behaviour and attitudes. Monitoring components include:

- Monthly collection, volume measurement and analyses of urine solution (flush water plus urine) for N, P, K, and pathogens;
- Field and laboratory experiments investigating pathogen die-off
- Social survey of the behaviour and attitudes of users and the likelihood of adopting the technology in the longer-term; and
- Analyses of some common pharmaceuticals and their fate in stored urine.

Table1. Estimated nutrient loads and crop requirements for wheat (values for nutrients from STOWA, 2002).

Nutrient	Urine kg/p/yr	200 kg grain
N	4.4	4.5
P	0.4	0.6
K	1.0	1.0

The first stage of the project will also document the practical aspects of UST such as plumbing challenges (wall mounted vs. floor mounted toilets), blockages, odour, storage and pumping issues.

On-site reuse of urine

The average mass of nutrients excreted in the urine compared with the requirements for grain production is presented in Table 1. The average adult excretes sufficient nutrients in their urine to grow enough wheat (200kg/year) to produce a loaf of bread a day for each day of the year.

There are several options for urine reuse at the Ecovillage. These include land application on crop area such as food crops and fruit trees, forage crops for mulch supply (i.e. cut and cart); application on public use land and park (i.e. landscape); use in the plant nursery as a fertiliser; land application on dedicated area, (e.g. in the Stage 2 of the research project) and off-site reuse as a fertiliser to farmers who directly supply food to Ecovillage residents.

To determine the initial feasibility of using urine as a fertiliser in the cropping areas, estimates of areas required for uptake of urine fertiliser were calculated, and are shown in Table 2. There is clearly sufficient land in the 110 ha development to sustainably reuse the nutrients from 20 or more houses.

In Sweden, it is common for tank wagons or tractors, equipped with a pump, to be used to spread urine solution using trailing hoses or tynes. Application should be subsurface with timing to coincide with active crop growth periods and should take into account the potential of some crops to burn if ammonia is applied on the plants themselves. Chloride and sodium salts can be present at high concentrations. (e.g. EC of urine/water solution ~ 1 to 3 dS/m). Guidelines for the *Use of Urine and Faeces in Crop Production* (Jönsson *et al.* 2004) will be used as a guide for establishing protocols for urine reuse during the project. A urine reuse management plan will be written and implemented, in consultation with Queensland Health and Gold Coast City Council.

Consultation and decommissioning

Consultation with Queensland Health, the Environmental Protection Agency, Department of Local Government, Planning, Recreation and Sport, Gold Coast City Council, and Gold Coast Water has been undertaken. Implementation of the 20 household UST project may require Ministerial exemption under the relevant legislation *(Plumbing and Drainage Act 2002)* as a temporary research project.

At the completion of the project, retrofitting with a standard toilet unit, if desired by the householder, will be at the cost and responsibility of DNRW. Participants who choose to retain their UST will do so at their own cost, and share responsibility with the Body Corporate who will manage the pump-out of the USTs, and the urine storage and reuse scheme.

Conclusions

An Australian-first project where twenty urine separation toilets will be trialled at The Ecovillage at Currumbin is underway in southeast Queensland. Urine contains the most concentrated source of N and P in human wastewater and can be reused beneficially as a liquid fertiliser. Life cycle assessment of UST indicate that substantial energy savings at the STP, and from reduction in fertiliser manufacture can be gained from separating urine at the source.

The objectives of the first stage of the project are to quantify the recovery per person of nutrients that are achieved by UST, explore the reuse alternative for urine, gauge the social acceptance of UST and assess disinfection efficacy using extended storage duration.

The second stage of the UST project will focus on the potential crop production on-site from urine fertiliser. Swedish studies have shown that urine fertilisers can achieve at least 85% of that from yields fertilised with manufactured mineral fertiliser.

Table 2. Estimated nutrient loads and crop requirement data assuming 3 people per household and 100% use of UST.

Crop	kg N/hh/yr[A]	N uptake (kg/ha)[B]	Area (m^2) required/hh[C]	Area (ha) required for 20 households (hh)
Rice	8.6	150 - 200	≤ 300	≤ 0.60
Corn	8.6	135 - 225	≤ 200	≤ 0.40
Grasslands	8.6	200 - 400	≤ 215	≤ 0.45

A. Assuming 0.008 kg N per person/day

B. Based on nutrient uptake rates reported in Reid (1990)

C. Assuming 50% plant uptake efficiency

The Authors

Cara Beal, Ted Gardner (email: ted.gardner@nrw.qld.gov.au) and **Warish Ahmed** are with the Department of Natural Resources and Water, Brisbane. **Chris Walton** is a Director of Land Matters P/L the developer of the Ecovillage at Currumbin, and **David Hamlyn-Harris** is Director of Bligh Tanner Pty Ltd, Brisbane.

References

Johansson, M., Jönsson, H., Höglund, C., Stintzing, A., & Rodhe, L. (2002) Final Report for *Source-Separated Human Urine: A Future Source Of Fertilizer For Agriculture In The Stockholm Region?* Prepared for the Stockholm Water Company, Stockholm, 2002.

Jönsson, H, Stinzing, A R., Vinnerås, B. & Salomon, E. (2004) Guidelines for the Use of Urine and Faeces in Crop Production. EcoSanRes Publications Series, Report 2004-2, Stockholm, Sweden.

Kvarnström, E., Emilsson, K., Richert Stintzing, A., Johansson, M., Jönsson, H., Petersens, E., Schönning, C., Christensen, J., Hellström, D., Qvarnström, L., Ridderstolpe, P., & Drangert, J. (2006). Urine separation: One step toward sustainable sanitation. Stockholm: EcoSanRes Programme and the Stockholm Environment Institute..

Leinert, J., Burki, B., Escher, B. (2007) Reducing micropollutants with source control: Substance flow analysis of 212 pharmaceuticals in feces and urine. Proceedings of IWA Advanced Sanitation conference, Aachen, March 2007:15.1 – 15.9.

Maurer, M, Schwegler, P & Larsen, T A (2003) Nutrients in urine: energetic aspects of removal and recovery. *Water Science and Technology,* 48 (19), 37-46.

Maurer, M, Pronk, W & Larsen, T A (2006) Treatment processes for source-separated urine. *Water Research,* 40, 3151-3166.

Reid, R. (1990). The manual of Australian agriculture (5th ed.). Butterworths Pty Ltd.

Schönning, C., Leeming, R., & Strenström, T. (2002). Faecal contamination of source-separated human urine based on the content of faecal sterols. *Water Research,* 36, 1965-1972.

STOWA (2002) Separate urine collection and treatment. Options for sustainable wastewater systems and mineral recovery. Stichting Toegepast Onderzoek Waterbeheer (STOWA), Utrecht, Holland, November 2002.

Vinnerås, B., Jönsson, H. (2002). The performance and potential of faecal separation and urine separation to recycle plant nutrients in household wastewater. *Bioresource Technology,* 84, 275-282.

Watkinson, A., Murby, E. & Costanzo, S. (2007) Removal of antibiotics in conventional and advanced wastewater treatment: Implications for environmental discharge and wastewater recycling. *Wat.Res.,* doi:10.1016/j.watres.2007.04.005.

Wilsenach, J A, Loosdrecht, MCM (2006) Integration of processes to treat wastewater and source-separated urine. *Journal of Environmental Engineering,* 132 (3), 331-341.