Installation, operation and acceptance of urine separating toilets in detached dwellings in SEQ

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Abstract
Nutrient recovery from wastewater streams (i.e. sewage) is important for a number of reasons including energy savings associated with sewage treatment, and a reduced dependence on manufactured nutrients (N, P, K) for agriculture. These nutrients are either energy intensive to produce (eg nitrogenous fertilisers) or have a diminishing stock of raw product (eg phosphorus and potassium fertilisers). Nutrient recovery at source is an attractive option, and can be achieved via urine separating toilets (UST) where the nutrient rich urine is kept separate from the rest of the blackwater waste stream.

This paper reports on a study of 10 USTs installed in privately owned, detached dwellings at 'The Ecovillage', Currumbin, Southeast Queensland (SEQ). The aim of this paper is to provide a report on the issues and practicalities encountered during the trial. It is concluded that the cost effective reticulation of collected urine to a central storage location, the control of odour, toilet installation issues and the availability of nearby agricultural land for reuse are major challenges to the widespread adoption of USTs in urban areas of Australia.

Keywords: urine separating toilets, source separation, sustainable development, urine reuse, Currumbin Ecovillage

Introduction

Urine source separation has emerged in recent times as a means of reducing the energy associated with the treatment of nutrient rich wastewater. Although urine makes up only 1% of the blackwater volumetric flow, it contains up to 80% of total nitrogen (N), 50% phosphorous (P) and 60% potassium (K) (Beal et al, 2008).

Conventional waste water treatment plants function on the premise of nutrient removal from wastewater before discharge to water bodies, without consideration for the potential re-use of the contained nutrients. Urine separation can also reduce the peak flows of ammonia in sewage treatment plants by 30%, and reduce the impact of sewer overflows on aquatic environments (Wilsenach and Losdrecht, 2006).

N, P and K are usually the limiting factor in agricultural production and their availability is essential to sustain the earth's food supply. Nitrogen is readily available in its atmospheric form, but its fixation to produce agricultural fertilizers is highly energy intensive requiring up to 13kWh/kg (Maurer et al, 2003). Furthermore, as globally mined stocks of P and K decline, alternate sources of these valuable nutrients need to be sought (Cordell et al, 2008). Source separated urine can be used as a safe fertiliser with only minimal treatment (Richert et al, 2010). Extensive field trials and studies into this low energy alternative fertiliser have been undertaken in European countries over the last decade, and have proven the potential of source separation (Lienert and Larson, 2009).

Currently in Australia, there is a dearth of information on operational issues associated with urine separating toilets. This paper hopes to bridge this information gap, and provide an insight into the practicality and overall operation of USTs in private residences.

What is a Urine Separating Toilet?

USTs separate urine at the source before joining the wastewater stream. This is often achieved through the use of a smaller separate urine collecting bowl incorporated into the front of the main bowl of a conventional toilet (Figure1). The unit chosen for the field trial was the Gustavberg GBG 393U model. This model was chosen as a result of earlier Swedish trials (e.g. Johansson et al, 2002; Vinnerås et al, 2002) for its combination of low water usage (2/4L half and full flush respectively), ability to be used by men whilst standing to urinate, and a design which included an easily accessible urine pipe for clearing of blockages. The urine is drained to a storage unit through a dedicated 12mm stainless steel urine collection pipe, whilst the faecal waste joins the sewer network as per usual. The separated urine is generally stored in a communal storage unit. However this may not be practical in detached dwellings, where spatial separation is an issue.

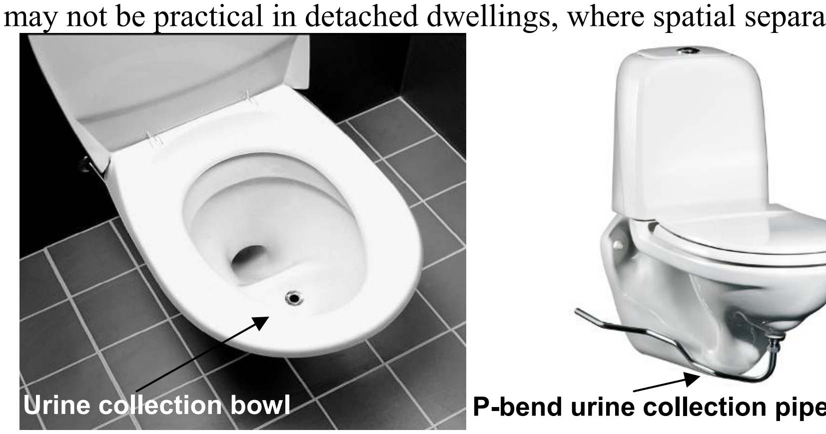


Figure 1: The Gustavberg wall mounted UST, showing the urine collection bowl in front of the toilet pan (left) and the external urine collection pipe for conveyance of the urine and flush water solution to an on site storage vessel (right).

<u>Project description</u>

Overview of project location

The Ecovillage is a 110 hectare, 144 lot development located in Currumbin, Queensland. A minimal environmental impact approach to construction and living has been achieved through best practice design principles including water & nutrient management, energy management, and housing materials with a focus on environmental sustainability (Hood et al, 2010).

Participant recruitment
Literature from European countries with extensive experience in urine separation trials has suggested that carefully planned information campaigns are a key element in the successful large scale introduction of USTs to private bathrooms (Lienert and Larson, 2009 & Narangala et al, 2010). In keeping with this idea, an informative and structured proposal was made to the Ecovillage body corporate and residents for the implementation of 20 USTs. Information brochures and packages explaining the intention of the study, and the potential uses of source separated urine were distributed to the residents (described in Beal et al, 2007). The Ecovillage residents were enthusiastic about the proposal, and this is an important factor in assessing the feasibility of a project of this nature.

In total, ten USTs were installed rather than the initial target of 20, due to several of the initial willing participants selling their lots before house construction. Planning delays coupled with subsequent rapid construction and irregular communication with stakeholders also resulted in several houses being plumbed with conventional toilets before USTs could be installed. The first toilet was installed and commissioned in November 2007, with the last installed in November 2009.

Regulatory/legislative issues
USTs are a relatively new and unused technology in Australia. Since they are not widely used, information gaps exist in regulatory bodies governing the safe installation and use of such radical sewerage technology. After wide consultation with several organisations (QLD Health, QLD Environmental Protection Agency, Local Government Department of Planning, Recreation and Sport, Gold Coast City Council and Gold Coast Water), a ministerial exemption was granted under the Queensland Plumbing & Drainage Act (2002) on the grounds that this was a temporary research project (Beal et al, 2008).

Installation issues
- *Wall mounting*
Installation of the USTs required particular design considerations as they are wall mounted, P trap toilets (Figure 1), as opposed to traditional floor mounted, S trap units. This required installation of a reinforced bracket to distribute the load of the toilet across the structure of the wall, especially when the unit was in use. The wall mounted design also requires sufficient space in the wall cavity behind the toilet for plumbing of both the urine collection pipe and the 90mm main waste pipe. This was generally not a problem, as toilets were installed in conjunction with house construction. If these toilets were to be retrofitted, issues would be encountered with modifications to previously tiled or finished walls.

This issue is illustrated in Figure 2a for a participant's house, which had a UST retrofitted to an existing wall. The large wall cavity required behind the UST had to be created by the fabrication of a makeshift cupboard behind the bathroom wall. The outcome was acceptable in this particular case, however the option to extend the wall cavity may not always be possible or desirable if retrofitting is required.

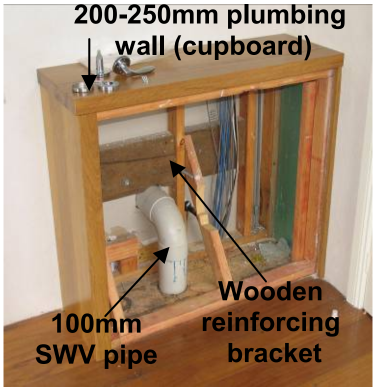


Figure 2: (a) Wall modification to fit rear plumbing (left) and (b) Gustavberg wall mounted UST with incorrectly modified urine pipe (right).

- *Plumbing Issues*

The majority of issues encountered with the Gustavberg units were due to poor plumbing and faulty installs. Faulty installs occurred in three of the ten USTs used in the trial. This was most likely due to plumbers lacking familiarity with USTs, and wall mounted toilets in general.

One particular issue was the cracking of the porcelain urine bowl. This occurred as a result of the pre fabricated urine pipe being altered by the plumber to exit through the floor instead of the wall behind the toilet (Figure 2b), as per the design specification for the UST. Undue strain on the porcelain urine bowl eventually caused it to crack. The participant chose to have his broken toilet replaced with a conventional mixed waste unit, leaving only nine USTs in the trial. At another house the urine collection pipe was poorly joined to a larger 50mm polyethylene (PE) pipe. These inadequately joined pipes resulted in urine spilling into the wall cavity and pooling beneath the house. This resulted in serious odour issues, which were later rectified by the installation of the correct joining pipe.

Maintenance Issues

- *Blockages*

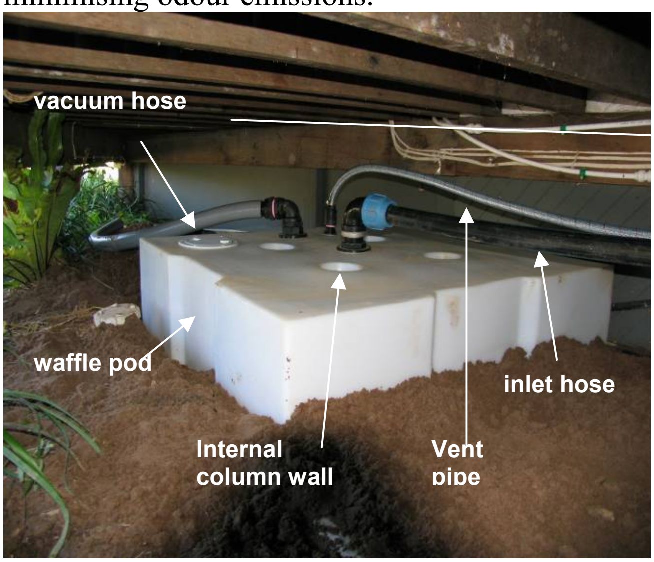
A frequent problem associated with urine separation and storage is the precipitation of phosphorus to form struvite, $(NH_4)MgPO_4.6H_2O$ (Gethke *et al*. 2007). Struvite formation is particularly prevalent in cases where urine is subject to prolonged contact with metal surfaces. Small diameter pipes such as the 12mm urine collection pipe in the Gustavberg toilet are particularly susceptible to blockages caused by struvite build-up.

The Gusavberg toilets pre fabricated stainless steel urine pipe requires a fall of at least 1 in 50 to ensure complete drainage. It is shaped to have a P bend water trap to prevent gases from diffusing back into the bathroom (Figure 1). At one residence, the urine pipe was installed to exit above previously installed skirting tiles which prevented the urine pipe from having the correct fall. This lead to some drainage and odour issues due to pooling of concentrated urine solution in the P trap, rather than flush water. This toilet has also required clearing of blockages with a combination of citric acid, boiling water and a pneumatic drain cleaner on several occasions.

- Odour Issues

A major complaint encountered several times during this study was ongoing odour issues from some of the storage units. Initially, 300L flexible polyurethane storage bladders (http://www.turtlepac.com/products/super-deck-tanks.html) were used for urine storage at individual houses. The flexible bladders were chosen to allow a vacuum pump out truck to collect the urine with relative ease. Furthermore, polyurethane was appropriate regarding a 'no PVC' policy in place at the Ecovillage. Several residents in low set houses complained of lingering offensive urine odours emitted from the bladders. This was found to be due to a combination of poor airflow underneath houses (built on short piers) and gas permeable bladders.

To remedy this issue, 300L rigid walled, airtight waffle pods (http://www.remtec.net.au/other-products.html) constructed from 6mm thick PE were plumbed with appropriate fittings (Figure 3). These fittings included a 50mm PE inlet pipe with a fall of at least 1 in 50, a 50mm vacuum hose for urine removal, and a 12mm vent pipe joined to the nearest available house vent to clear odours, as well as reducing the risk of cracking the rigid structure during vacuum pump-outs. Waffle pods have now replaced all of the flexible bladders, and have worked extremely effectively at minimising odour emissions.



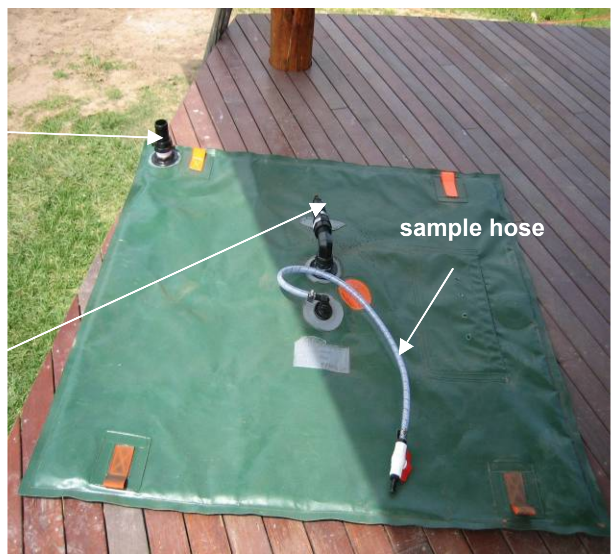


Figure 3: 300L rigid wall PE waffle pod installed under a home at The Ecovillage (left), and the original flexible polyurethane storage bladder (right).

- Faecal Contamination

The majority of complaints made by residents within the first six months of UST use were about the passing of excrement into the front bowl of the toilet. This is unpleasant to clean from the urine bowl as well as causing contamination of the separated urine. As the trial progressed this complaint became less frequent, suggesting most residents became accustomed to sitting further back on the toilet.

Transportation Issues
- Pump Outs
From 2007 to April 2010, urine collection was managed by 6 weekly pump outs using a septic vacuum pump truck that collected urine from the individual residences and discharged it to the municipal STP. The cost to pump out the nine individual storage tanks at the Ecovillage is $400, which is the highest ongoing cost of the project. From May 2010, the separated urine has been pumped into one of three 23,000L PE storage tanks housed on the Ecovillage site, fitted with an activated carbon odour filter. The tanks were sized to allow three months of storage for pathogen reduction before the urine could be used. However with only nine houses in operation, the average volume collected every three months was 3000 litres, which is significantly less than the volume expected when sizing the tanks.

There is concern with cross contamination from the residual sewage contained in the pump out truck, despite it being washed out with water before collecting the urine solution. This may extend the 'die off' period leading to an increased time required in storage before safe reuse of the urine can occur. Washing the truck out with a 5.25% hypochlorite solution may provide a solution to pathogen contamination. This may not be necessary however, if the stored urine is tested to ensure its safety for use as a fertiliser following appropriate reuse guidelines.

Figure 4: Communal storage tanks showing activated carbon filter and shared pipe (left) and vacuum pump out truck transferring the urine solution to a communal storage tank (right).

- Asynchronous Filling of Bladders
A major problem associated with the use of individual storage units at residences was asynchronous filling of the units. One home frequently approached storage capacity (300L) at the end of each six week period, whilst the vast majority of pods at other homes were only partially filled. A remedy is to install another waffle pod in series at the house to double their storage capacity and reduce the pump out frequency, which would lower the ongoing costs of the system. A reduced pump out time would also provide an extended detention time to allow pathogen die-off before reuse. This could be achieved with larger individual storage tanks, similar to those used in Sweden for source separation where tanks are sized for pumping out once a year (Kvarnstrom et al, 2006). These are important issues to consider, as the residents of the Ecovillage are expected to take responsibility for project maintenance including the operating costs.

Communal Storage Considerations

A major concern with storing and using urine is odour nuisance. For the large (23kL) communal storage tanks, an activated carbon filter was fitted to the vent pipe in May 2010, prior to adding urine to the tanks. All emitted gas from the sealed system must pass through this filter, which renders the gas effectively odourless. The carbon filter will eventually require replacement, however the specific life time of the carbon for this particular application remains unknown. To date there have been no complaints from residents or detectable odours emitted from the storage tanks.

Reuse

There is a void of information and regulations dealing with the use of source separated urine. Regulations exist for the reuse of greywater and sewage in Qld, but it is still to be determined which guidelines pertain to urine. Due to low pathogen concentrations it is possible that the urine product can be treated as faecally contaminated greywater. The Queensland Plumbing and Wastewater code (2008), under the Standard Plumbing and Drainage Act (2003) requires greywater for specific end uses with a medium level of human contact to have a concentration of less than 30 thermo-tolerant organisms per 100mL. Table A1 of the QPWC (2008) regulations (shown in the Appendix) outlines the greywater quality guidelines that must be satisfied for particular end uses.

The reuse of human waste as a fertiliser substitute is a tightly regulated area as pathogen content poses an obvious public health risk. In a study conducted by Johansson et al (2002) in Europe, it was reported that a storage period of greater than six months at a temperature higher than 20°C, will eliminate all pathogens and will allow safe reuse for all crops. Storage for one or more months at 20°C will eliminate pathogens except viruses, allowing for safe reuse on processed food crops and forage crops. Average temperatures at Currumbin are generally higher than 20°C, and thus between one and six months will be a safe die off period for the Ecovillage depending on the specific end use for the collected urine solution. Die off experiments have been conducted by Ahmed (pers. comm, 2010) using urine solution spiked with bacteria to determine the die off period at different temperatures. Results indicate that *E. coli* showed a 7 $\log_{10}$ reduction in concentration in three days. Once published, these results will be used to develop a safe reuse management plan in conjunction with QLD Health and Gold Coast City Council as outlined in Beal et al (2008). Regulatory permission to use source separated urine is a major obstacle to the implementation of the reuse phase of the project.

Intended Uses

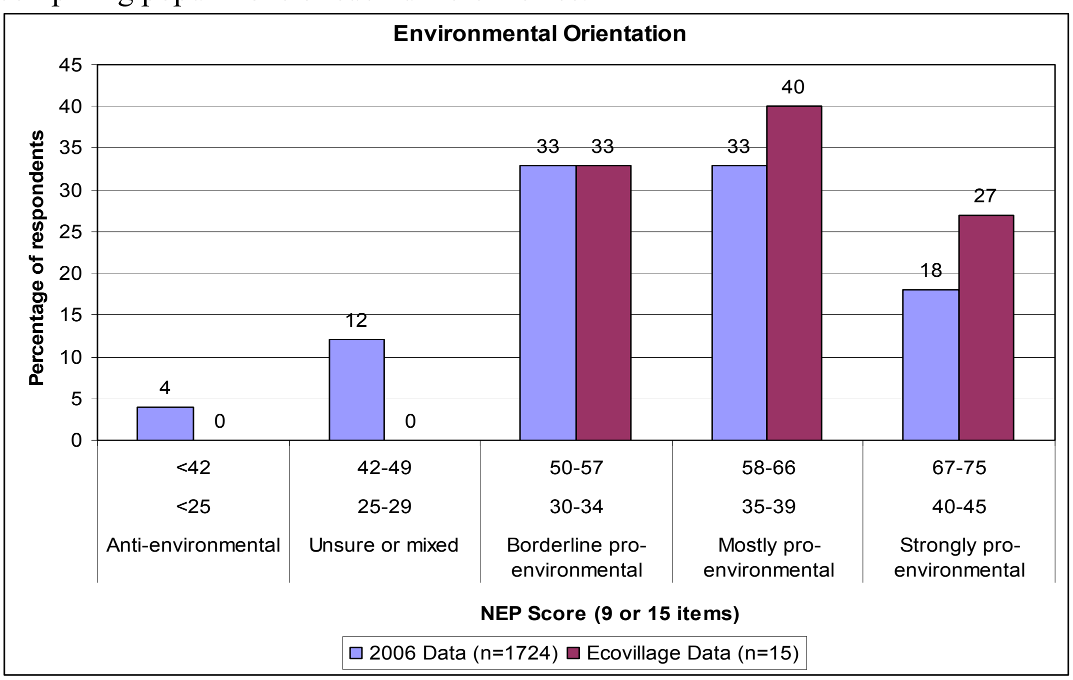
According to ECOSAN (2006), the ideal mode of application as a fertiliser is by subsurface irrigation, as opposed to spray based application. As well as maximising the nutrient availability to plants, this would both reduce odour related issues, and avoid any health risks associated with spray application.

The separated urine at the Ecovillage is intended to be used as fertiliser for their community vegetable garden and individual gardens, which include tree crops. Neither of these areas have a subsurface irrigation network, and thus pouring or drip irrigation will be required. A draw off tap has been installed at the base of the storage tanks which will allow residents access to the treated urine. It is envisaged that the residents will collect the urine into sealed containers and transport it to their homes for individual use with watering cans. There is also an option of onsite reuse for communal public open space irrigation, as well as offsite use by farmers on nearby properties.

In the initial feasibility studies conducted by Beal et al (2007), estimates of areas required for uptake of urine fertiliser were calculated, and it was found that there is adequate irrigation area at the Ecovillage for the reuse of the urine onsite.

Social Acceptance of UST's

Following recruitment into the UST program, participants were requested to complete a series of questions to gauge their environmental awareness known as the 'New Environmental Paradigm' (NEP) (Dunlap et al, 2002). Their scores are shown in Figure 5 and are compared with the distribution of environmental orientations reported in the 'Who Cares About The Environment 2006' report published by the NSW Department of Environment and Conservation. The results show that the prospective participants (n=15) in the UST trial were slightly skewed towards a more pro-environmental outlook compared with their NSW counterparts (n=1724) although care is clearly required in comparing populations of such different sizes.



Note : This figure is adapted from data presented in 'Who cares about the environment 2006' NSW DoEC

Figure 5: Environmental orientation of The Ecovillage residents vs NSW residents based on 'New Environmental Paradigm' scores.

The survey data suggests that residents of the Ecovillage may be more tolerant than the general population when it comes to the inconveniences of using USTs over conventional toilets, (i.e. odour issues) due to their pro-environmental outlook.

Over the life time of the project, the ongoing attitude of the residents towards their UST became more accepting. It is believed that using the toilets became second nature, as the unfamiliarity of such a different system dissipated. Larsen and Lienart (2009) found in a meta-analysis of 33 surveys, up to 79% of respondents would be willing to accept USTs in their private residences. In contrast to this, up to half of the respondents to social acceptance surveys conducted in Austria in 2003 indicated a desire to change back to a conventional toilet at the conclusion of a similar trial of 88 USTs in apartments (Lienert, 2007).

Monthly surveys were conducted to provide regular feedback from the residents regarding acceptance and satisfaction with their USTs. We found throughout the trial period that higher acceptance scores correlated with periods in which residents did not have to deal with maintenance issues themselves. The lowest satisfaction scores correlated directly with complaints of odour emissions for a variety of reasons (poor plumbing, water rats chewing inlet hose, storage bladder leaking odour). In cases where the UST operated as intended and urine was transported without a lingering odour, no complaints were received.

Operating Costs

As previously mentioned, the initial target of 20 UST installations was not met, and so ongoing costs per person are significantly higher than anticipated. If this project were to continue after DERM ceases its involvement, then the ongoing costs of pump-outs and maintenance must be shared amongst the current nine participants. At the current cost of $400 per vacuum truck pump out, and pump out frequency of six weeks, each of the nine participants will have to pay $385 per year. It is believed that cost will be a major factor in determining the continuance of the project beyond DERM funding and involvement.

If a second waffle pod were to be installed at every residence to double individual storage, the yearly cost of pump outs per household would be halved to about $200. It is believed at this reduced cost, participants would be more willing to continue the project on their own. The initial cost of adding a second waffle pod is about $600/household (inclusive of pod, labour and fittings), and would be offset by the savings on pump outs after three years of operation. Over the intended lifetime of the system, this would result in significant savings.

An additional ongoing cost to the operation of the project is the annual replacement of the activated carbon filter on the communal storage tanks, which costs around $500. A possible option to further lower operational costs would be a pro rata contribution from The Ecovillage body corporate, which would allow for the use of separated urine on communal open areas at the Ecovillage. It is also necessary to do microbial testing on each batch of treated urine to ensure it meets guidelines for reuse (see Table A1 in the Appendix). Testing would cost about $100 per sample, and would occur after each six month sanitising period.

Conclusion

The UST trial at the Currumbin Ecovillage has been successful in identifying the practicalities and issues encountered when utilising USTs in private residences in Australia. Of the problems encountered, none were considered insurmountable, and most were overcome fairly easily. Overall, the participants in the trial appear to be satisfied with their toilets, despite some initial problems.

One of the major issues was the unfamiliarity of plumbers with USTs, which led to problems associated with faulty installations. This may have been overcome if a single plumber familiar with the system had been employed to install every toilet, or perhaps by writing a UST installation protocol. Quality control to ensure correct plumbing of pipe work is essential. Perhaps more importantly, fewer problems would have been encountered if a floor mounted S trap UST was installed instead of the wall mounted P trap toilets. This is seen as an important issue to address, should USTs become more popular in the future. Another major issue requiring resolution was odour leakage from the use of unsuitable bladder materials, which was remedied by the installation of gas impermeable storage units.

Minimising ongoing pump out costs is seen as a major factor in the success of USTs. To reduce pump out frequency, and therefore costs, increasing individual storage tank sizes to contain three months of urine production (~600L) is crucial. Not only will this reduce ongoing maintenance costs, but also will significantly reduce the net GHG emissions through a reduction in vacuum truck pump outs.

The regulatory obligations regarding the safe reuse of urine in Australia, are yet to be resolved. Once safe reuse guidelines have been established, then the second 'reuse' phase of the UST project can commence. It must be determined whether the treated urine solution is classified as faecally contaminated greywater or sewage effluent in order to establish which reuse guidelines the urine must adhere to. This issue is a major limiting factor for the progression of this project.

If USTs were to be widely adopted in new urban developments in Australia some general issues also need to be taken into account. These include the availability of nearby agricultural land for reuse of the treated urine, and the possible cost effective reticulation of collected urine to a central storage location.

Nonetheless our small scale trial has highlighted many of the household scale practical problems in using USTs in urban Australia, and we believe that viable solutions are available for all those we encountered. As such we conclude that our study will help in the wider adoption of this technology in Australia as evidenced for example by the 100 house installation underway at Kinglake, Victoria (Narangala et al, 2010).

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<u>Appendix</u>

Table A1 from The Queensland Plumbing and Wastewater Code (2008). Greywater quality guidelines that must be satisfied for particular end uses, for production of less than 3kL per day.

Potential End Uses	Parameter	Effluent Compliance Value
End uses with a high level of human contact, including: • Sanitary flushing • Laundry use (cold water source to washing machines) • Vehicle washing • Path/Wall washdown	Biochemical oxygen demand (BOD5) Total suspended solids (TSS) Thermo-tolerant organisms (org/100ml) pH Turbidity Disinfection	≤10 mg/L ≤10 mg/L <10 6.5 – 8.5 <2 NTU (95%ile) / <5 NTU (maximum) Cl: 0.2 – 1.0 mg/L residual (where used as primary disinfection)
End uses with a medium level of human contact, including: Lawn and garden spray irrigation	Biochemical oxygen demand (BOD5) Total suspended solids (TSS) Thermo-tolerant organisms (org/100ml) pH Turbidity Disinfection	≤20 mg/L ≤30 mg/L <30 6.5 – 8.5 <5 NTU (95%ile) Cl: 0.2 – 1.0 mg/L residual (where used as primary disinfection)
End uses with a low level of human contact, including: • Lawn and Garden manual bucketing, surface broadcasting, sub-surface irrigation	Biochemical oxygen demand (BOD5) Total suspended solids (TSS) Thermo-tolerant organisms (org/100ml) pH Disinfection	≤240 mg/L ≤180 mg/L N/A N/A N/A