COMPOSTING TOILET WITH REED BED GREYWATER TREATMENT: TWO SYSTEMS

Leigh Davison [1] and Phillip Wallace [2]
[1] School of Resource Science and Management, Southern Cross University, Lismore.
[2] Smith & Wallace Engineers, Byron Bay.

Abstract

Domestic on-site systems based on composting toilets and greywater treatment by reed bed are becoming an increasingly popular option on the NSW far north coast. This paper describes two such systems and briefly discusses their performance in terms of water quality outcomes, effect on disposal area requirement and level of management. It is concluded that, because both technologies reduce hydraulic and pollutant loadings, they lead to improved effluent quality and lower disposal area requirement. This is particularly important in environmentally sensitive locations or where there is limited availability of suitable disposal area. The level of management required appears to pose no problems for current users of these systems. The use of greywater primary treatment devices such as grease/sediment traps and gravel filters as alternatives to the septic tank is discussed. It is suggested that there may be some merit in a management approach that involves do-it-yourself, relatively frequent operations involving little or no equipment, and comparatively innocuous wastes. Further monitoring of these systems, as their use becomes more widespread, should throw more light on the costs and benefits of including these treatment elements in on-site systems.

Keywords:

composting toilet, constructed wetland, gravel filter, grease trap, greywater, on-site system, reed bed, sediment trap.

1 Introduction

The level of performance of an on-site treatment and disposal system is a function of:

- capital (cost of system and replacement parts);
- energy (electricity or solar);
- land area (available for treatment devices and particularly for disposal); and
- labour (level of monitoring and maintenance).

Designing a system for a client (with a given level of wealth and set of values) on a particular site (with its various strengths and weaknesses) involves producing an acceptable environmental outcome by juggling the above four factors.

Domestic on-site systems typically dispose of treated wastewater via land application to absorption trench or irrigation network. Because of evidence of widespread system failure in Australia, regulatory bodies have moved to ensure a more rational approach to sizing of disposal areas with a resulting increase in system cost. The recently released NSW guidelines (DLG *et al.*,1998) provide a good example of this trend. For a given site the Guidelines suggest that the size of the disposal area is a function of both the hydraulic and pollutant loadings. Geary and Gardner (1996) point out that the hydraulic disposal capacity of absorption trenches is decreased over time by the phenomenon of biomat clogging at the soil effluent interface. This has been a particular problem in traditional blackwater septic systems which remove only about 50% of SS and BOD and virtually no nutrients from the disposed effluent. NSW DLG *et al.* (1998) suggest that the biomat problem can be ameliorated by periodically diverting effluent to an alternative disposal destination (eg a second trench or an irrigation area) to facilitate a period of aerobic breakdown in the biomat. Another approach to biomat reduction is to remove SS and BOD from the effluent before it gets to the absorption trench by the inclusion of a suitable treatment element in the system.

NSW DLG *et al.* (1998) declare a preference for disposal by irrigation so that effluent-borne nutrients are either immobilised by soil in the case of phosphate (P), or removed as biomass (eg grass clippings or produce) in the case of the more mobile nutrient, nitrogen (N). They also suggest that in sizing an irrigation disposal area N is often the determining pollutant. It is therefore apparent that a system which minimises hydraulic loadings and includes a pre-disposal treatment train which minimises nitrogen loading will result in a reduced disposal area requirement.

This paper explores the opportunities for disposal area reduction offered by on-site systems based on composting toilets with secondary greywater treatment by reed bed. The strengths and weaknesses of primary treatment devices which are lower in cost than a septic tank but which require regular maintenance are also discussed. By way of illustration two case studies are presented.

2 The Technologies

The replacement of the standard flush toilet by a composting toilet can cause significant reductions in the hydraulic and pollutant loadings associated with the aqueous waste stream of a typical domestic dwelling. It is difficult to precisely quantify the gain because the actual figures for the various pollutants of major interest will vary considerably with the situation. Jeppeson and Solley (1994) quote a study by Siegrist (1977) which states that of the total household wastewater load, greywater contains 63% of the BOD, 39% of SS, 18% of N, 70% of P and 65% of the hydraulic loading. This is one of the main reasons why composting toilets are being increasingly accepted around the globe. Perhaps the most spectacular application of the technology to date is a three storey office building in Vancouver, Canada which saves 6,500 L of water per day through the use of dry composting toilets (Del Porto and Steinfeld, 1999). Closer to home, Pollard *et al.* (1997) report that in the Lismore City Council area of northern NSW composting toilet based systems have risen from 2% in 1992 to 22% in 1997 of all on-site approvals. These authors also report that composting toilet users appear to be satisfied with the performance of the technology and that any initial management problems appear to have been easily overcome. In the adjacent Byron Shire a large number of submissions to a 1995 community consultation on wastewater management (Turnbull Fox Phillips, 1996) supported the use of composting toilets in sewered areas. In response Byron Council recently offered to halve the sewerage access rate of $406 pa. for households which disconnect their toilets from the mains and install a composting toilet. (*pers. comm.* Councillor R. Staples). NSW DLG *et al.* (1998) also take a positive attitude to this technology, devoting nine pages of the new Guidelines to it and grouping it with low flow appliances and low phosphate detergents as appropriate ways to minimise disposal area.

Not so comprehensively addressed in the new Guidelines is the use of reed beds or subsurface flow wetlands as secondary or ancillary treatment. In the USA, however, there is growing recognition of the value of this "natural" approach to wastewater management. For example Reed *et al*. (1995) report that 'a disposal bed or trench after a wetland system can typically be at least one third to one half the "normal" infiltration area because of the improved water quality'. Kadlec and Knight (1996) report that reed beds typically remove up to 90% of SS and BOD from wastewaters and (depending on hydraulic residence time) 50% of TN. In addition, as reported by Headley and Davison (1999), reed beds have been found to reduce hydraulic loadings by up to 40% in summer. As a result several states in the USA permit a halving of leach field area when preceded by an appropriately designed reed bed *(pers. comm.* S. Reed).

While the septic tank has traditionally been the major primary treatment device used in Australian on-site systems there is growing interest in smaller, cheaper devices such as grease traps and gravel filters where only greywater is being treated. For such devices the maintenance interval is of the order of months, as opposed to septic tanks where it is of the order of years. Advantages of such devices are lower capital cost and elimination of the need for tanker access.

Marshall (1996) studied a composting toilet / reed bed system at Nimbin (northern NSW). He concluded that the system performed well and that maintenance was low. He also found that the system was robust under extreme peak loadings. This approach to on-site management achieved a certain level of official imprimatur when the NSW Department of Land and Water Conservation awarded the system a Rivercare 2000 Environmental Award. A description of the function and performance of two similar systems follows.

3 System 1

The system shown in Figure 1 serves a communal house and laundry on a 20 person multiple occupancy in the Lismore area (northern NSW) and is managed by the first author of this paper. The two sources of greywater are the house itself (kitchen and bathroom) and the laundry. Primary treatment in each case is by a 360 L grease/sediment trap as depicted in Figure 2. These two sources, plus leachate from the composting toilet, pass through the reed bed and are disposed of either in an absorption trench or by irrigation. It is difficult to equate the system loading to a normal domestic situation because the residents of the community all have their own houses and normally wash and eat breakfast and lunch in them. However community guests (typically 2 to 4 in number) eat all meals and perform ablutions at the community house. There is a communal evening meal 6 nights per week attended by between 10 and 30 people. Occasional social functions generate peak loadings. Kitchen scraps (typically a 20 L bucket per day) are disposed of in the compost toilet or in a worm farm adjacent to the house. Milking buckets, butter-making gear and cheese-making equipment (including cheese cloths) all get washed at the community house.

The system is gravity fed. The current absorption trench and kitchen grease/sediment trap were installed in January 1998 when their predecessors were perceived to be performing poorly. The reed bed which had previously only treated laundry water was cleaned, regravelled, replanted and connected to the house greywater system at the same time. The leachate line from the 8 person capacity concrete block Minimus composting toilet (built in 1984) was connected to the system in June 1998.

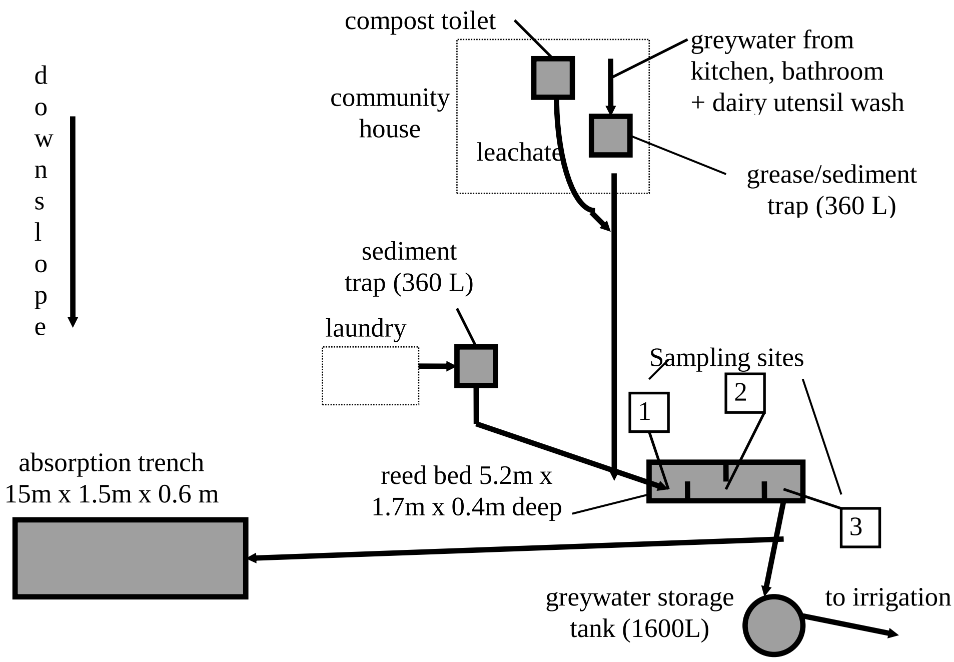

Figure 1: Layout of System 1 (not to scale)

The laundry sediment trap was installed in February 1999 because the previous gravel filter was extremely difficult to desludge. It is planned to extend the irrigation area to a patch of bananas (N removal as produce > 20 $mg/m^2/d$) above the house when a pump is installed later this year.

The grease and sediment traps are both 360 L capacity and are almost identical in design. Figure 2 shows the operating principle. Desludging, carried out monthly, is a relatively simple 10 minute operation. The composting toilet heap is levelled once per month (1 minute) and emptied every six months (10 minutes). The destination of reed bed effluent is switched from irrigation to subsurface disposal as dictated by weather conditions.

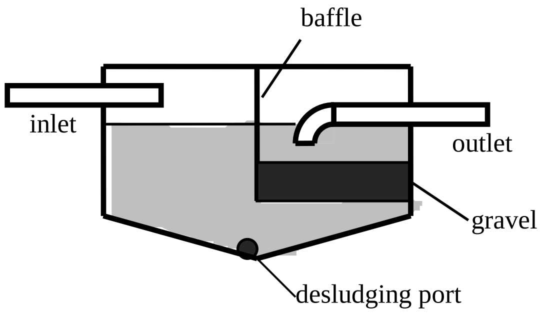

Figure 2: Grease and sediment trap

Water quality sampling was conducted during August and September 1998 at three sites in the reed bed (Fig. 1) about 7 months after replanting. The reeds were in senescence during sampling. At this time they had reached a height of about 1.5 m and were covering the reed bed surface quite densely. While some investigators including Mitchell (1995) and Marshall (1996) have suggested that greywater may not provide sufficient nutrition to promote healthy macrophyte growth, the reeds were observed to grow vigorously even before connection of the toilet leachate line. Table 1 shows results of the sampling program for the parameters of most interest.

Table 1: Performance of System 1 reed bed from sampling during August and September 1998 (before installation of laundry sediment trap). The concentrations are arithmetic means and are expressed in mg/L except for faecal coliforms which are geometric means and are expressed in cfu/100 mL.

pollutant	influent conc. Site 1	mid-point conc. Site 2	effluent conc. Site 3	n	% removal rate	typical % removal rates*
Total N	23.8	19.6	15.3	7	36	53.8
Total P	5.3	3.9	2.9	7	46	**
BOD_5	397	283	49.8	7	88	70-95
SS	854	470	18.2	5	98	88-96
Faecal c.	1.29×10^5	8.6×10^5	2.2×10^4	7	83	92-99.9

* as reported in Kadlec and Knight (1996), and Reed *et al.* (1995)
** Long term P removal is usually minimal
Average hydraulic loading = 600 L/day = 0.6m^3/day
Dimensions 5.2m x 1.7m x 0.4 m deep. Volume = 3.6m^3. Porosity = 0.4. So volume of water = 1.4m^3
Residence time = 1.4 / 0.6 = 2.3days

Table 1 shows that the reed bed influent (Site 1) is relatively high in BOD. This is probably because of the presence of milk and whey (BOD 12,000 mg/L) in the dairy utensil wash. Influent suspended solids concentrations are also much higher than one would expect in typical residential greywater. This could be due to the fact that an efficient sediment trap had not been installed on the laundry at the time of sampling and that desludging of the community house grease trap was not occurring on a regular basis at the time the first samples were taken. Another factor thought to contribute to the strength of the influent (as opposed to more typical greywaters) is the fact that the community house tends to be a place of eating rather than living, so the ratio of kitchen to bathroom greywater is higher than in a normal domestic situation.

Pollutant concentrations, particularly of BOD and SS, at the reed bed mid-point (Site 2) showed less reduction from the influent readings than would normally be expected. This fact indicated that short circuiting was occurring due to clogging around the reed bed inlet as a result of the high SS influent. It has been widely reported, for example by Reed *et al.* (1995) and Kadlec and Knight (1996), that this can be a problem with subsurface flow wetlands. Remedial measures include appropriate inlet structure design and efficient primary treatment.

4 System 2

System 2 serves a single person dwelling at Byron Bay (northern NSW) occupied by the second author of this paper. The layout is depicted in Figure 3. The system can be described as an experiment in urban on-site wastewater treatment and disposal where reuse is the primary design objective. The aim is to produce water quality which satisfies current NSW guidelines for above ground irrigation.

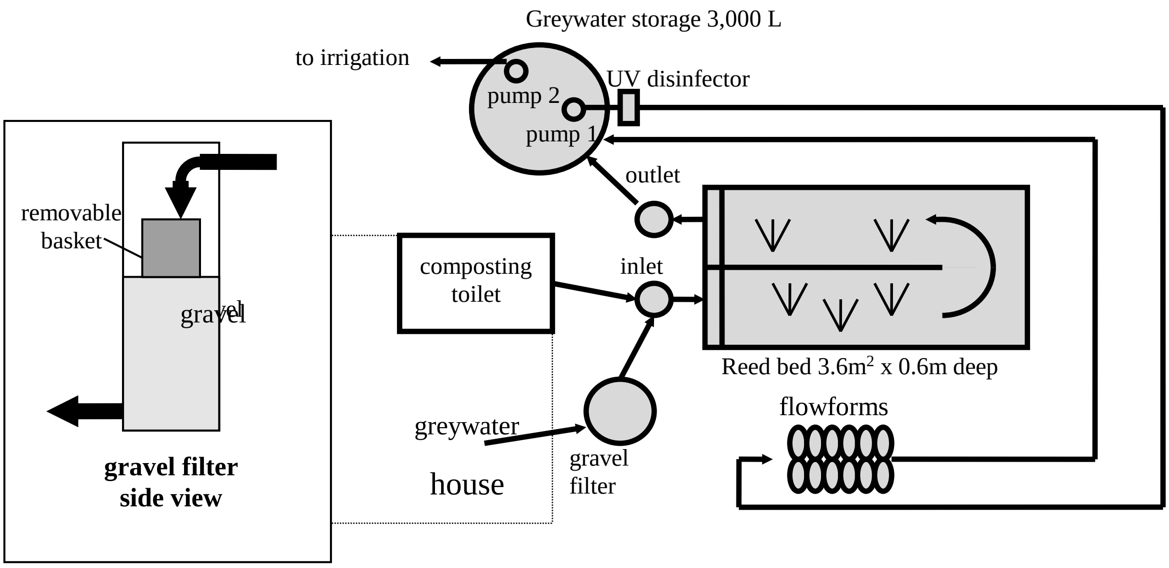

Figure 3: System 2 layout with detail of gravel filter (not to scale)

Greywater passes through a vertical flow gravel filter which contains a removable wood chip basket for collection of gross solids and fats. Various media have been used in the basket from hair clippings to casuarina needles, all with success. Media is consigned to the composting toilet every two months. The reed bed receives the filtered greywater and leachate from the Clivus Multrum CM8 composting toilet. At an average daily flow into the reed bed of 100 L, the average hydraulic residence time is about 8 days. The reed bed discharges into a 3,000 L concrete storage tank via an outlet structure designed to facilitate water level variation. Pump 1, the lowest of the two submersible pumps in the tank, circulates water through the UV disinfection unit and flowform cascade for 4 hours every day under the control of a time clock. A hose fitting in this line provides an opportunity for reuse. Pump 2, also controlled by a time clock, is set at the top of the tank and is connected directly to the absorption trench. The design incorporates the following public health safety features:

- subsurface flow reed bed with no free water visible;
- low flow pumps suitable for plant watering or washing compost buckets and garden tools;
- taps located close to ground with appropriate signage; and
- timer set to operate only in daytime with manual override.

Management operations include checking the inlet filter every month with change of media generally required every second month. The reed bed requires only a check every month with no major maintenance expected for 5 years. The storage tanks and dual pumps which operate the recirculation and irrigation systems require checking once every 6 months.

The results of water quality monitoring conducted between February and May 1999 are shown in Table 2. The final column shows removal rates for the System 1 reed bed to indicate the effect of increased residence time (8 vs. 2.3 days) on treatment performance. This effect is most marked in the case of TN (55% vs. 36%), is moderate for faecal coliforms and is negligible in the case of TP and BOD. The low rate of suspended solids removal in the System 2 reed bed can be explained by the fact that the influent concentration for this parameter was already quite low. In a test of the disinfection system in September 1998 the faecal coliform count in the greywater tank dropped from 300 to 0 cfu/100 mL after two passes through the UV unit. Turbidity at the time of the test was 9 FTU.

Table 2: Performance of System 2 reed bed. Samples were taken from February to May 1999. The concentrations for all parameters are arithmetic means and are expressed in mg/L except for faecal coliforms which are geometric means expressed in cfu/100 mL.

pollutant	conc. at inlet	conc. at outlet	n	% removal rate System 2 res. time = 8 days	% removal rate System 1 res. time = 2.3 days
Total N	8.3	3.7	11	55	36
Total P	1.20	0.63	11	47.5	46
BOD_5	43.7	4.3	11	90	88
SS	37.7	13.9	10	63	98
Faecal c.	9.7×10^5	5.2×10^4	11	95	83

5 Discussion

Crites and Tchobanoglous (1998) suggest that "Although most of the treatment units used in decentralised wastewater management systems require very little maintenance, they rarely receive any". This is confirmed by numerous Australian authors including Geary and Gardner (1996), and Jellife (1996) who report that a large proportion of septic tanks surveyed in recent studies appear to be receiving zero pump-out maintenance. One conclusion that could be drawn from this fact is that expensive, irregular maintenance operations involving large equipment and potent effluents may be less likely to be performed by householders than do-it-yourself, relatively frequent operations involving little or no equipment, and relatively innocuous wastes. Primary treatment devices for both Systems 1 and 2 fall into this latter category. A problem for regulators with this approach might be that it depends heavily on the level of management (albeit minor) applied to a system. While there is a natural tendency to assume that people will be lax in performing regular maintenance operations, experience is showing (eg. Pollard *et al*.,1997) that a significant number of householders are capable of this level of attention. In cluster systems, where one suitably competent householder or an outside contractor can be paid a small amount to monitor and maintain the system, this would be even more likely.

Despite a hydraulic residence time of less than three days and the fact that sampling occurred during the colder months, the System 1 reed bed exhibited a high level of SS and BOD removal. Reed *et al.* (1995) point out that most SS and BOD removal in reed beds occurs within the first 3 days of residence, suggesting that even relatively small units will produce considerably increased absorption trench longevity through biomat reduction. Efficient primary treatment and thoughtful inlet design are clearly important if reed beds are to work to their full potential. In the case of System 1 the frequency of grease trap maintenance was increased in an attempt to lower the high SS concentrations in the reed bed influent. In addition the reed bed outlet structure has been modified to allow for periodic water level lowering which should facilitate a degree of aerobic self-cleaning in the upper two thirds of the gravel substrate. According to Kadlec and Knight (1996) this practice also has the beneficial effect of encouraging root penetration to full reed bed depth thereby enhancing treatment. A study is currently being conducted on the two reed beds described in this paper to more fully investigate the effect of water level lowering.

Numerous studies have shown that constructed wetlands are capable of sustained nitrogen removal. For example Reed *et al*. (1995) report removal rates as high as 79%. However these authors also suggest that "the potential for nitrogen removal may take several years to develop". They also point out that nitrogen requires longer residence times (typically 8 -10 days) than BOD and SS for removal rates to reach their full potential. Not surprisingly then the System 1 removal rate is only 36%. With an 8 day residence time System 2 showed a removal rate of 55%which is comparable to the typical removal rate for reed beds shown in Table 1. At the time of sampling System 2 had only been in use for 9 months, so the TN removal rate could improve.

While composting toilets have the potential to remove up to 80% of N from a typical domestic aqueous wastestream, a certain proportion of the liquid loading will leach from the heap. The amount of N lost to leachate in any given situation will depend on the toilet design. Units with large chambers can take more bulking material than smaller toilets and should thus be able to detain a greater proportion of the urine load. Facilitation of evaporation losses from the toilet by solar or electric heating, or by efficient flue design, also minimise nitrogen leaching. The effect of toilet capacity and design on nutrient retention could prove to be a fruitful area for further research. It is worth noting here that in parts of Europe the process of nutrient source control is enhanced by the use of toilets which separate and collect the urine for use in agricultural applications. In a study on 10 adults Hellstrom and Karrman (1996) found an average excretion of 1.5 ± 0.5 L of urine containing 13 ± 3 g of N and 1.0 ± 0.4 g of P. They suggest that urine contains approximately 50% of the P excreted. Marshall (1996) reports that a composting toilet used by three adults produced 1.6 L/d of leachate containing 0.48 g of P and 3.7 g of N, suggesting that a large proportion of the excreted N and P was being held by the heap and that, despite the fact that the study was done in the coldest month of August, probably over half of the moisture load to the toilet was being evaporated. In environmentally sensitive locations (*eg.* shallow soils, or close to waterways) it would be possible to collect the leachate in a tank for disposal / reuse at a more suitable location.

While both reed beds described in this paper are currently removing P from effluents this is not expected to continue indefinitely. Numerous studies, including that of Headley and Davison (1999), confirm that P uptake in reed beds ceases once available adsorption and precipitation sites have been taken up. In environmentally sensitive situations where P removal prior to disposal is essential, the inclusion of an amended soil or clay in the treatment train may be an option. At least one such proprietary product will soon be available in Australia. The developers of this product suggest that it may be used either as an additional element in the treatment train or as a reed bed substrate.

On-site system designers are experimenting with various reed bed shell materials. The basic requirement is long term watertightness. Plastic liners have been the preferred method for larger systems where suitable clay is not available. For smaller systems ferro cement (as used in System 1) is effective but labour intensive and may thus be appropriate in a "do-it-yourself" situation. Stainless steel (System 2) is expensive but has the advantage of being able to be transported to inaccessible sites in pieces and bolted together using a jointing compound. Concrete block walls set on a concrete slab have been used, but care must be taken to seal the walls with a plastic liner or suitable sealing compound. There has been a recent trend to plastic cattle troughs, and these may prove to deliver the best tradeoff between cost, labour and durability for systems up to 10 m^2.

A properly designed and constructed reed bed will itself require little management apart from visual checks and water level adjustment to promote deeper root growth and breakdown of clogging material in the upper layers of the substrate. In smaller systems hand harvesting every year or two removes some nutrients and rejuvenates the reeds.

6 Conclusions and Recommendations

Where available land area is limited or site conditions poorly suited to the traditional septic tank/land application approach to on-site disposal, additional capital, energy and/or management will be required to achieve acceptable environmental and public health outcomes. There will be many situations in which source control by composting toilet and greywater treatment by reed bed will provide suitable and cost-effective options. Because of their capacity to reduce hydraulic and pollutant loadings, such systems can produce improved and more sustainable performance from smaller disposal areas. Reed bed residence times of as low as three days should significantly improve absorption trench sustainability. Eight day residence times are probably needed to obtain optimal N removal and hence to achieve minimisation of irrigation area where this form of disposal is practised. Further studies are needed to determine more exactly the extent of the environmental gains and economic tradeoffs to be obtained by including a reed bed in an on-site wastewater system.

Composting toilets and reed beds appear to be readily understood and capably managed by the householders who are currently using them. However, as the technologies become more widespread, further studies will be required to monitor the level of user competence. This will also be true in the case of "low cost / regular maintenance" primary greywater treatment devices of the kind described in this paper.

Acknowledgements

The authors wish to thank Andy Edwards, Dan Murray and Meg Edmonds for assistance with water quality sampling and analysis. Thanks to Tom Headley for technical advice.

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