# THE PERFORMANCE OF A GREYWATER SYSTEM AT THE HEALTHY HOME IN SOUTH EAST QUEENSLAND – THREE YEARS OF DATA

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## Abstract

This study reports on the results from a recirculating sand filter installed in an eco-efficient home on the Gold Coast to treat greywater from the laundry and bathroom. Over 30 months of monitoring clearly established that the system could reliably supply treated greywater with $BOD_5$ <5, SS <3, Turbidity ≤1 and faecal coliforms ≤1 making it suitable for reuse for toilet flushing and garden irrigation, with a potential water saving of over one third the annual potable water demand of the home. The constraints on extending this technology to eco friendly subdivisions is the high cost relative to the value of water saved (Benefit: Cost ratio <0.4) under existing infrastructure charging policies, and the very high energy inefficiency of on-site systems (six times less efficient than reticulated sewerage systems). Centralised treatment and reticulation systems are likely to be more cost effective and energy efficient methods of recycling water in urban environments.

## Key Words

economics, faecal coliforms, greywater, recirculating sand filter, water savings

## 1 Introduction

The recent drought that has been experienced over most of urban eastern Australia over the last few years has encouraged urban water authorities to examine different methods of meeting non-consumptive water demands (e.g. external, toilet and possibly laundry). Rainwater tanks for example have become very popular in Sydney and Brisbane with authorities offering rebates of up to $650 per household. In Victoria this subsidy has been expanded to include domestic greywater recycling systems with subsidies of up to $320 per household.

However, in Queensland the Sewerage and Water Supply Act 1949 specifically forbids the use of greywater in sewered areas, based largely on the adverse health and public nuisance experience of local authority engineers and health officials. This is rather ironic in that Jeppersen and Solley of Brisbane City Council led the way forward in Australia by examining options for domestic greywater reuse in the early 1990s (Jeppersen and Solley 1994). More recently the Gold Coast City Council has experienced the most severe drought on record and imposed Level 5 water restrictions which prohibited all outside water use (including car washing by hose) as well as turning off public water features and beach showers. Understandably there was an explosion of interest in greywater reuse and an "unofficial" compromise was reached where greywater (from laundries, kitchens and bathrooms) could be manually bucketed onto domestic gardens.

The subsequent return to average rainfall conditions in 2003 has reduced the demand for greywater, but watering restrictions still apply because of relatively low levels (c 50%) in

Hinze Dam, the main water supply for the Gold Coast. However the drought has focused the attention of many local authorities on how they will meet the water supply demand for the next three million people that are expected to live in south east Queensland by 2050 (a doubling of existing populations, DLGP 2001).

Somewhat fortuitously we have been measuring the water, sewage and energy balances of an eco-friendly home on the Gold Coast since 1999, and believe it is one of the few studies in the world that have quantified water consumption and water quality by end use over a reasonable period of time (3.5years).

In this paper we report on the operation, quantity, quality and energy characteristics of a recirculating sand filter installed to treat the greywater from the bathroom and laundry. A major objective of this part of the study was to provide scientifically sound data to local authorities and state regulators that appropriately installed and managed greywater treatment systems could consistently produce water that was fit for unrestricted external and toilet flushing uses (e.g. as per DNR On-Site Guidelines 1999).

## 2. House Design, Construction and Monitoring

The design vision for the Healthy Home was a "Water and Energy efficient home that promotes human well being in a high density urban environment" (Chris and Kim Prosser – home owners 1999). The home was built on a 420m$^2$ allotment using lightweight building materials with low embodied energy; low recurrent energy using a combination of insulation, breezeways and thermal stack effects; recycled, plantation and reconstituted timber for construction; low outgassing coating including paint and floor coating; no PVC plumbing; a solar hot water system; a photovoltaic system linked to the power grid; rainwater for potable use, and a greywater treatment system for (potential) toilet flushing and garden irrigation. 120 m$^2$ of the 167 m$^2$ roof area supplies roof runoff to a 22 kL concrete cistern installed under the low set house.

The greywater system is a recirculating sand filter (supplied by Envirotech P/L) contained within a partially buried 6 kL concrete tank. The tank is compartmentalised to form an 1800L septic/surge tank, two pump wells and a 1.5 m$^2$ by 600 mm deep sand filter (Figure 1). The flow controller *doses* the sand filter up to 96 times per day to maximise contact between the attached media growth and the percolating greywater. When the water level in the (second) pump well goes "high", about 30% of the treated greywater is discharged to waste (or to another storage), to maintain hydraulic balance, with the remainder recycled through the system i.e. the recirculation ratio is about 2:1.

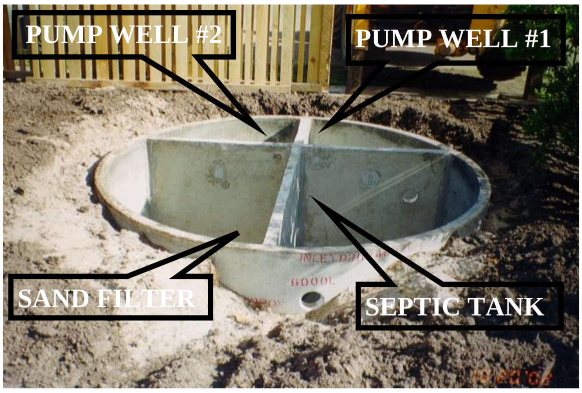

**Figure 1: Recirculating sand filter system installed at the Healthy Home to treat greywater (6000 L concrete container is on the left).**

An 80 Watt (2 x 40W) UV disinfection system was added to the second pump well in November 2000 to ensure the effluent met microbiological standards for unrestricted external reuse. The effluent was collected in the sand filter underdrain and passed under gravity through a U section of PVC pipe and UV lights before exiting into pump well 2.

Under the Queensland Sewage and Water Supply Act (1949), greywater reuse is prohibited in sewered areas. Permission to install the greywater system was given by the Gold Coast City Council on the proviso that all greywater from the bathrooms and laundry was discharged to sewer. All other liquid waste from the house (toilets and kitchen) is discharged to sewer.

The biophysical performance of the house is extensively monitored using a large number of sensors including contact closure water meters, and details are given in Gardner *et al.* (2002).

## 3. Water Sampling

The water entering the greywater system (ever 10 minutes) was calculated by monitoring the water meters connected to cold and hot water lines in the bathrooms and laundry. All the treated greywater was discharged through a single 32 mm pipe into the sewerage system. A 20 mm water meter was installed in this exit pipe to provide an independent check on the potable water consumption of bathrooms and laundry.

Water sampling for chemical and microbiological analysis occurred on an approximately fortnightly basis from three locations. The first sample was a composite sample taken before entry into the greywater system using a bleed line connected to the 100 mm inflow pipe, and this drained into a 4 L glass jar. The second sample was taken manually from the overflow from the septic tank into the first pump well. The third sampling location was the exit line for treated greywater from the pump well 2. Because there were up to 12 discrete pump out events over a 24 hour sampling period, an ISCO automatic sampler was plumbed into the exit line – sampling was initiated by the contact closure pulse from the water meter installed in the exit line. At the end of the sampling event the 1000 mL samples were bulked and a sub sample taken for analysis.

At the end of a 24 hour sampling run, four greywater samples (1 x pre septic tank; 2 x septic tank; 1 x post sand filter) were submitted to Gold Coast City Council's NATA registered laboratory for analysis of total coliforms, faecal coliforms, *E. coli*, $BOD_5$, suspended solids, pH, electrical conductivity and turbidity. On every second to third sampling occasion the analyses suite was expanded to include Total N ($NH_4^+$, and $NO_3^-$), Total P (and $PO_4^{3-}$), chloride and sodium adsorption ratio (SAR). Analysis of all the age sensitive parameters (especially coliforms and $BOD_5$) was commenced on the day of sample submission – sample age was always less than 24 hours old.

## 4. Water Quality Results

Water quality results from over 30 months of sampling (April 2000 to November 2002) are shown in Table 1, and it is clearly evident that the median values of $BOD_5$, suspended solids, turbidity and faecal coliforms have passed the DNR (1999) guidelines for the reuse of greywater for above ground irrigation and toilet flushing (also shown in Table 1). The high microbiological standard obtained for both faecal and total coliforms (1 and 9 cfu/100ml respectively) is due to a combination of very clear effluent (turbidity ≤1 NTU) and a high UV dose (≥40 mJ/cm$^2$) from the 80 watt UV lamps.

**Table 1: Water quality of greywater at the Healthy Home before and after treatment**

| | Raw Greywater (n = 27) | | | | Sand Filtered Greywater (n = 32) | | | | DNR(1999) Irrigation Guidelines |
|---|---|---|---|---|---|---|---|---|---|
| | Median | Min | Max | SD | Median | Min | Max | SD | |
| $BOD_5$ mg/L | 97 | 6 | 300 | 78 | 6 | 3 | 60 | 12 | ≤10 |
| SS mg/L | 48 | 2 | 370 | 91 | 3 | 2 | 49 | 11 | ≤10 |
| Turbidity NTU | - | - | - | - | 1.0 | 0.7 | 22 | 5 | <2 |
| FC cfu/100 mL | 100 | 0 | 240000 | 45954 | 1 | 0 | 300 | 54 | 10 |
| TC cfu/100 mL | 180000 | 300 | 650000 | 193800 | 9 | 0 | 15000 | 2990 | - |
| SAR | - | - | - | - | 1.8 | 0.4 | 4.9 | 1.1 | - |
| TN mg/L | 6.6 | 1.2 | 16.0 | 4.1 | 3.0 | 0 | 7.4 | 1.4 | - |
| TP mg/L | 0.7 | 0.04 | 12.0 | 3.2 | 0.7 | 0.2 | 7.5 | 1.9 | - |
| EC mS/cm | - | - | - | - | 0.4 | 0.1 | 1.3 | 0.2 | - |

$BOD_5$ = 5 Day Biochemical Oxygen Demand; SS = Suspended Solids; FC = Faecal Coliforms; TC = Total Coliforms; TN = Total Nitrogen; TP = Total Phosphorus; EC = Electrical Conductivity; SAR = Sodium Adsorption Ratio

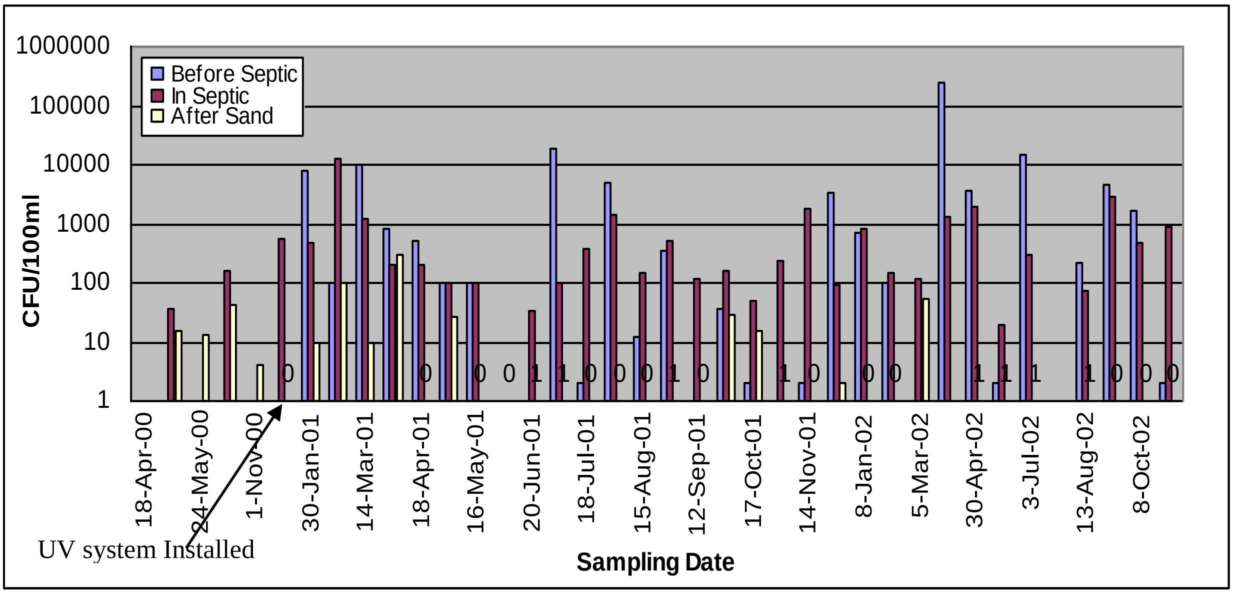


**Figure 2: Faecal coliform concentrations in greywater at the Healthy Home before, during and after treatment.**

Figure 2 shows the data triplets for faecal coliforms in the greywater before it enters the septic tank chamber, in the septic chamber and after sand filtration/disinfection.

Faecal coliforms up to $10^5$ cfu/100ml have been recorded for raw greywater, with only a small reduction (a log or less) after passage through the septic tank – these results are similar to those reported by Christova-Boal *et al* (1995) for greywater systems in Melbourne as well as for American (Gerba *et al* 1995) and European studies (Eriksson *et al* 2002).

The median total coliform count at $10^5$ cfu/100ml (Table 1) is much higher than the faecal coliforms reflecting the ability of these suite of organisms to reproduce in warm, nutrient rich environments (Bitton, 1994). The 4 log reduction in TC demonstrates the disinfection efficacy of the UV system and it is likely that bacterial pathogens such as *Campylobacter*, *Staphylococci* and *Salmonella* (if present) were also made non infective.

The consistent reduction in $BOD_5$ from 100 mg/L to <10 mg/L (Table 1) is in accord with the performance of recirculating sand filter described by Crites and Tchobanoglous (1998 Chapter 11) because the intermittent dosing ensures that film flow occurs around the media material (5mm gravel at the Healthy Home) thereby maximising oxygen exchange for the aerobic bacteria responsible for the oxidation of carbonaceous material.

Nutrient reduction was not particularly effective by sand filtration (N and P – Table 1) which is as expected for P, but a little surprising for N where the concentration was approximately halved from 7 mg/L TN to 3 mg/L TN after treatment. Most of the remaining N was in the oxidised form (i.e. $NO_2^-/NO_3^-$ – data not shown) as expected, suggesting that denitrification was incomplete due to inadequate anoxic conditions (Solomon *et al* 1998).

Sodicity and salinity are water quality parameters of particular interest when using reclaimed greywater for garden irrigation. Table 1 shows SAR <2 which is substantially less than the figures of concern (e.g. >5) reported by Patterson (2000) for septic sullage in Australia. Presumably the low SAR (and P) reflect the type of washing machine detergent (Biozet) and personal soaps used in the Healthy Home. Similarly, the greywater salinity of 260 mg/L (i.e. c 0.4 mS/cm) is well below figures that would be of concern for irrigating most ornamental plants and lawns (D.N.R. 1997).

## 5. Water Supply and Demand Results

During the three years of water monitoring from 2000 to 2002, the Healthy Home consumed 223 kL/year of water (610 L/day) compared with an average Gold Coast detached household consumption of 297 kL/year (810 L/day) – (pers. com. Gold Coast Water).

Figure 3 shows the partitioning of water use in the Healthy Home with the majority (36%) being used in the bathroom, followed by toilet flushing (21%) and outside use (16%). The low outside consumption is a function of the small block size ($420m^2$), the permaculture garden, and external watering restrictions imposed in June 2002.

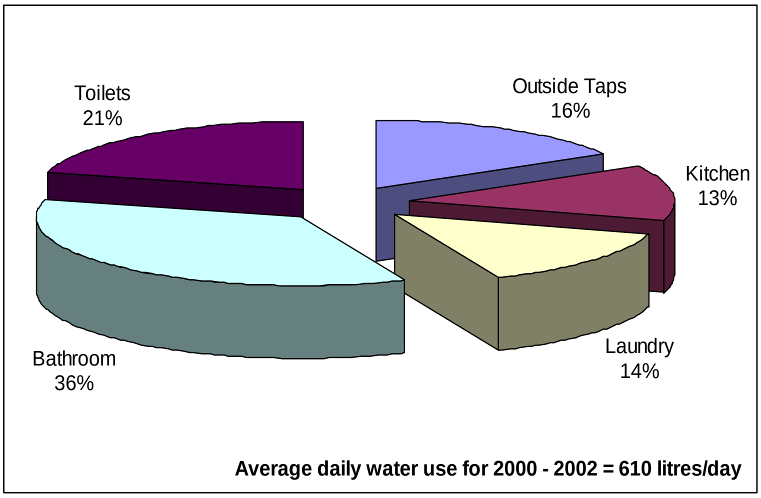


**Figure 3: Partitioning of Water Use in the Healthy Home for 2000 - 2002**

Figure 3 also shows that approximately 37%, or 82 kL/year of total water use (toilets/ external) could be replaced by greywater treated to an appropriate standard. Table 2 explores this idea, showing the *virtual* water balance for the combined years where it is assumed that all toilet flushing water (164 kL) is sourced from treated greywater, with 50% of the balance of greywater (77 kL) used for garden irrigation. When combined with rainwater supply (245 kL), the self-sufficiency of the Healthy Home could increase to over 70% (486 kL) of the 668 kL consumed from 2000 to 2002. It is notable that these were years where annual rainfall was substantially less than the 25th percentile figures. In an average rainfall year, the self-sufficiency for water at the Healthy Home could increase to almost 90% (Gardner *et al* 2002).

**Table 2: Virtual [(1)] Water Balance of the Healthy Home for the combined years of 2000, 2001 and 2002**

| | kL |
|---|---|
| Greywater Treated | 318 |
| Toilet Water Use | 164 |
| ∴ Greywater Available for Irrigation | 154 |
| Assume 50% Availability | 77 |
| ∴ Potential Greywater Use | 241 |
| Rainwater Used | 245 |
| ∴ Potential Rain + Greywater Use | 486 |
| Total Water Use | 668 |
| *∴ Rain + Greywater = 73% of Total Water Use of 668 kL* | |

[(1)] Current Queensland Government regulation prohibits the reuse of greywater in sewered areas

The reuse figures in Table 2 are only approximate because they do not explicitly consider the mismatch between episodic external water demand and daily greywater production. However toilet demand is regular and daily, so the storage volume required to buffer the mismatch between toilet demand and greywater prediction should be much smaller. Figure 4 explores this idea by comparing hourly toilet water demand with greywater production averaged over four months, selected from each of the four quarters of 2002. It is evident that the mismatch is less than 20L, suggesting that a 50L header tank could adequately meet toilet demand on the day of greatest recorded demand and supply mismatch.

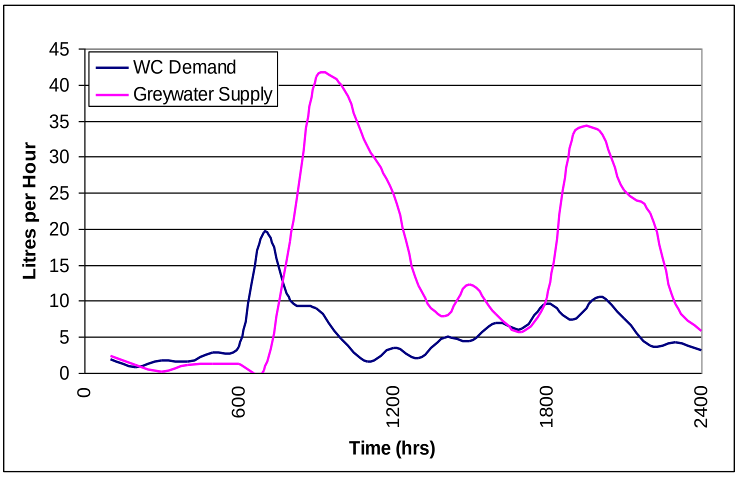


**Figure 4: Hourly Greywater Supply and Toilet Flushing Demand at the Healthy Home for a typical day**

## 6. Energy Consumption

A detailed analysis of energy consumption of the Healthy Home showed that it consumed about 6 kWh per day less than the average Queensland house (16.2 kWh/day vs 22.8 kWh/day) and generated about 6 kWh/day of its own power consumption using a 1.5 kW photovoltaic array (Gardner *et al* 2002). However balanced against this saving is the extra power consumed over and above that from local authority reticulation and treatment infrastructure. For example during 2002 the greywater system consumed 804 kWh of electricity to treat 111 kL of greywater i.e. an efficiency of 7.2 kWh/kL. In comparison Gold Coast Water sewerage system has an energy efficiency of 1.0 kWh/kL (Shaun Cox, pers. com.) suggesting a six (6) fold energy penalty for self-sufficiency.

This comparison is not quite fair as greywater at the Healthy Home potentially substituted for 36% of potable water use (Table 2). A centralised reticulation system to achieve a similar substitution would require about 0.2 kWh/kL for reticulation and possibly 0.6 kWh/kL for tertiary treatment and disinfection (Griffiths 2003) – i.e. 0.8 kWh/kL, still substantially more efficient than the on-site domestic technology (i.e. 1.8 kWh/kL vs. 7.2 kWh/kL).

A closer examination of the Healthy Home data showed that less than 10% of the greywater power consumption was due to the pumps – the balance was from the 80 Watt UV lamps. Clearly a more energy efficient method for disinfection is required if gains in water efficiency are not to be largely offset by losses in energy efficiency – every kWh of mains electricity generates about 1 kg of $CO_2$ equivalent.

## 7. Economics

It is unlikely that the adoption of on-site greywater treatment systems will become widespread unless the systems pay for themselves in water savings over a short period of time; or subsidy is paid to the home owner by the local water authority; or a reduction in water and sewerage headworks charges is given to the land developer.

Table 3 shows a simple economic analysis for the Healthy Home where the capital cost of the concrete tank, pump and plumbing ($5,500), is compared with the difference between water savings and the operating and maintenance costs of the greywater system. Assuming a mains water saving of 82 kL/year at $1.10/kL and an operating and maintenance cost of $230 per year ($54.83 electricity + $140 maintenance + $35 pro rata pump replacement cost), the payback period is infinite.

**Table 3: Economics of greywater system at the Healthy Home.**

| | |
|---|---|
| Greywater Capital Cost | $5,500 |
| O&M Costs | $230/year |
| Water Savings 82 kL @ $1.10/kL | $90.20 |
| Payback Period | Never |

Similar financial findings were reported by Christova-Boal *et* al (1995) for greywater systems installed in Melbourne at costs of ≤$2,000 per unit. Benefit/cost ratios were ≤0.2 and did not reach break even value of 1 unless the potable water saved was costed at $4 to $6 per kL – current Gold Coast Water prices are $1.10/kL.

Alternatively, the greywater system could be replaced by a decentralised system that treats and reticulates greywater from a group of houses. The financial break-even point for this type of technology is about 1,000 households and falling (Mitchell *et al* 2002). A large subdivision constructed along water sensitive urban design principles, where cost of alternatives to the developer and council are clearly documented, would substantially clarify the issues of decentralised, self-sufficient water and sewerage alternatives for the urban development industry.

Such a study is being undertaken in the Pimpama-Coomera region of the Gold Coast where a 150,000 person greenfield development is being evaluated on water savings, avoided sewage discharge, nutrient and salt balances, and economics which explicitly consider environmental externalities (Cox and Hamlyn-Harris 2003).

## 8. Conclusion

The recirculating sand filter has consistently delivered a high clarity treated greywater that is safe to use for toilet flushing and above ground irrigation. As such the results are similar to other studies on recirculating sand filters that are sourced with all domestic effluent (e.g. Solomon *et al* 1998).

When combined with potential urban water savings (over one third of total household water use), these biophysical results make on-site greywater systems very attractive for new and infill urban developments. However the costs outweigh the potential benefits by almost 3:1 at a household scale, so unless there are structural changes in infrastructure charges (including the costing of externalities), private costs will be subsidising the public good (e.g. from reduced dam and sewer construction).

A dual reticulation system in greenfield sites will probably provide a more cost effective reuse solution, certainly a more energy efficient one, to meet the challenge of increasing demand on potable water supplies in south east Queensland over the next few decades.

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