A BIO-ENGINEERING SOLUTION TO RURAL DOMESTIC WASTEWATER REUSE

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ABSTRACT

An alternative on-site wastewater reuse system for rural domestic households is currently being trialed in Central Queensland, Australia. The system combines hydroponic principles with existing septic and grey water disposal technology. Traditional on-site wastewater principles combined with biological nutrient removal techniques are used to treat the wastewater. The wastewater from the non-sewered household is first treated by a septic tank or a vertical greasetrap, depending on its source. The black and grey water is then mixed together in a holding tank and pumped to sub-surface waterwell pots in which various plant species are grown. The system is fully contained, any excess water that is not used in plant transpiration is returned to the holding tank. This system of modified hydroponics enables resilience by the plants to otherwise toxic levels of nutrients, and perhaps heavy metals, at concentrations normally detrimental to plant health, and lends itself to the dissipation of water containing high levels of ions. A trial site has been operating in Rockhampton since June 1997. Multiple test sites spread across six shires will be in place by the end of 1999. Research is focusing on plant-water relations, nutrient removal, heavy metal and salt accumulations, and in the future, pathogenic analysis.

KEYWORDS

wastewater, transpiration, on-site, reuse, waste ions, biological treatment, subterranean hydroponics

INTRODUCTION

The environmentally sustainable reuse of domestic wastewater has become a major issue in Australia. Recently, the processes of wastewater disposal came under intense public and government scrutiny after people were infected with Hepatitis A from oysters contaminated with septic tank discharge.

In Australia most domestic wastewater is processed by Local Government owned sewage treatment plants (STPs). Wastewater discharged from these plants is regularly monitored and STPs are continually updated to improve discharge water quality. For example, 82% of Sydney's domestic wastewater received only primary treatment in 1992. By the year 2011 it is predicted that 75% of Sydney's domestic wastewater will receive secondary treatment, and the remaining 25% tertiary treatment. No primary treated or untreated wastewater will be discharged (Lang, 1994).

If not treated in STPs, most other domestic wastewater in the Australian environment is disposed of via septic tanks. Australia wide, approximately 2 million people use septic tanks to treat domestic wastewater on-site (Gardner et al., 1997). The Queensland Interim Code of Practice for On-site Sewage Facilities states that the minimum sewage flows for design purposes must equate to daily per capita flow of 200 L/person/day (DNR, 1999). Using these figures approximately 400 ML/day or 146,000 ML/year of wastewater are treated by on-site septic tanks.

Conventional septic systems comprise the tank itself, which acts as a passive anaerobic chamber, and an absorption trench, into which the discharge from the tank flows. Septic tanks which only treat toilet water (blackwater) remove approximately 50% BOD_5, 75% suspended solids, 10% total N, 15% total P, and reduce numbers of biological contaminants (Gardner et al., 1997). Household septic tanks which treat both blackwater and greywater (sinks, showers, baths) are becoming more common. The quality of the greywater varies greatly and often contains anti-microbial agents that harm the anaerobic microbial treatment of wastewater in the tank. Performance values for these combined wastewater septic systems need to be considered on a case-by-case basis.

Septic systems, and in particular the absorption-trench component may not conform to environmental statutes. Indicators from surveys have shown that the performance of on-site domestic disposal systems needs significant improvement to overcome possible public health and environmental pollution problems associated with failing systems (Geary and Gardner, 1996).

Many of the problems associated with the on-site disposal of wastewater are addressed by the bio-engineered solution to domestic wastewater reuse, being trialed by the Primary Industries Research Centre, Central Queensland University.

PROCEDURES

System components

The system combines traditional on-site wastewater disposal technology with biological processes and modified hydroponic principles to treat and reuse all the wastewater produced by a household, that is, black and grey water.

Blackwater is treated by a traditional septic tank and greywater by a deep vertical greasetrap. The latter is used to overcome the problems associated with hot water flushes and interceptor-designed greasetraps. Prototypes also include septic tanks that treat a combination of black and grey water.

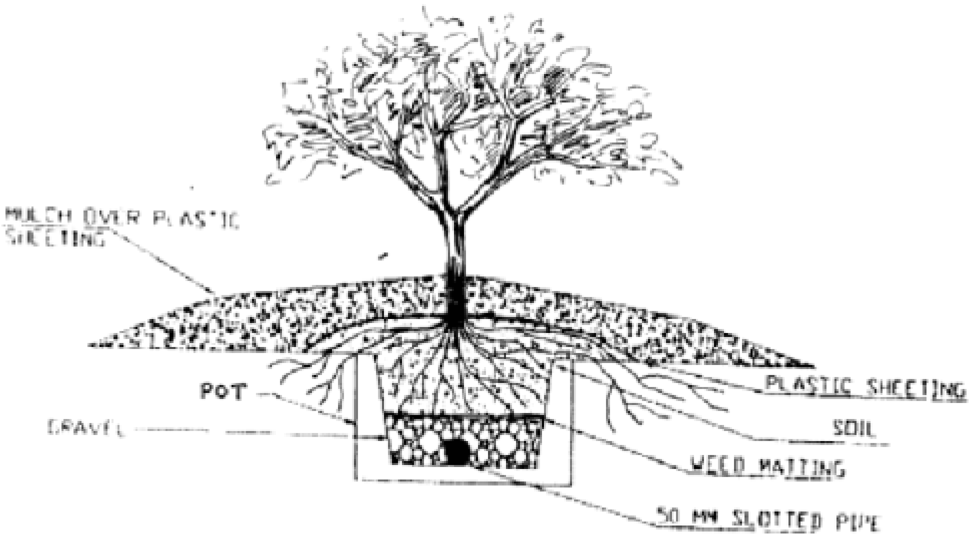
Once treated, wastewater flows to a holding tank from which it is pumped, aerated by a Venturi valve, to a series of interconnected waterwell pots. These pots are concrete chambers, 3 m long, 1 m wide and 0.4 m deep. In the bottom of these pots is a 50 mm slotted PVC pipe covered by a 10 mm layer of blue metal aggregate, and terra-firma matting covers the aggregate. Depending upon site characteristics, the remainder of the concrete pot is filled with sandy soil. The soil surface is covered with black plastic film, which is covered by hydrophobic mulch.

The pots are installed so that the top rim is above the surrounding ground level, and soil is built up around them (Figure 1). This allows the plants to have roots both inside and outside the pot, while limiting run-off storm water from entering the system.

A wide variety of plants has been grown in the pots. Through transpiration, plants reuse the wastewater pumped into the bottom of the pots. The plants also utilise some of the waste ions present in the wastewater, through normal growth. The system has been designed to return the wastewater not transpired by the plants back to the holding tank. This prevents the flooding of the pots with wastewater and development of anoxic soil conditions that may lead to plant death. It also means that the system is a closed circuit.

Figure 1

Cut Away Diagram of Pot Structure



System Safeguards

Most health and environmental problems with septic tanks occur due to the failure of the absorption trench. When this occurs the wastewater may pass to the land surface where it can come into contact with humans and possible disease vectors. Alternatively poorly treated wastewater can enter groundwater, spreading biological and chemical contaminants over considerable distances (Gardner et al., 1997). The bio-engineered system is a significant improvement, with the closed circuit design preventing wastewater discharge into the soil environment.

Biological treatment systems for on-site wastewater disposal or reuse have suffered because of their high maintenance requirements and highly technical installation procedures. The present system has been designed such that a qualified plumber can install the required infrastructure. The concrete products are available from most precast concrete yards and standard pipework and fittings are readily available elsewhere. The only moving part in the system is the pump used to move the wastewater through the pots.

Plant roots invading the pipework are a problem with many septic systems. To prevent plant root intrusion into the system's pipework, several safeguards have been incorporated. The slots on the 50 mm PVC all face down, and the pipe itself has been covered with a stocking-like filtersock. The terra-firma matting is a high quality water-porous material commonly used underneath roads to prevent root intrusion. The water level in the bottom of the pots is kept 10 cm above the matting. Waterlogging in the bottom 10 cm of soil hinders root movement down into the pipework.

High rainfall could also waterlog the system and kill the plants. The black plastic and hydrophobic mulch has prevented 90% of rainfall intrusion into the original trial system (unpublished data). The fact that pot rims are raised slightly above ground level and soil built up around them overcomes the problem of water leaching into the system from the ground.

If the system encounters an overload, such as from a faulty toilet or tap, the excess water is shunted into an emergency absorption-trench. An alarm has been fitted to notify the householder once the absorption trench is used. As an added safeguard the system has been designed to include a five-day wastewater production holding capacity.

A constant flow of wastewater is maintained by connecting the system to a low-water feed. Thus if the occupants of the dwelling are absent and no wastewater is produced, the system taps into the local water supply and keeps the plants and pots watered.

Both effluent treatment and biological reuse systems have been known to suffer from salt build-ups. The closed circuit design incorporated in our system could potentially make salinity a major concern. Although not a problem to date, high salinity levels in the pots could be reduced through the application of water to the top of the pots and the subsequent leaching of salts from soil and into the excess water which returns to the holding tank. By turning off the pump in the holding tank, the salt laden water could then be contained till removed by a waste contractor to an STP for more advanced treatment. To date this has not been necessary in our sites.

All wastewater treated by this system is kept underground or in tanks. During normal operation of the system the wastewater should never come into human contact. This should minimise the chance of any disease transfer from the wastewater to the public. With the wastewater kept underground the system produces no odour.

The owner of the system has only to maintain the plants growing in the pots; no chemicals need to be added nor sprinklers shifted. The only maintenance required under normal operating conditions is the pumping out of the septic and holding tanks according to the requirements of the local authority's by-laws. The low level of maintenance required from the householder makes this environmentally sustainable wastewater disposal system a practicable alternative to conventional technologies.

EXISTING TRIAL SITES

Rockhampton Site

A trial site located in Rockhampton, Central Queensland, has been in operation since July 1997. The site treats and reuses the wastewater from SW Kele and Co Pty Ltd, a precast concrete manufacturer. The wastewater is sourced from the toilets and workers' clean-up area. Small amounts of industrial wastes such as oils and fuels are also treated by the system.

This site has been used primarily for design experimentation. Originally a five pot system was installed to deal with the blackwater produced on-site. The wastewater flowed through the bottom of one pot to the next.

Initially no mechanism for the return of wastewater in excess of plant requirement was provided. This seriously affected the health of the plants as too much water reduced the aerobic soil volume for rooting, and retarded plant growth. After a return mechanism for directly controlling the water level in the pots was installed in February 1998, plant health and visual growth rates significantly improved.

The system was expanded in July 1998 to additionally treat and dispose of the greywater produced from the industrial site. Eight additional pots were installed and placed in a herring bone fashion, with the pots all feeding off the one main line. The benefits and liabilities of the flow through pot to pot and the herring bone designs will be examined over the next two years.

A wide variety of plant species have been grown at this site. They include bamboo, banana, heliconia, pawpaw, citrus, longan, five corner fruit, avocado, conifers, roses, groundcovers, and Australian natives such as the Golden Bouquet Tree and a *Callistemon*. Plant health and growth have been excellent, and no death of plants has been noted. It is suggested that because plants have access to water from the soil in the pot, and through the mound access to normally drier soil outside the pot, most plant species, even those susceptible to anaerobic conditions, will perform well in the system.

In September 1998 it was noticed that the soil had become very acidic (pH 4), compared with the beginning of the trial (pH 7). The wastewater flowing through the pots was anaerobic since the black plastic film used to prevent rainfall intrusion apparently hindered gas exchange between the soil and atmosphere. To combat this a Venturi valve was added to aerate the wastewater when pumped into the pots. This stabilised soil pH at 6.5.

Since July 1998 the water quality of the system has been regularly tested. So far no indications of build-up of NH_4^+, NO_3^-, PO_4^-, and K^+ have been observed (Table 1 & 2).

Table 1

Chemical Characteristics of Holding Tank Water at Rockhampton Site

Test/Date	6/6/99	7/6/99	8/6/99	9/6/99	10/6/99	Average 11/98-6/99
NO_3^- ppm	2	2	2	2	2	1.95
NH_4^+ ppm	20.0	44.0	33.0	14.8	12.4	32.8
PO_4^- ppm	57	31	39	36	30	28.2
K^+ g/L	0.3	0.32	0.29	0.28	0.28	0.28
pH	7.14	6.6	7.24	7.00	7.34	7.32
Conductivity mS/cm	0.73	0.633	0.722	0.746	0.694	0.719

Table 2

Chemical Characteristics of Non-transpired Water at Rockhampton Site

Test/Date	6/6/99	7/6/99	8/6/99	9/6/99	10/6/99	Average 11/98-6/99
NO_3^- ppm	2	2	1	1	1	1.15
NH_4^+ ppm	30.4	32	38	12.4	9.3	20.7
PO_4^- ppm	48	35	62	53	42	32.5
K^+ g/L	0.29	0.34	0.31	0.31	0.29	0.27
pH	7.01	6.94	7.21	6.97	7.04	7.22
Conductivity mS/cm	0.62	0.597	0.713	0.746	0.741	0.712

Metal ions did not accumulate over time in the wastewater contained within the system. However, there was a doubling in concentration of Al^{+++}, Cr^+, Fe^{++}, Na^+, and Ni^+ and a slight increase in Cu^{++} over a five month period in bamboo leaves. The values, nevertheless, are within ranges considered normal for plant growth and may reflect ontogenetic trends in accumulation (Reuter and Robinson, 1997).

The electrical conductivity of the water varied greatly over time, and could be attributed to variations in the characteristics of the water entering the system (Figure 2 & 3). Suggesting that incoming wastewater quality was a greater immediate influence on water quality throughout the system rather than that of the aerial or edaphic growing environment.

Figure 2

Electrical conductivity of holding tank and non-transpired water at Rockhampton Site

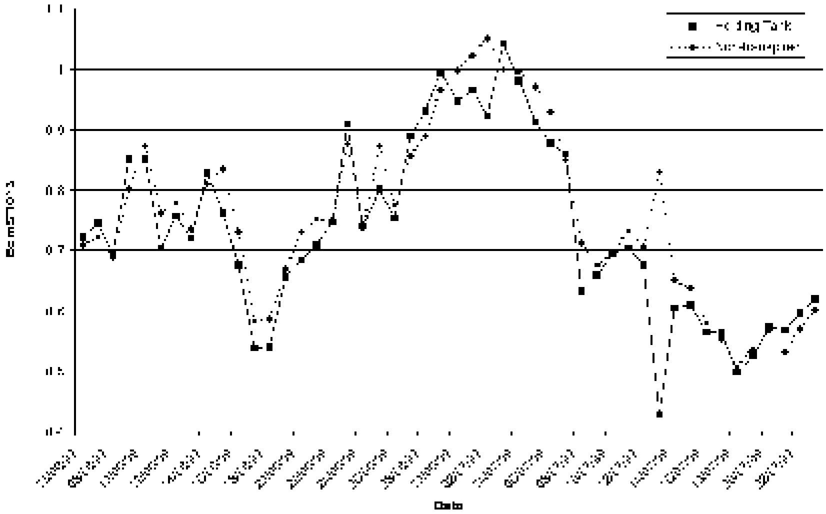
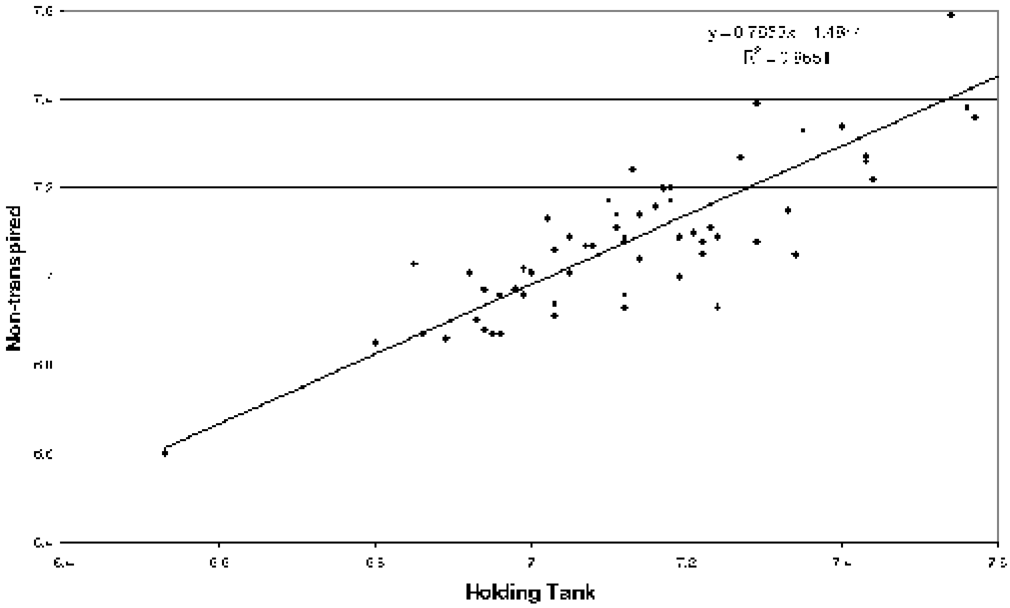


Figure 3

Relationship between pH for holding tank and non-transpired water at Rockhampton Site



The pH of the water in the system (Figure 3) did not exhibit as much change over time as expected. The water in pure hydroponic systems has a tendency to increase in pH over time, whereas the water in this system has to this point has showed no significant change.

The average water use of the system was 32 000 L/month, although climate, and particularly number of sunny days, had a large influence on plant transpiration. Total precipitation in Rockhampton averages 836.4 mm/year, with 91 rain days and 69.7 cloudy days per year (Bureau of Meteorology, 1998).

Yaamba Site

This system was installed in October 1999, three months prior to the construction of a house on the property. One of the difficulties with the system is that the plants need time to recover from the shock of transplant and to establish their root system. By installing the system before the house was built, plants were established before wastewater treatment and disposal was necessary. During this time the plants were watered from the low-water feed. At this site a bore supplies the water for the low-water feed. After house construction all the household greywater will have its origin from onsite rainwater tanks, and the toilet water, which does not need to be of a potable standard, will be from the bore.

The system has eight pots, and the wastewater flows from pot to pot. There is a mixture of fruit trees and ornamentals, and native and exotic plant species. The pots have been densely planted with an average of five plants per pot including two tree species, and three shrubs for the understorey.

St Lawrence Site

The Broadsound Shire Council owns four residential properties close to the St Lawrence River. The River has been classified a Class A fishery, and hence no sewage outfall is permitted into the river. These four houses all had blackwater septic tanks, but no greywater treatment process. The Council provided nearby parkland for installation of waterwell pots and in October 1999 site installation commenced.

The wastewater from all four houses was combined and 24 pots were installed for its processing and reuse. The 24 pots were split into 4 treatments of 6 pots each. Two of the treatments were pot-to-pot systems, the other two were based on the herring bone design. One of each treatment design was planted with an understorey. Plant species in each of the comparable treatments were kept identical.

Emerald Sites

There are two sites currently monitored in Emerald Shire, both located at the Gem Fields 50 km west of the city. Due to land limitations in both of the sites, wastewater flows from pot to pot. The first site is at the Rubyvale Community Hall and the second at the Anakie Retirement Home. Both site installations commenced in October 1999.

The Rubyvale Community Hall system has eight pots and currently all the wastewater is sourced from a large toilet block on the property. A combined black and grey water septic tank was installed at this site, although only very little greywater is produced at this site.

The Anakie Retirement Home has a seven pot system, and only treats and reuses the greywater. The traditional septic system at the retirement home works quite efficiently, but the greywater produced at the site needs to be utilised in a more environmentally sustainable manner.

Further Trials

Other trial site installations are planned in the beginning of the year 2000. These include a site at the Central Queensland University focused on studying the effects of soil type, an additional site in Emerald Shire, and sites in the Gladstone and Mackay shires.

CONCLUSIONS

The system under development appears to offer an environmentally friendly solution for wastewater management to households not connected to sewage treatment plants. Installed for more than two years, there has been no noticeable build-up of ions, while contributions of wastewater to plant growth and amenity value have been appreciable. By extending the geographic locations of the test sites, we continue to upgrade our information on the relevance of the system.

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REFERENCES

Bureau of Meteorology (1998) Climate Data Rockhampton Airport. Single Sheet Handout.

Department of Natural Resources (1999) Interim Code of Practice for On-Site Sewage Facilities. *Queensland Government Gazette* **1** No.65 pp. 17-18.

Gardner T, Geary P, and Gordon I (1997) Ecological Sustainability and On-Site Effluent Treatment Systems. *Australian Journal of Environmental Management* **4** No. 2, pp. 145-147.

Geary P M, and Gardner E A (1996) On-Site Disposal of Effluent. *Invited lectures on Land Management for Urban Development*, Australian Society of Soil Science, Brisbane, pp 291-294.

Lang A H (1994) A Review of Domestic Re-use in Australia. *Melbourne Water Research Report* **2** pp10-11.

Reuter D J, and Robinson J B (1997) *Plant Analysis an Interpretation Manual*, 2nd edition, CSIRO Publishing, Australia.