ON-SITE RECIRCULATION SYSTEM USING TRANSPIRATION AND FILTRATION BEDS

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Abstract

The Central Queensland University (CQU) has developed an on-site wastewater treatment and reuse system that can be used in residential, public, and industrial situations. It is economically viable, environmentally friendly and accepted by the public. The system uses existing on-site treatment processes, such as septic tanks and grease-traps, in conjunction with an innovative recirculating transpiration and filtration bed. The gravel filtration bed is contained within a concrete channel with the evapotranspiration system located above the filtration bed. The soil in the transpiration system can absorb water from the filtration bed. The wastewater undergoes biological treatment as it passes through the gravel bed, and any water not absorbed and used by the evapotranspiration part of the system is returned to the holding tank. The system has the double advantage of neither releasing effluent into the local environment nor being dependent on the soil type of the locality.

The system is being assessed at seven different sites in four Central Queensland Shires. Three more sites are planned. The sites chosen either have a history of soakage drain failure due to inappropriate soil type or are in environmentally sensitive areas. The sites include residential houses, public toilet blocks, retirement homes, and a small industrial workshop. Data collection focuses on water quality parameters, site wastewater production trends, plant growth, microbial ecology, accumulation of salts and heavy metals, soil-water interactions and overall system feasibility. CQU aims to gain system type certification by the end of 2001.

Keywords

Irrigation, microbial ecology, plants, retrofit, reuse, soil, sustainable, water-usage

1 Introduction

On-site wastewater treatment is, for the foreseeable future, a permanent feature for many rural and regional areas of Australia. In remote or dispersed housing situations it is not economically feasible to implement centralised sewage infrastructure and treatment facilities (Geenens and Thoeye 2000). On-site technology has proved to be an economically viable form of wastewater treatment in Australia. Research into the performance of on-site wastewater treatment systems has identified potential environmental and public health concerns (Goonetilleke *et al*. 1999). The two major forms of on-site wastewater treatment used in Australia are septic tanks and aerated wastewater treatment systems (AWTS). Problems with septic tanks occur mainly due to overloading or poor soakage trench design, stemming from insufficient initial site characterisation work (Geary,1992). AWTS are theoretically an improvement over septic tanks; nevertheless field-testing of units has shown, for a variety of reasons, a high rate of failure in respect to the required performance standards (Beavers *et al*.,1999).

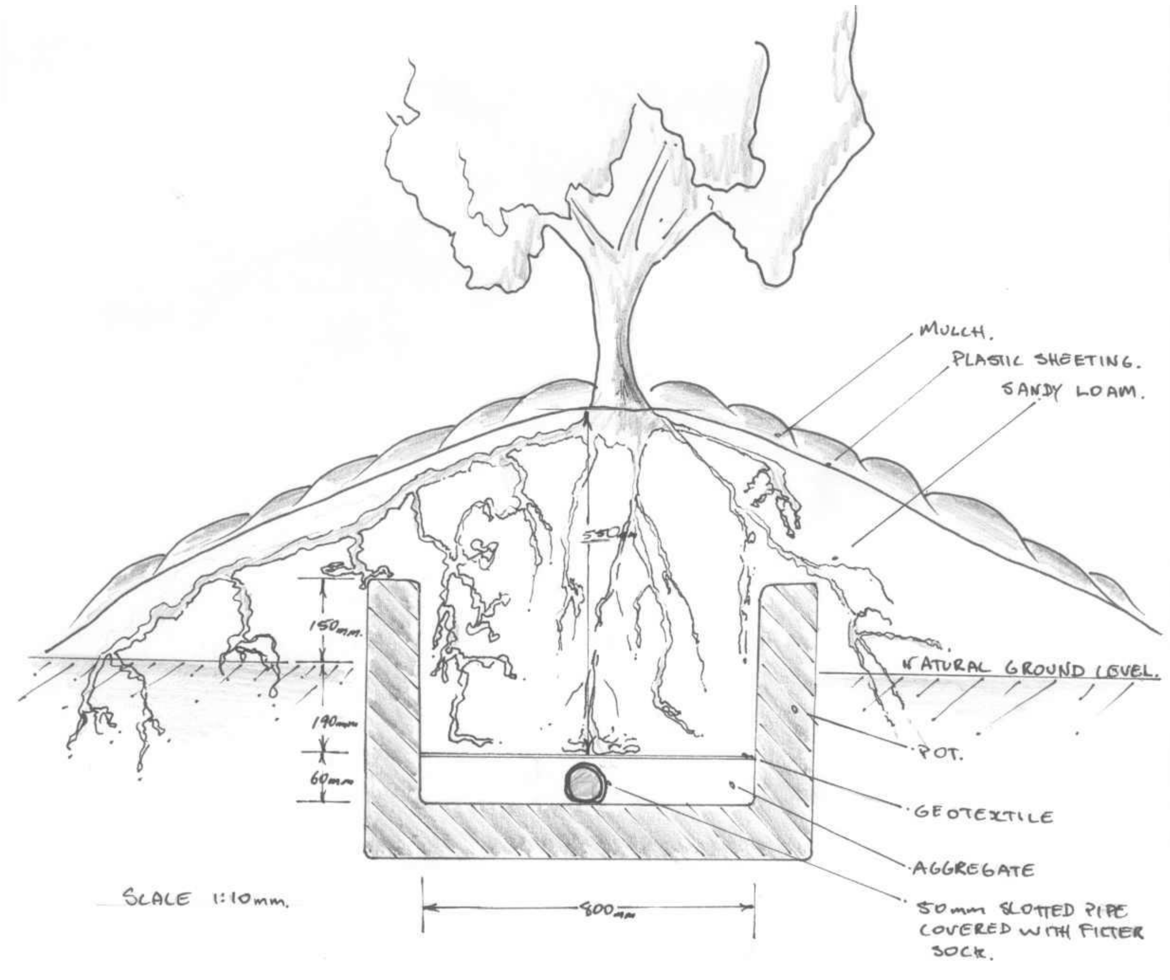
The attitude of the Australian community towards public health risks and environmental pollution caused by failing and poorly performing on-site wastewater systems has hardened

(Gardner *et al.*,1996). The need to move towards positive performance outcomes has been recognised by the legislative and regulatory authorities with the new Australian/New Zealand Standard for on-site domestic-wastewater management (WS/13/1 2000).

2 Materials & Methods

The Central Queensland University (CQU) has designed and is currently assessing an on-site treatment system that should safeguard public health and meet ecologically sustainable development guidelines (Kele *et al.,* 2000). The wastewater entering the system is first treated primarily, either through an all-waste septic tank, or separately in a blackwater septic and a greywater vertical greasetrap. The primarily treated effluent then flows into a holding tank. The effluent from the holding tank is pumped, aerated by a venturi valve, and then enters a self-contained concrete channel (see Figure 1). A 50 mm slotted PVC pipe runs the length of the channel. The pipe is surrounded by aggregate, which is designed to act as a gravel-filter.

Figure 1. A Cross-section of the Transpiration Channel



Geotextile matting covers the aggregate layer and provides a porous barrier between the gravel- filter and the soil-bed. The effluent moves from the gravel-filter into the soil-bed, where it undergoes further natural treatment and ultimately is reused through transpiration. Any effluent not absorbed by the soil or reused by the plants returns to the holding tank. The holding tank has sufficient capacity to retain at least 48 hours worth of wastewater production. The holding tank incorporates a timer and alarm for the pump, a low-water feed, and an emergency form of effluent disposal. The timer allows for the delivery of regulated doses of effluent to the transpiration channel at specific times, to avoid complete saturation of the soil.

The alarm is fitted to give warning of pump failure. The low-water feed is required so that in times of reduced wastewater production, sufficient soil moisture is retained to support growth of the plants. Keeping the soil moist reduces the risk of roots penetrating the geotextile matting in search of water. In the event of system failure, such as pump breakdown, or excessive wastewater production, a safe temporary alternative for disposing of the excess effluent from the system is provided. The emergency effluent disposal can be in the form of a soakage drain or AWTS.

The system is currently being tested in seven different sites throughout Central Queensland (Table 1). Data collection focuses on water quality, water usage, plant growth, microbial ecology, accumulation of salts and heavy metals, soil-water interactions and overall system feasibility.

The pH, electrical conductivity (EC), and total dissolved salts (TDS) were monitored regularly using the best practices described by Csuros and Csuros (1999) and using a TPS WP-81T meter. In addition to these tests, turbidity measurements, solids determinations, and oxygen levels were analysed. Standard procedures were followed and involved plate counts of non-fastidious heterotrophic (Csuros and Csuros 1999), faecal coliform, *Escherichia coli* (Manafi and Kneifel 1989), and *Salmonella* (Frampton et al. 1988). Pour plate methods were used, and all coliform counts were performed on Merck chromocult agar. The nutrient ions were analysed using a Merck RQflex reflectometer following the methods described by Kleinhenz *et al.*, (1997). The study is being conducted at seven different field sites (Table 1). CQU has no control over the wastewater inputs into the trial sites, these are governed by the intrinsic features of each site (Table 1). To broaden the forms of relevance of the research on the trial sites, other forms of on-site treatment technology in similar locations are being monitored. This paper provides an overview of some of the data collection undertaken. In the long-term, the study aims to interpret main effects and possible interactions between the various treatments and reuse components of the trial system. The trial sites were chosen to provide a broad range of on-site conditions.

Table 1. General Description of the Seven Trial Sites

SITE	TYPE OF ON-SITE FACILITY	TYPE OF WASTEWATER	DATE INSTALLED	NEW/ RETROFIT
Rockhampton	Small-Industrial	All waste	June 1997	Retrofit
Yaamba Domestic	3-Bedroom	All waste	October 1999	New
St Lawrence Domestic	4 X 3-Bedroom.	All waste	November 1999	Retrofit
St Lawrence Recreation Area	Amenities Block	All waste	February 2001	Retrofit
Anakie	Small Retirement Home	Greywater	January 2000	Retrofit
Sapphire	Amenities Block	Blackwater	June 2000	Retrofit
Rubyvale	Amenities Block	Blackwater	April 2000	Retrofit

Patterns of wastewater production at the sites were quantified, using water meters

3 Results & Discussion

3.1 Water quality

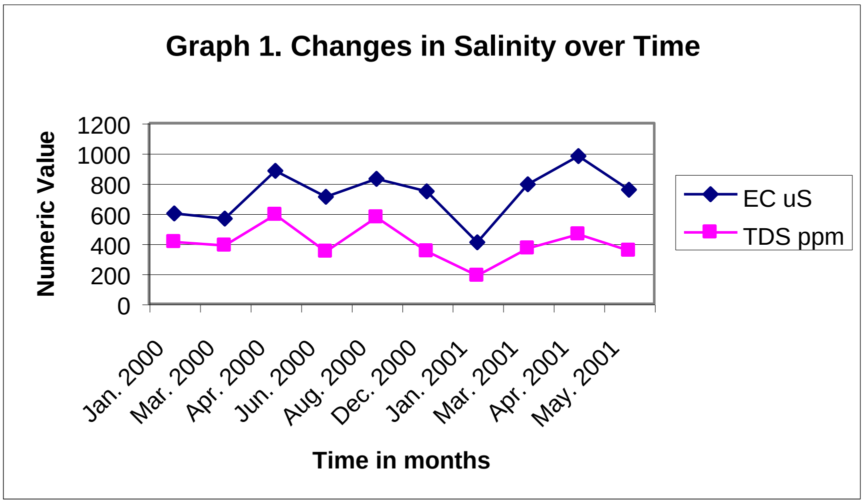
Various components of water quality are being monitored. The most frequently performed tests are pH, EC, and TDS. The St Lawrence Domestic site treats and reuses the wastewater produced by four, 3-bedroom households. The pH, EC, and TDS values for the holding tank over a 17-month period are given in Table 2.

Table 2. Water Quality in the Holding Tank at the St Lawrence Domestic Site over Time

DATE / TEST	JAN 2000	MAR 2000	APR 2000	JUN 2000	AUG 2000	DEC 2000	JAN 2001	MAR 2001	APR 2001	MAY 2001
pH	7.45	7.39	7.24	7.18	7.31	7.14	7.21	7.56	7.5	7.31
EC µS/cm	600	565	883	711	830	746	408	794	981	758
TDS mg/L	411	387	591	346	575	348	187	369	462	353

The pH shows very little change over time, indicating that there may be a buffering effect, perhaps from the soil in the transpiration channel. This is supported with data from the other seven sites with pH values for the seven holding tanks in the trial between 6.5 and 8, but with average values between 7.2 and 7.5. The pH values of the wastewater entering the system show much larger variations. The minimal impact that in-flow variations in pH have over the effluent within the system does indicate some form of buffering system. CQU plans to investigate this further with laboratory experiments using a small-scale version of the system.

The EC and TDS values within the St Lawrence Domestic site holding tank over time were much more variable (see Graph 1). Variations within the system are often related to changes in the system inputs from the householder or amenities users. The monitoring of salinity in an enclosed system is very important as a build-up over time may prove toxic to the plants in the transpiration channel.



The slight rises in EC and TDS in April 2000 and April 2001 correspond to short-term increases in the number of people residing in the houses. These increases in residents resulted in larger volumes of wastewater entering the system and a rise in the input level of EC and TDS.

The large decrease at the end of January 2001 was the result of a flood event filling the emergency soakage drain and backfilling and flooding the holding tank. While it is important to monitor salinity in the effluent within the various parts of the system, it is of particular importance to examine the level of salts within the soil in the transpiration channel. The accumulation of salinity within the root-zone has been identified as a limiting factor in relation to effluent reuse through irrigation (Bond 1998).

CQU is collecting data overtime on the concentration of salts and sodium within the soil in the transpiration channel. The CQU trial system has in-built measures to limit the effects of salt accumulation within the soil-bed. In the event of a toxic level of salinity, the holding tank can be pumped out and fresh water added to the tank. The fresh water can then be pumped through the system at a rate far greater than normal to induce soil saturation, flushing the channel. The process of diffusion allows salts to leave the soil-bed and re-enter solution. The 'flush' water can then be pumped out of the holding tank. The flush process is expected to increase the life of the transpiration channel and increase the sustainability of the system.

The accumulation of nutrient ions within the system is also of concern. Even nutrients required for plant growth can become toxic at high concentrations. Table 3 shows the concentrations for nitrate, ammonia, phosphate, and potassium in the holding tank at the Rockhampton site over a 22-month period.

Table 3. Nutrient Concentrations in the Holding Tank at the Rockhampton Site over Time

DATE / TEST	JUNE 1999	OCTOBER 1999	JUNE 2000	DECEMBER 2000	APRIL 2001
NO_3^- mg/L	2	2	2	4	2
NH_4^+ mg/L	20	12.4	43	88	55
PO_4^- mg/L	57	30	34	32	26
K^+ g/L	0.3	0.28	0.32	0.33	0.26

There has been no significant rise in nitrate over time. This is expected, as nitrate is a biologically available form of nitrogen and therefore readily absorbed by plants. The ammonia level is largely dependent on the amount of blackwater entering the system. During December 2000 there was a 20% increase in the number of people using the facilities at the Rockhampton site. This may account for some of the rise in the ammonium levels. The jump in the nitrate levels during this time may be due to an increase in nitrification by *Klebsiella* (see Table 4). Phosphorus levels have decreased over time. Data from the soil indicate no significant rise in soil phosphorus levels, with an average level of 15 mg/kg. CQU plans to use the molecular techniques described by Bond *et al.*, (1999) to identify if the microbes thought to be involved in biological phosphorus removal processes are present in the system. There has been no dramatic changes or accumulation in the potassium levels.

3.2 Microbial Ecology

The study of microbial ecology within a recirculating system produces data that are difficult to analyse. Addition of new aliquots of primarily treated effluent to the recirculated effluent means that the quantification of treatment effectiveness cannot be deduced through normal methods. Even the long-term study of microbial numbers in the trial systems is susceptible to large unplanned variations, such as the influence of a disinfectant in the wastewater.

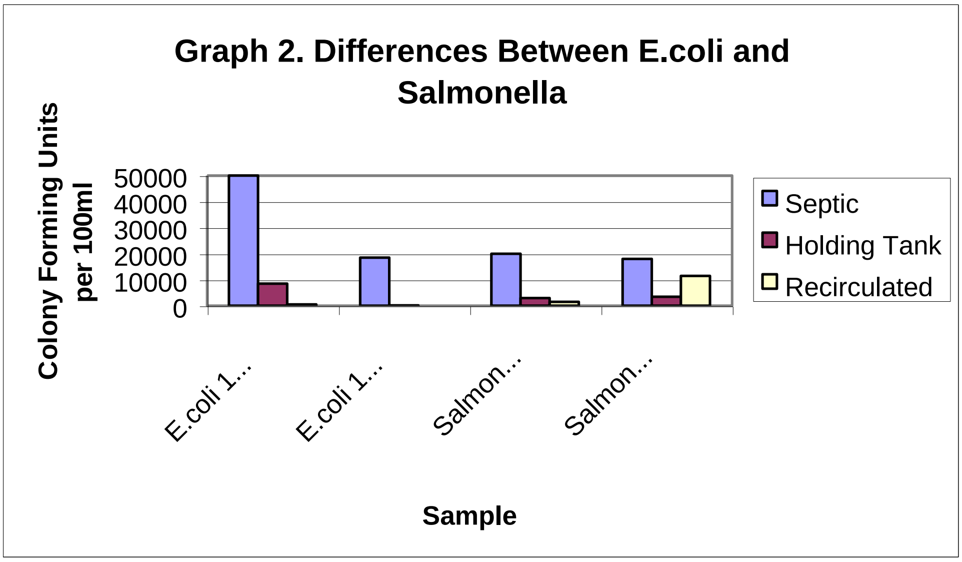
An experiment was conducted at the Rockhampton site over the Easter long weekend. This site was chosen as it was closed during the holiday period and there were no new inputs of wastewater over that period. Samples were taken from four positions throughout the system again at 5.00 p.m. Easter Thursday and 5.00 a.m. the following Tuesday and results are presented in Table 4.

Table 4. Colonial Forming Units per 100 ml for the Rockhampton Site over the Easter Break

Sample	Non-Fas Hetero.[1] 14/4/01	Non-Fas Hetero. 19/4/01	CEK[2] 14/4/01	CEK 19/4/01	*E.coli* 14/4/01	*E.coli* 19/4/01	*Salmonella* 14/4/01	*Salmonella* 19/4/01
Treated Grey	$9.8*10^6$	$4.5*10^{10}$	15 050	33 500	<1	<1	<1	<1
Septic	$5.8*10^7$	$1.8*10^9$	45 500	30 500	50 000	18 500	20 000	18 000
Holding Tank	$3.3*10^8$	$5.7*10^8$	37 000	89 500	8 500	100	3000	3500
Recirculated	$3.7*10^8$	$4.4*10^8$	47 500	20 000	500	<1	1500	11 400

[1]Non-Fas Heter – Non-Fastidious Heterotrophs
[2]CEK – *Citrobacter*, *Enterobacter*, and *Klebsiella*

The results show that the numbers of non-fastidious heterotrophs increased in all samples over the five days. The non-fastidious count is important as it gives a non-selective microbial enumeration. The largest non-fastidious heterotroph increase was in the treated greywater. A major component of the treated greywater comes from a hand-washing area where significant quantities of an anti-microbial soap are used. The absence of new aliquots of this soap entering the greasetrap during the experimental run is the most likely cause for the exponential increase in colony forming units. The increase in *Citrobacter*, *Enterobacter*, and *Klebsiella* (CEK) numbers in the treated greywater during this period supports the argument. The numbers of CEK increased in the holding tank, and decreased in the recirculated water. This may also be in part due to the reduced amount of anti-microbial agents from the greasetrap entering the holding tank. Further research is needed to examine why the CEK numbers in the holding tank and recirculated effluent changed over time in the way that they did. The data for *E.coli* and *Salmonella* are shown graphically in Graph 2.



Data in Table 4 clearly show that the numbers of *E.coli* in the system is reduced with treatment and time. The graph also highlights the increase in numbers of *Salmonella* species in the holding tank and recirculated effluent over the five day period. *E.coli* is noted to have relatively low survival time in water, especially when compared to *Citrobacter*, *Enterobacter*, and *Klebsiella* (Baudisova 1997). Yates (1986) reported that *Salmonella* had a longer waterborne survival time than *E.coli*. It has been reported that *E.coli* has a longer survival time in soil than *Salmonella* (Gerba et al. 1975). However no contamination from *E.coli* in the soil-bed leaching back into the recirculated effluent appears to have occurred. CQU plans to repeat this experiment in conjunction with microbial soil analysis at several sites.

3.3 System feasibility

The CQU trial system can be, and has been (see Table 1), retrofitted to failing septic and AWTS installations. On-site treatment systems, especially septics that are situated on inappropriate areas such as those with the wrong soil type for effluent disposal, or on high groundwater tables, or close to aboveground natural water-bodies have been shown to have a high rate of failure (Geary 1993). Factors that cause AWTS installations to fail, such as the requirement for the regular addition of chlorine (Hanna *et al*., 1995), are unlikely to arise with the CQU trial system. It is not economically feasible to change on-site procedures nor politically realistic to expect governments to remove people from their houses and lands to stop the use of on-site treatment in inappropriate areas. The major proposed application of the CQU trial system is in areas with particular environmental concerns or where the soil type is not conducive for effluent disposal. The technology has the dual benefits of being independent of the local soil type and that of containing the effluent within the system.

While the research has been promising, the trial has encountered some difficulties. Two of the sites are located on flood plains. It was found that in high rainfall events the emergency soakage drain filled and added water to the holding tank, flooding the system. Adding rainfall/runoff infiltration prevention measures to the emergency soakage drain has solved this problem. At some sites the high incidence of animal feeding on the plants has been of concern. This has been solved by fencing and by the use of chemical deterrents. There have been other minor problems, such as foreign object damage to pumps, and infrastructure failure, for example the continuous flushing of toilets, within the households/amenities blocks. The seven CQU trial systems have so far been able to prevail over the adverse conditions/problems encountered.

4 Conclusion

CQU is confident that the trial system is a practical solution to on-site wastewater treatment and reuse. The enclosed nature of the technology means that it is especially suited to sites with poor disposal conditions and/or environmentally sensitive areas. Intensive research into the trial system will continue until June 2002. CQU commences the procedures needed for system type certification on the 1/7/01. It is expected that by the beginning of 2002 the CQU system should be available to the public.

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