TREATMENT BY REED BED & SAND FILTER

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Abstract

This paper presents the results of a preliminary study conducted between August and October 2000 on the nutrient loadings and treatment performance of four secondary treatment trains in on-site systems located on the NSW Far North Coast.

Two of the treatment trains consist of horizontal flow wetlands (HFW), one consists of a HFW preceded by a vertical flow wetland (VFW), and the fourth consists of a HFW preceded by a sand filter (SF). One HFW-only system treats just greywater; the two multiple element systems treat combined wastewater (both black and grey), while the second HFW-only system treats combined wastewater augmented by loading from an in-sink garbage grinder. The age of the systems at the time of the study varied from 5 to 12 months.

Per capita annual nutrient loadings to the greywater system were 0.3 kg for total phosphorus (TP) and 2.0 kg for total nitrogen (TN). For two of the combined wastewater systems, TP loadings were 0.4 and 0.6 kg, and TN loadings 3.2 and 3.9 kg. The figures for the combined system with a garbage grinder were considerably higher, at 1.2 kg TP and 6.3 kg TN, indicating the effectiveness of source control. Percent load removal ranges for the four secondary treatment trains of TSS (76-99), BOD (82-99), TP (14-79), TN (38-83) and FC (87-99.99) compare favourably with performances reported in other studies.

Keywords

Horizontal flow, nutrient loadings, reed-bed, sub-surface, sand filter, vertical flow, wetland.

1 Introduction

There is a trend towards the inclusion of secondary treatment elements in on-site wastewater management systems, particularly where site conditions are limiting. Among the elements being implemented in parts of the NSW Far North Coast are subsurface flow wetlands (both horizontal and vertical flow) and sand filters. The senior author of this paper has designed and constructed a number of such systems and funding was recently obtained under the NSW Department of Local Government Septic Safe Scheme to assess the performance of four of these (shown schematically in Figures 1 to 4). System 1 treats combined wastewater for a family of two using two horizontal flow wetlands (HFW) in series. System 2 treats greywater only for a family of four (including two babies in nappies) using two HFWs in series. System 3 treats combined wastewater for a family of three using a vertical flow wetland (VFW) followed by a HFW. System 4, treating combined wastewater for a family of five, uses a single pass sand filter (SF) followed by two HFWs in series.

Although HF wetlands were initially designed to treat solely for BOD and TSS removal it is clear that other pollutants receive considerable treatment. Aerobic and anaerobic bacteria degrade the organic compounds. Suspended solids are filtered and settled. Ammonium is oxidised to nitrate by nitrifying bacteria in the aerobic zones (nitrification) whilst denitrifying bacteria convert nitrate to gaseous nitrogen in the anoxic zones (Cooper *et al*., 1998, Kadlec *et al.*, 2000). HFWs are suited to denitrification but, because of low oxygen transfer capability, they have limited capacity for nitrification.

This deficiency has led in recent years to the practice of preceding a HFW with a VFW which is dosed intermittently at the top, allowing liquid to drain vertically, and discharge at the base of the wetland to the HFW (Cooper *et al*., 1998). After the VFW drains, air refills the space between the media and roots of the vegetation (*Phragmites australis*) allowing oxygen transfer for BOD reduction and nitrification of NH4-N. Cooper (1998) summarises the differences and potential complementarities of horizontal and vertical flow wetlands thus:

- HFWs are good for removal of suspended solids, bacteria, BOD (up to a set oxygen transfer capacity) and denitrification. However they are poor for nitrification because of limited oxygen transfer capability (OTC).
- VFWs are good for nitrification (high OTC), the removal of BOD and some bacteria but less good for suspended solids removal and denitrification.

This paper describes the results of the first of two monitoring periods conducted under the NSW Department of Local Government's Septic Safe program and discusses these results in the light of previous similar studies. As a number of councils in NSW are sizing disposal areas on the basis of their capacity to deal with nutrients there is some interest in the question: "how much TN and TP does a typical human generate in a year?" Therefore note is also made of the per capita nutrient loadings generated by the respective households.

2 System Descriptions and Methods

The wetlands are contained in round baffled polyethylene cattle troughs. Those used for the HFWs have surface areas of 6.83m^2 each while the VFW has a surface area of 3.14m^2. Media within the HFWs consists of a thin lower layer of stones (>60mm ø) overlain by 10-20mm ø gravel to 550 mm. The VFW contains graded media of gravel (10– 60mm ø) to 400mm beneath a 100mm layer of sand. The two in-ground sand filters, of surface area 12 m^2 each, are constructed within impermeable membranes (Canvacon 7000®) with a lower layer of 60mm ø gravel to 150mm overlain by 600mm of sand, topped by 100mm of 10mm ø gravel. At any given time one sand filter will be resting to facilitate breakdown of clogging material while the other is being dosed 3 times per day. The systems studied contain these three element types in the combinations shown in Figures 1 to 4 and summarised in Table 1.

A total of eight samples were taken at the points shown in Figures 1 to 4 at weekly intervals from August to October 2000. Mainly fine weather prevailed during the sampling period. The samples were analysed for Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Total Phosphorus (TP), Total Nitrogen (TN) and Faecal Coliforms (FC) at the Environmental Analysis Laboratory, Southern Cross University using methods in accord with APHA (1992). Water meters, read weekly, were attached to all water supplies to measure internal household usage and hence inflow to wastewater systems. Outflows from wetland systems were estimated by subtracting an assumed evapotranspiration flow from the measured inflow. The amount subtracted varied from 10% to 20% of inflow, based on prevailing weather conditions and experience gained in a previous local study (Headley and Davison 1999). A more detailed description of the study outlined in this paper is given in Davison *et al.* (2001).

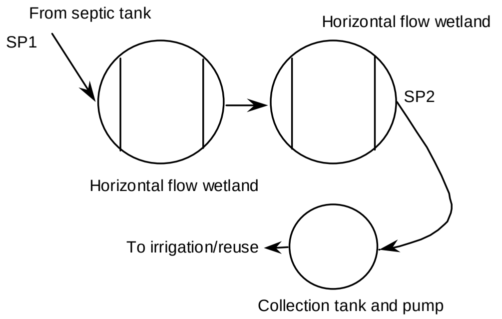

Figure 1: System 1 – Horizontal flow wetlands – black/greywater

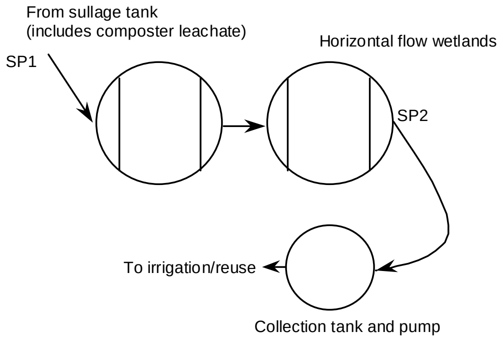

Figure 2: System 2 – Horizontal flow wetlands – greywater only

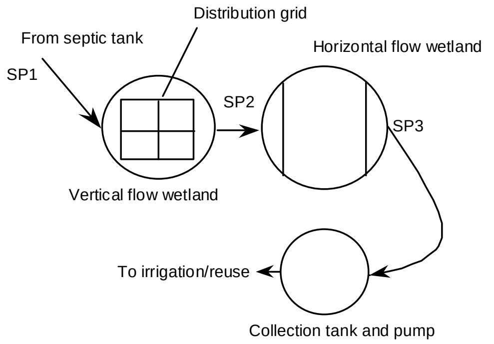

Figure 3: System 3 – Vertical and horizontal flow wetlands black/greywater

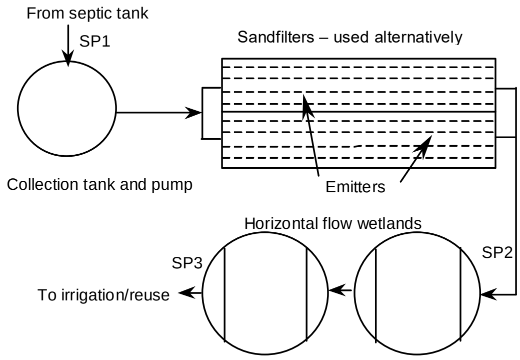

Figure 4: System 4 – Sandfilters and horizontal flow wetlands black/greywater

SP = sampling points

Table 1: System Details and Loading Rates

System Feature	System 1	System 2	System 3	System 4
Age @ time of study	12 months	5 months	8 months	5 months
Type of load	Black and greywater	Greywater only	Black and greywater	Black and greywater
No. people	2 adults	2 adults 2 toddlers	3 adults	2 adults 3 children
Mean hydraulic load (L/d)	350	600	120	650
Primary treatment	Septic tank	Sullage tank	Septic tank	Septic tank
HFW surface area (m^2)	13.7	13.7	6.8	13.7
Mean HRTn (days) *	7.8	4.2	11.3	4.2
Loading rate (mm/d)	26	44	11	47
Plants	*Phragmites, Lomandra spp.*	*Baumea sp., Lomandra*	*Phragmites*	*Phragmites*
Plant development at time of study	well developed	immature	immature	immature
VFW surface area	na	na	3.14 m^2	na
SF surface area	na	na	na	12 m^2 x 2

*HRTn = nominal hydraulic retention time

3 Results and Discussion

Table 2 summarises estimates of the annual per capita nutrient loadings for the four households based on the eight samples taken in this study. For comparison, Table 3 summarises the same quantities based on previous studies. Despite the small sample size of four households, Table 2 indicates that source control by eliminating blackwater is an effective way to lower nutrient loads. The loadings from Household 1 clearly demonstrate the undesirable effect of kitchen sink garbage grinders on nutrient loadings. An examination of Tables 2 and 3 suggests that nutrient loading rates are variable between households (depending on lifestyle, diet, level of attention to source control etc.) and even within a given household over time (stage of life, availability of low P detergents). This level of variability poses a challenge for regulators who have to assume representative nutrient loadings for the purpose of sizing disposal fields.

Table 2: Annual Per Capita Nutrient Loading Rates for The Four Households Studied (sampled at septic/sullage tank outlet).

	Household 1	Household 2	Household 3	Household 4
TP (kg/p/yr)*	1.2	0.3	0.4	0.6
TN (kg/p/yr)*	6.3	2.0	3.2	3.9
comments	Combined waste-water with garbage grinder on sink	Greywater includes nappies for 2 babies	Combined wastewater No laundry	Combined wastewater Strict vegetarian

* kg/p/yr = kilograms per person per year

Table 3: Annual Per Capita Nutrient Loadings from Other Studies

	Whelan & Titammis (1982)	Witt *et al.* (1974)	Griffiths (1997)
TP (kg/p/yr)	0.6	1.5	0.9
TN (kg/p/yr)	3.8	2.2	4.2 to 5.5
comments	Western Australian study Sampled in absorption trench	Rural Wisconsin, USA Sampled before septic tank	Based on studies at several Australian STPs

Table 4 summarises results relevant to the treatment performance of the four systems studied. The performance of secondary treatment elements is dependent to some extent on the composition of the effluent being treated, and hence on the preceding level of primary treatment. In this context it is worth noting that System 4 (SF/HFW) was subject to some carry-over of solids from the septic tank leading to a very high TSS concentration in the sand filter influent. This is probably because the septic tank had not formed a good scum layer at the time of the study, possibly a result of the fact that this system served the only strictly vegetarian family in the study. Concentrations of all parameters in the System 3 (VFW/HFW) influent were very high since per person water usage was only 40 l/day compared to 130 to 170 l/day at the other sites.

System performance is assessed on the basis of three performance indicators: (a) effluent concentration (mg/l or cfu/100ml), (b) areal removal rate (gm/m^2/d) and (c) load removal (%) where load is in g/d.

In the case of Faecal Coliforms, areal removal rate is replaced by log load removal, where each log represents a decrease of one order of magnitude in pollutant load. Each indicator has its strengths and weaknesses. Effluent concentration is important where a regulatory standard has to be met but is strongly influenced by influent concentration as well as by system performance. Areal removal rate measures the actual rate of removal of pollutant mass per unit area and is a very useful performance indicator where space is limited. It has the disadvantage of being influenced by the influent concentration, as more concentrated effluents show higher areal removal rates in any given system. Percent load removal has the advantage of being somewhat independent of influent concentration for a given residence time and of being a widely accepted indicator.

Table 4: Summary of Results for Water Quality Data and Treatment Performance

L=litres/day, r = retention in days, p = people, a = area m^2

	Variable	System 1 L=350, r=7.8 p=2, a=13.66 HFW	System 2 L=600, r=4.5 p=4, a=13.66 HFW (Grey)	*System 3* L=120 p=3, a=3.14 *VFW only*	*System 3* L=120, r=11.3 p=3, a=6.83 *HFW only*	System 3 L=120, r>11.3 p=3, a=10 VFW, HFW	*System 4* L=650 p=5, a=12 *SF only*	*System 4* L=650, r=4.2 p=5, a=13.66 *HFW only*	System 4 L=650, r>4.2 p=5, a=25.66 SF/HFW
TSS	inf. conc. mg/l	73.5	59.0	*171.0*	*73.8*	171.0	*390.0*	*4.0*	390.0
	eff. conc mg/l	21.4	8.7	*73.8*	*33.0*	33.0	*4.0*	*2.0*	2.0
	inf. load g/d	25.7	35.4	*20.6*	*8.9*	20.6	253.4	*2.6*	253.4
	eff. load g/d	6.4	4.5	*8.9*	*3.4*	3.4	2.6	*1.0*	1.0
	rem. Rate g/m^2/d	1.38	2.40	*3.74*	*0.80*	1.72	*17.91*	*0.12*	9.12
	% load removal	**76.0**	**89.0**	***53.0***	***61.0***	**81.0**	***98.0***	***53.0***	**99.0**
BOD	inf. conc. mg/l	157.3	77.5	*417.0*	*50.0*	417.0	*188.0*	*2.9*	188.0
	eff. conc mg/l	13.4	14.4	*50.0*	*32.0*	32.0	*2.9*	*2.0*	2.0
	inf. load g/d	55.0	46.5	*50.1*	*6.0*	50.1	122.4	*1.9*	122.4
	eff. load g/d	3.9	7.2	*6.0*	*3.2*	3.2	1.9	*1.1*	1.1
	rem. Rate g/m^2/d	3.89	2.70	*14.00*	*0.40*	4.70	*7.13*	*0.06*	3.64
	% load removal	**92.0**	**82.0**	***88.0***	***26.0***	**93.0**	***98.0***	***17.0***	**99.0**
TP	inf. conc. mg/l	19.0	5.2	*29.0*	*25.0*	29.0	*13.0*	*6.0*	13.0
	eff. conc mg/l	15.7	5.1	*25.0*	*18.0*	18.0	*6.0*	*3.0*	3.0
	inf. load g/d	6.7	3.1	*3.5*	*3.0*	3.5	8.3	*3.9*	8.3
	eff. load g/d	4.6	2.6	*3.0*	*1.9*	1.9	3.9	*1.7*	1.7
	rem. Rate g/m^2/d	0.150	0.038	*0.150*	*0.168*	0.160	*0.360*	*0.170*	0.260
	% load removal	**26.0**	**18.0**	***11.0***	***35.0***	**43.0**	***51.0***	***46.0***	**79.0**
	load/p/yr (kg)	*1.2*	*0.3*	*0.4*	*0.4*	*0.4*	*0.6*	*0.6*	*0.6*
TN	inf. conc. mg/l	98.5	36.3	*217.0*	*157.2*	215.0	*82.0*	*68.7*	82.0
	eff. conc mg/l	71.6	6.9	*157.2*	*110.0*	110.0	*68.7*	*52.0*	52.0
	inf. load g/d	34.5	21.8	*25.8*	*18.9*	25.8	53.1	*44.7*	53.1
	eff. load g/d	21.1	3.5	*18.9*	*11.1*	11.1	44.7	*28.6*	28.6
	rem. Rate g/m^2/d	0.98	1.30	*2.20*	*1.10*	1.50	*0.70*	*1.18*	0.96
	% load removal	**38.0**	**83.0**	***23.0***	***40.0***	**53.0**	***15.0***	***30.0***	**44.0**
	load/p/yr (kg)	*6.3*	*2.0*	*3.2*	*3.2*	*3.2*	*3.9*	*3.9*	*3.9*
FC	inf. conc. cfu/100ml	7.0E+05	1.1E+06	*1.1E+06*	*1.1E+05*	1.1E+06	*3.1E+06*	*1.1E+04*	3.1E+06
	eff. conc cfu/100ml	3.8E+04	7.2E+04	*1.3E+05*	*4.3E+04*	4.3E+04	*1.1E+04*	*4.1E+02*	4.1E+02
	inf. load cfu/d	2.1E+09	3.5E+09	*1.3E+09*	*1.6E+08*	1.3E+09	*2.0E+10*	*7.3E+07*	2.0E+10
	eff. load cfu/d	1.0E+08	3.2E+08	*1.6E+08*	*4.5E+07*	4.5E+07	*7.3E+07*	*2.2E+06*	2.2E+06
	% load removal	**95.2**	**91**	**88**	**72**	**97**	**99.6**	**97**	**99.99**
	% load removal	**1.3 logs**	**1 log**	**0.92 logs**	**0.55 logs**	**1.5 logs**	**2.4 logs**	**1.5 logs**	**4 logs**

VFW = vertical flow wetland HFW = horizontal flow wetland SF = sandfilter Grey = greywater (only)

The SF/HFW combination (System 4) produced the best percentage load removals for TSS (99%), BOD (99%), TP (79%) and FC (99.99% or 4 logs) highlighting the synergy obtained by combining the aerobic sand filter with the largely anaerobic reed bed. The FC concentration in the System 4 effluent was extremely low at 410 cfu/100ml. This level of performance, a requirement for the constrained site, was achieved by increasing the area of treatment with a subsequent rise in capital cost. At 26 m^2, the total treatment area in System 4 is almost twice that of the next largest system. Of the individual treatment elements studied, the sand filter achieved the lowest BOD and TSS concentrations at 2.9 mg/l and 4 mg/l respectively. These levels are well within the 20mg/l / 30 mg/l levels used by Standards Australia (2000) to define secondary treated wastewater. Both HFW-only systems (Systems 1 and 2) also achieved secondary treatment status.

At 83% load removal, the HFW in System 2 produced the best TN treatment. It is likely that TN removal for Systems 3 and 4 will improve as the macrophytes develop. At 6.9 mg/l, System 2 achieved the lowest effluent concentration for TN partly because, being greywater only, it started from a low influent level (36.3 mg/l). An interesting feature of the System 2 TN removal performance is that the areal removal rate (1.3 g/m^2/d) exceeded that of the other three HFWs despite the fact that they all had higher influent concentrations. This is surprising because both theory (eg Reed *et al.*, 1995) and recent local experience (Davison *et al*., 2000) suggest a positive relationship between influent concentration and areal removal rate.

TP removal rates varied from as low as 18% for System 2 (greywater with influent concentration of only 5 mg/L) to 79% for the SF/ HFW combination of System 4. Note that with the exception of System 2, areal removal rate for TP was similar for all systems at about 0.16 g/m^2/d. Because phosphorus removal occurs mainly via precipitation and adsorption processes, it is expected that these removal rates will gradually fall off as P removal sites become saturated.

Table 5: Percent Removal Rates for HFWs in This and Other Studies

	Mixed wastewater				**Greywater**	
	HFW in System 1	**McCarthy *et al.*, 1998**	**Summary Kadlec et al., 2000**	**Thom *et al.*, 1998**	***HFW in System 2***	**Davison & Wallace, 1999**
TSS	***76***	**75**	**74-87**	**72**	***89***	**63-98**
BOD	***92***	**83**	**63-90**	**76**	***82***	**88-90**
TP	***26***	**54**	**21-42**	**57**	***18***	**46-48**
TN	***38***	**42**	**32-44**	**60**	***83***	**36-55**
FC	***95.2***	**99**	**98.5**	**99**	***91***	**83-95**

Table 5 compares the percent removal rates achieved by the HFW-only Systems 1 and 2 studied here with rates reported in other studies on HFWs. A 17% removal rate for BOD occurred in HFW 4 (preceded by the sand filter) reducing effluent from the extremely low figure of 2.9 mg/l to 2.0 mg/l. In more mature systems the decomposition of litter from fallen leaves would probably cause an increase in BOD in an effluent of this quality, incidentally providing carbon to support denitrification.

The VFW/HFW combination (System 3) monitored in this study achieved 53% TN removal. TN removal in the VFW section was 23% indicating that some denitrification was also occurring here. One would expect the 40% TN removal in the subsequent HFW element to improve with time as the reeds develop and increase their capacity to generate denitrifying carbon. The summary of results in Table 6 supports the view of Sievers (1998) that the treatment media supports a suite of aerobic microorganisms producing "high quality effluent which is very low in organic matter (BOD and TSS), ammonia nitrogen" and reduced levels of faecal coliforms, *Giardia* and *Cryptosporidium*. The results in Table 6 show that the System 4 sand filter generally compares favourably with the other systems except for the reduction % indicated for TN reported by Cagle & Johnson (1994).

Table 6: Percentage Load Removals for System 4 SF & Other Intermittently Dosed Sand Filters

	System 4* SF element only	**Cagle & Johnson 1994**	**McCarthy *et al.*, 1998**	**Jantrania *et al.*, 1998**
TSS	**98**	**78-93**	**89-96**	**89**
BOD_5	**98**	**98-99**	**96-99**	**94**
TP	**51**	**na**	**39-53**	**27**
TN	**15**	**40-47**	**12-32**	**19.5**
FC	**99.6 (2.4 log)**	**99 (2 log)**	**99.8 (2.6 log)**	**97.5 (1.6 log)**
Dosage	**54L/m^2/day***	**50L/m^2/day#**	**32L/m^2/day#**	**88L/m^2/day#**

*Intermittent dosage rate was 18L/m^2 X 3 times per day
Actual intermittent rate unknown.

Sand filters can be affected by clogging through solids accumulation (Miller *et al.*, 1994). More frequent, smaller doses and pre-treatment can alleviate this accumulation. Venhuizen (1996) suggests that loading rates of >400 L/m^2 can be supported for prolonged periods where pre-treatment (eg by HFW) to reduce TSS and BOD is applied.

The performance data presented in Table 6 relate to single pass intermittent pressure dosed units. Venhuizen (1998) and Jantrania *et al*. (1998) both note that an intermittently dosed recirculating system would be more efficient at nitrogen reduction.

3 Conclusions

At 0.3 kg/p/yr and 2.0 kg/p/yr for TP and TN respectively, the greywater in System 2 produced the lowest nutrient loadings. Loadings for the combined wastewater in Systems 3 and 4 were respectively 0.4 and 0.6 kg/p/yr for TP, and 3.2 and 3.9 kg/p/yr for TN. System 1, producing combined wastewater plus effluent from a garbage grinder in the kitchen sink, produced loadings of 1.2 kg/p/yr and 6.3 kg/p/yr for TP and TN respectively. These figures provide eloquent testimony to the efficacy of source control.

The four treatment systems monitored were all relatively immature at the time of this study with ages varying between five and twelve months. Load removals for the HFW system treating black and grey water were TSS 76%, BOD 92%, TP 26%, TN 38% and FC 91%. Corresponding figures for the HFW system treating greywater (only) were TSS 89%, BOD 82%, TP 18%, TN 83% and FC 88%. The VFW/HFW system treating black and grey water achieved load reductions of TSS 81%, BOD 93%, TP 43%, TN 53% and FC 91%. Finally, the SF/HFW system treating black and grey water achieved removal rates of TSS 99%, BOD 99%, TP 79%, TN 44% and FC 99.9%.

Of the individual elements, the sand filters in System 4 showed the best performance in four of the five indicators tested. In the fifth parameter, TN, the low removal rate (15%) highlights the lack of denitrification opportunity in the sand filter's largely aerobic environment. The total TN removal rate in System 4 increased to 44% after passing through the horizontal flow wetland. This TN removal rate may be expected to increase as the wetland matures. Balanced against System 4's high performance is the fact that its treatment area is almost twice as great as the two single element HFW systems.

The results highlight the potential for natural secondary treatment elements such as wetlands and sand filters in on-site systems. Each of the elements has its own strengths and weaknesses and the choice of element or combination of elements will depend on the context.

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References

American Public Health Association, American Waterworks Association/Water Environment Federation. 1992. *Standard Methods for the Examination of Water and Wastewater.* 18th Edn, Washington, DC, USA.

Cagle, W.A. & Johnson, L.A. 1994. On-Site Intermittent Sand Filter Systems – A Regulatory/Scientific Approach to Their Study in Placer County, California. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems,* ASAE, 283-291.

Cooper, P. 1998. A review of the design and performance of vertical-flow and hybrid reed bed treatment systems. *Wat. Sci. Tech.* 40, 3, 1-9.

Cooper, P., Griffin, P., Humphries, S. and Pound, A. 1998. Design of a hybrid reed bed system to achieve complete nitrification and denitrification of domestic sewage. *Wat. Sci. Tech.* 40, 3, 283-289.

Davison, L. & Wallace, P. 1999. Composting Toilet with Reed Bed Greywater Treatment: Two Systems, in *Proc. On-Site '99 – Making On-site Systems Work*, University of New England, Armidale, NSW, July.

Davison, L., Headley, T. and Edmonds, M. 2000. On-site Wastewater Treatment by Reed Bed in the Moist Subtropics, In *Proc. 7th International Conference on Wetland Systems for Water Pollution Control*, Orlando, Florida.

Davison, L., Kohlenberg, A., Craven, J. & Bayley, M. in preparation. *Treatment of On-site Domestic Wastewater by Reed Bed and Sand Filter*, Septic Safe Project Report, Southern Cross University, Lismore.

Griffiths, P. 1997. Achievable Effluent Quality from Biological Nutrient Reduction Systems Under Australian Conditions – Modelling and Full Scale Operating Experience. In *Proc. BNR3 Conference* pp 145-152, Brisbane.

Headley, T. and Davison, L. 1999. On-site Treatment by Reed Bed and Pond: a Study of Two Systems, in *Proc. On-site '99 - Making On-site Systems Work*, Conference University of New England, Armidale, NSW, July.

Jantrania, A.R., Sheu, K.C., Cooperman, A.N. and Pancorbo, O.C. 1994. Performance Evaluation of Alternative Systems – Gloucester, MA, Demonstration Project. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems*, ASAE, 480-489.

Kadlec, R.H., Knight, R.L., Vymazal, J., Brix, H. Cooper, P. and Haberl, R. 2000. *Constructed Wetlands for Pollution Control*. IWA Publishing, London.

McCarthy, B, Axler, R., Geerts, S.M., Henneck, J., Nordman, D., Crosby, J. and Weidman, P. 1994. Performance of Alternative Treatment Systems in Northern Minnesota. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems*, ASAE, 446-457.

Miller, D.A., Sack, W.A., Dix, P., Misaghi, F.K. and Lambert, M.E. 1994. Solids Accumulation in Recirculating Sand Filters. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems*, ASAE, 301-309.

Sievers, D.M. 1994 *Pressurized* Intermittent Sand Filter With Shallow Disposal Field For a single Residence In Boone County, Missouri. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems*, ASAE, 403-409.

Venhuizen, D. 1994 Sand filter/Drip Irrigation Systems Solve Water Resources Problems. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems*, ASAE 356-362.

Weaver, C.P., Gaddy, B.S. and Ball, H.L. 1994 Effects of Media Variations on Intermittent Sand Filter Performance. In *Proc. 7th Int'l Symposium on Individual and Small Community Sewage Systems*, ASAE, 363-370.

Whelan, B.R. and Titammis, Z.V. 1982. Daily chemical variability of domestic septic tank effluent. *Water, Air and Soil Pollution*, 17, 131-139.

Witt, M., Siegrist, R. and Boyle, W.C. 1974. Rural household wastewater characterisation in *Home Sewage Disposal – Proc. National Home Sewage Disposal Symposium*, ASAE, 79-88.