ON-SITE TREATMENT BY REED BED AND POND: A STUDY OF TWO SYSTEMS

Thomas Headley and Leigh Davison
School of Resource Science and Management, Southern Cross University, Lismore

Abstract

This paper describes a study which examined the effect of season, system maturity and peak loading on two septic tank / reed bed / pond systems, each treating effluent from a 250 student school. One system was eight years old, the other was newly commissioned. Both reed beds were found to be effective in treating biochemical oxygen demand, suspended solids and total nitrogen. The newer reed bed underwent an adaptation period of about six months before approaching the treatment levels of the mature one. There appeared to be no seasonal effect on the level of treatment. A one-day doubling of load on one of the systems produced minimal change in the quality of pond water, thus demonstrating its robustness under peak loadings. One of the ponds was found to achieve a substantial total nitrogen reduction while experiencing an increase in suspended solids through algae growth. A summertime water balance showed that 40% of the hydraulic loading was being evapotranspired. It was concluded that the inclusion of reed bed / pond elements in on-site systems has several beneficial effects, including smaller and more sustainable disposal areas. It is suggested that the use of ponds and other nitrogen reducing technologies becomes more feasible when treatment is provided on a cluster rather than an individual basis.

Keywords:

cluster scale systems, on-site wastewater management; peak loading; ponds; reed beds; seasonal variation; system maturity;

1 Introduction

In recent years there has been a growth of interest in so-called "natural" wastewater treatment systems. Constructed wetlands and ponds (or lagoons) are two examples of natural elements that may be included in a wastewater treatment train. Ponds are one of the oldest and most widely used wastewater treatment technologies. While they have mainly been used in large centralised situations to date, they are now finding a place in on-site systems for wet weather storage and polishing of secondary treated effluent prior to in-ground disposal or irrigation. Kadlec and Knight (1996) point out that the long detention times in ponds generally ensure that they are effective at reducing biochemical oxygen demand (BOD) and pathogens, with some potential for nutrient removal.

Constructed wetlands are wastewater treatment elements designed to enhance the pollutant removal and transformation processes that occur within natural wetlands, only under more controlled conditions (Bastian and Hammer, 1993). According to Juwarkar *et al.* (1995) constructed wetlands have been found to be effective in removing a wide range of pollutants, such as suspended solids, organic matter, metals and nutrients. They offer the following advantages for wastewater treatment:

- low-cost;
- low-maintenance;
- low-technology and simple operation;
- low energy input requirements; and
- desirable buffering capacity in treatment.

There are two types of constructed wetland that utilise rooted macrophytes. These are surface flow, and subsurface flow wetlands. In surface flow wetlands, the water surface is above the soil and is directly exposed to the atmosphere. In subsurface flow wetlands (often referred to as "reed beds"), the water flows through a porous media (usually gravel but sometimes soil or sand), into which the macrophytes have been planted. Reed *et al.* (1995) report that, while some large reed beds have been built (up to 13 ML/d), they are usually not an economical proposition above design flows of 0.25 ML/d. These authors estimate that over 500 on-site units have been built for single dwelling and cluster applications where they are generally placed after a septic tank prior to disposal or irrigation. Because the water surface is covered, reed beds tend to produce little or no odour, suppress mosquitoes and minimise risk of public exposure. Reed beds can be regarded as attached growth reactors, with the submerged media and macrophyte roots providing abundant treatment surfaces, and therefore affording a high level of treatment per square metre of wetland area. Figure 1 shows a cross-section through a typical reed bed. The principal pollutant removal and transformation mechanisms in reed beds are summarised in Table 1.

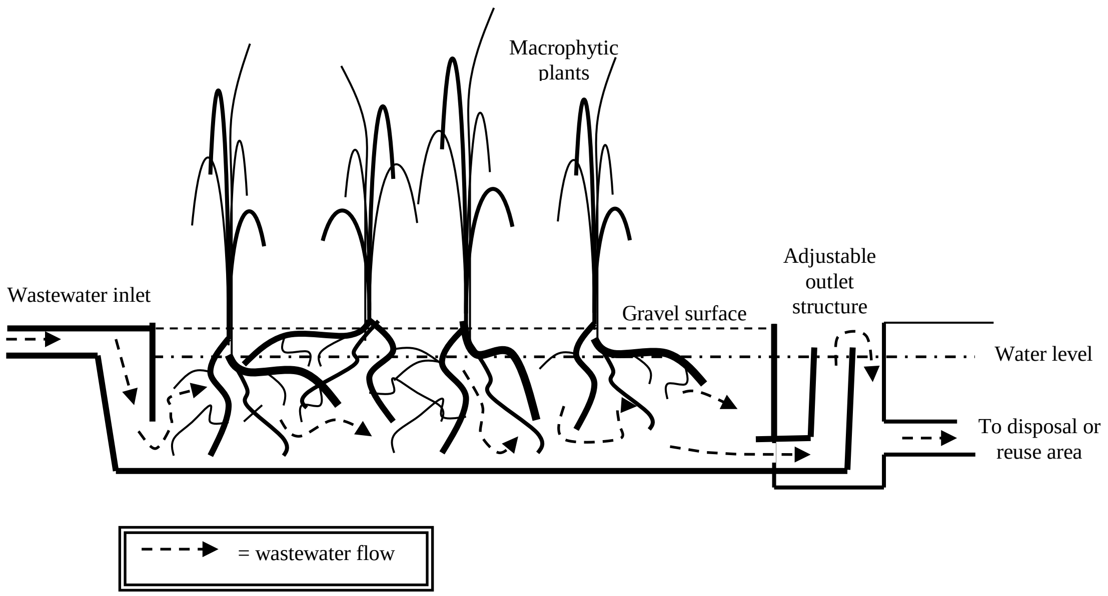

Figure 1. Cross-section through a typical subsurface flow reed bed, showing flow of wastewater from left to right through root zone.

Table 1. The principal pollutant removal and transformation mechanisms in reed beds (Adapted from Crites and Tchobanoglous, 1998).

Pollutant	Removal mechanisms
Biodegradable organics (BOD)	Bioconversion by facultative and anaerobic bacteria on plant and substrate surfaces
Suspended solids	Filtration and sedimentation
Nitrogen	Nitrification/denitrification, plant uptake, volatilisation
Phosphorus	Filtration, sedimentation, adsorption/precipitation, plant uptake
Heavy metals	Adsorption of plant roots and substrate surfaces, sedimentation
Trace organics	Adsorption, biodegradation
Pathogens	Natural decay, predation, sedimentation, excretion of antibiotics from roots of some plants.

Despite the abovementioned advantages, several uncertainties exist in relation to the use of reed beds. Questions have arisen regarding:

- seasonal variation in treatment, particularly efficiency reduction in winter;
- adaptation period for new systems to reach optimum treatment;

- finite life-span for phosphorus removal; and
- uncertainty of the capacity to cope with peak loads.

In addition there appears to have been little work done on the treatment capacity of ponds in on-site situations.

This paper:

- examines the effect of season, system maturity and peak loading on the performance of two reed bed / pond treatment systems, each serving a school of approximately 250 students, located on the NSW north coast; and
- discusses the issue of scale (single dwelling or cluster) in relation to the management and economics of these and similar systems.

2 System and Study Description

As depicted in Figure 2 each of the systems consists of a septic tank followed by reed bed planted with *Phragmites australis* (common reed) and a pond. Disposal is by subsurface irrigation or absorption trench. Dimensions and capacities are shown in Table 2. A more detailed description of the two systems can be found in Headley (1997).

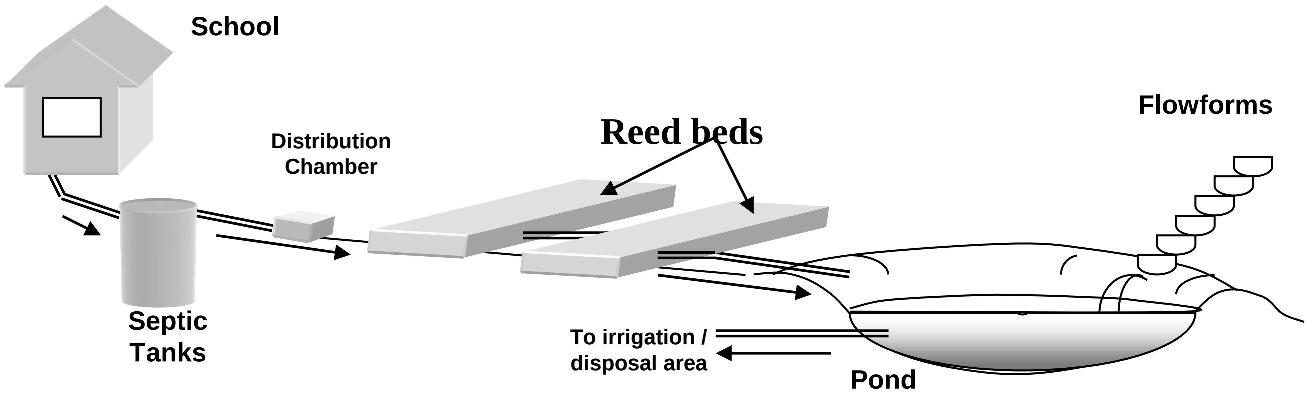

Figure 2. Stylised cross-sectional view of reed bed / pond treatment system.

Table 2. Summary of the main features of the Young and Mature Systems

System Features	Young System	Mature System
Date of commission	April, 1997	Feb, 1989
Students serviced	250	250
Reed bed surface area	80 m^2	80 m^2
Reed bed length : Width ratio	2:1	1:2
Reed bed depth	0.5 m	0.5 m
Reed bed theoretical water volume	16 m^3	16 m^3
Gravel size (diameter)	20 mm	20 mm
Theoretical detention time of reed beds	4.3 days	4.3 days
Pond surface area (approx.)	180 m^2	270 m^2

At the time of the study, both systems were loaded with approximately 2 500L / day at the reed bed inlet. While both systems are similar in design, one of the systems (the Young System) was only three months old at the commencement of study, whereas the Mature System had been in use for eight years.

Samples were taken from the reed bed inlets and outlets, and from the ponds themselves during three seasonal periods between July and December 1997. During each seasonal period, five lots of samples were collected over a two week interval. Samples were analysed for suspended solids (TSS), 5-day biochemical oxygen demand (BOD), faecal coliforms, total nitrogen (TN), total phosphorus (TP), pH and conductivity. Pollutant removal efficiencies were then determined based on average concentrations for these seasonal periods. Additional sampling was conducted during an open day held at the Young System school on 29 November 1997 to determine the effect of peak loading on level of treatment.

A water budget was also compiled for the Young System reed beds during December, 1997. From this, evapotranspiration losses were calculated for this period. Evapotranspiration was also measured more directly through piezometers.

3 Results

Evapotranspiration loss from the Young System reed bed was determined for the period 1-9 December when average daily maximum air temperature was 29.5^{o} C. The average evapotranspiration loss was found to be 10 mm/day, equivalent to about 40% of the reed bed's hydraulic loading. The crop factor (ratio of evapotranspiration to Class A Pan evaporation) for the most densely vegetated reed bed module during this period was found to be 1.6.

A summary of the results from the seasonal water quality sampling can be found in Table 3. Average concentration of pollutants and standard deviations for the five samples per season are given. Pollutant concentration removal efficiencies for the reed beds were determined for each season, and are shown in Table 4. In general the reed beds achieved high removal efficiencies for faecal coliforms (67% - 99.9%), TSS (56% - 95%) and BOD (35% - 85%). An adaptation trend is apparent in the Young System data for these three parameters, with performance improving rapidly during the six month study period to equal or better that of the Mature System.

A feature of the septic tank effluent in both systems is the relatively high TN concentrations. The overall average reed bed influent TN concentration of 163 mg/L compares with 50 - 60 mg/L for normal domestic septic tank effluent (NSW DLG *et al.*, 1998). Some individual readings exceeded 300 mg/L. This is probably a reflection of the fact that school systems carry a proportionately higher urine load than is normally found in domestic wastewater due to the lack of laundry and shower/bath components. On a removal efficiency basis, TN removal appears to decline from winter to summer in both systems. However, if the seasonal difference in evapotranspiration is taken into account it is found that approximately 50% of the TN mass loading was removed throughout the year. The Mature System reed bed TP removal efficiency was virtually zero for the summer sampling period, with outlet TP concentrations exceeding inlet TP concentrations on some occasions.

Table 3 shows that there was a considerable reduction in concentration of TN (74% - 81%) and TP (58% - 76%) in the Young System pond. On the other hand, BOD and particularly TSS often increased in this pond, particularly in summer.

The open day at the Young System school on 29 November 1997 generated a hydraulic load of 5090 L, over twice the average daily loading. Concentrations of TSS, BOD, faecal coliforms, TN and TP in the reed bed influent all increased during the day. All of these parameters, except TSS, were subsequently observed to increase in the reed bed effluent following the open day, but returned to normal levels within 11 days. In the pond, the only perturbation was a three day increase in faecal coliform concentration which commenced three days after the open day.

Table 3. Mean concentrations and standard deviations of the various pollutants in the reed bed inlet, outlet and pond water during the three seasons. Note: Mature System pond data incomplete due to mid-study pond modifications.

	WINTER						SPRING						SUMMER					
	Inlet		Outlet		Pond		Inlet		Outlet		Pond		Inlet		Outlet		Pond	
Young System	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*	mean	*s.d.*
TSS (mg/L)	**59**	38	**26**	18	**42**	21	**52**	18	**7.8**	4.3	**27**	19	**39**	7.3	**5.6**	2.9	**70**	25
BOD (mg/L)	**100**	57	**66**	37	**20**	8.2	**140**	53	**22**	15	**24**	16	**91**	27	**14**	5.1	**31**	8.6
Faecal coliforms (cfu/100mL)	**1.6 x10^5**	4.6 x10^4	**4.8 x10^4**	6.0 x10^4	**680**	590	**1.5 x10^5**	2.8 x10^5	**150**	210	**240**	350	**4.8 x10^5**	4.2 x10^5	**1.5 x10^3**	2.6 x10^3	**880**	580
TN (mg/L)	**130**	32	**70**	23	**19**	9.8	**190**	53	**110**	8.3	**24**	6.0	**94**	7.7	**61**	7.7	**12**	3.7
TP (mg/L)	**16**	2.2	**8.8**	4.2	**2.1**	1.0	**19**	3.9	**12**	2.3	**4.2**	0.2	**11**	0.2	**6.9**	0.8	**2.9**	0.5
PH	**7.1**	0.1	**7.8**	0.5	**7.4**	0.4	**7.3**	0.1	**7.9**	0.1	**8.5**	0.5	**7.1**	0.2	**7.2**	0.3	**9.0**	0.6
Conductivity (µS)	**1590**	345	**1290**	311	**582**	21.1	**1800**	498	**1390**	60.8	**626**	57.1	**1220**	108	**946**	85.4	**505**	32.2
Mature System																		
TSS (mg/L)	**240**	300	**18**	8.5			**69**	15	**3.3**	32			**65**	12	**25**	15	**35**	14
BOD (mg/L)	**120**	62	**22**	22			**110**	49	**42**	43			**120**	32	**18**	7.0	**10**	2.3
Faecal coliform	**1.39 x10^5**	8.64 x10^4	**2.94 x10^3**	2.3x 10^4			**1.98 x10^5**	1.88 x10^5	**6.52 x10^4**	6.30 x10^4			**1.46 x10^5**	6.16 x10^4	**9.11 x10^3**	9.30 x10^3	**605**	537.2

ms (cfu /100 mL)																			
TN (mg/L)	**140**	60	**73**	45			**250**	42	**150**	13			**170**	14	**120**	13	**4.8**	1.4
TP (mg/L)	**22**	4.6	**12**	4.6			**25**	1.3	**16**	1.7			**19**	0.9	**19**	3.4	**0.6**	0.03
PH	**7.7**	0.7	**7.1**	0.2			**8.0**	0.2	**7.4**	0.2			**7.3**	0.2	**7.3**	0.4	**9.0**	1.3
Conductivity (μS/cm)	**2240**	379	**1260**	426			**2470**	42.2	**1980**	117			**1860**	75.0	**1630**	96.3	**282**	13.9

NOTE: *s.d.* = standard deviation

Table 4. Pollutant removal efficiencies for the reed beds at the Young and Mature Systems.

Pollutant	System	Winter	Spring	Summer
Total suspended solids	*Young*	56.5%	85%	85.6%
	Mature	92.5%	95.2%	61.9%
BOD	*Young*	34.6%	84.1%	84.9%
	Mature	81.5%	61.3%	84.8%
Faecal coliforms	*Young*	69.9%	99.9%	99.7%
	Mature	97.9%	67.1%	93.8%
Total nitrogen	*Young*	46.1%	40.0%	34.8%
	Mature	49.6%	39.4%	29.8%
Total phosphorus	*Young*	46.0%	36.1%	36.1%
	Mature	42.8%	36.4%	0.32%

4 Discussion

The reed bed pollutant removal efficiencies determined in this study are generally in line with the findings of other researchers, for example Kadlec and Knight (1996). Table 4 shows that there was no consistent trend between seasons in treatment efficiency across all of the water quality parameters. This is despite the fact that the first order plug flow models normally used by wetland designers (e.g. Reed *et al.* 1995) predict improving performance as temperatures increase from winter to summer. The results certainly indicate that treatment occurs all year round in the sub-tropical climate of the NSW north coast. The Young System results for TSS, BOD and faecal coliforms indicate that this reed bed underwent a period of adaptation while macrophytes and attached growth micro-organisms established. The fact that a doubling of load on the system caused only a three day perturbation in one water quality indicator (faecal coliforms) demonstrates the robustness of the combined reed bed and pond under peak loadings.

TN concentrations in the Young System pond were consistently below 25 mg/L despite some readings above 300 mg/L in the reed bed influent. The TN removal rates of around 80% in the Young System pond accord with figures reported by Reed *et al.* (1995) who claimed that under ideal conditions, up to 95% nitrogen removal can be achieved in wastewater stabilisation ponds. These authors suggested "algal uptake, sludge deposition, adsorption by bottom soils, nitrification/denitrification and loss of ammonia" are the major removal mechanisms with losses to the atmosphere being dominant. If disposal is by irrigation, as recommended by NSW DLG *et al.* (1998), then the irrigation area is likely to be determined by the nitrogen loading. Therefore, a halving of the required irrigation area should be justified for reed bed residence times of over five days. Gains from additional nitrogen removal occurring in a pond, if used, are at least partly offset by BOD and TSS resurgence due to algal growth, particularly in summer. Among natural algal control strategies that could be investigated are the use of floating macrophytes such as duckweed. Poole (1996) reported that the floating macrophyte duckweed (*Lemna minor*) forms a mat which excludes 90% of incident light from the water column below thus suppressing algal growth, as well as removing nitrogen by plant uptake and nitrification/denitrification processes.

The TP removal rates in the Young System pond of 58%-76% may be largely due to adsorption and precipitation. Therefore, it is uncertain if this high removal rate will be sustained in the long term.

The high rates of BOD and TSS removal achieved by reed beds will reduce biomat buildup at the soil - water interface of absorption trenches. Unfortunately, the current Australian Standard 1547 (Standards Australia, 1994) bases absorption trench size purely on hydraulic loading rate and therefore provides no incentive to remove these pollutants. The reduction in turbidity occurring as a result of TSS removal in reed beds will also improve the performance of any disinfection device located downstream.

The high crop factor (1.6) and evapotranspiration rate (40% of flow) measured in the Young System reed bed in the first week of December indicate that significant effluent volume reduction can occur in summer via evapotranspiration. Ponds would contribute additional losses, further reducing irrigation area requirement in that season. This fact can be used to advantage by segmenting the disposal area (calculated on winter loadings) and resting independent segments during periods of high evapotranspiration (as recommended by NSW DLG *et al*., 1998) to facilitate biomat breakdown. It is suggested that, in relation to domestic on-site management, such disposal area segmentation would be less likely to occur in single dwelling systems than in clustered configurations.

In determining the relevance of this study of two school systems to the more familiar domestic situation it can be noted that, at 2 500L/d, the systems studied could serve the needs of more than 25 people, or between 5 and 10 households on non-reticulated water and composting toilets (based on NSW DLG *et al.* (1998) figure of <100 L/p/d). UWRAA (1998) notes the potential economies of scale that can be obtained by clustering of single dwelling on-site systems in relation to upgrading wastewater management in existing small settlements with unacceptably high densities of traditional septic systems. In addition, McComb (1996) and Gunn (1998) describe the environmental and lifestyle benefits that may be obtained by clustering in the rural residential context. Rather than spreading dwellings evenly over a development site the approach is to cluster them into an "eco-village", preferably on land unsuited to wastewater disposal or horticulture. Wastewater is irrigated or disposed of in the most favourable location and a large contiguous area is available for grazing, horticulture or reforestation. Thus, rather than creating a form of stretched-out suburbia, a pleasant rural ambience can be maintained and even enhanced.

One advantage of clustering is the fact that the cost of system refinements can be spread over several households. For example, Reed *et al.* (1995) described a nitrogen removal enhancement modification in which effluent from the reed bed is passed through a small trickling filter before being recirculated back into the reed bed inlet. Typically one third of the reed bed effluent is recirculated through the nitrifying environment of the trickling filter, then back into the reed bed where it combines with the carbon rich, relatively anaerobic reed bed influent to be denitrified. Another example of refinements made affordable by clustering is provided by Urbanc-Beric and Bulc (1995) who describe how the augmentation of an eight household system reed bed by two intermittently dosed vertical flow reed beds (for nitrification) at the front end improved the nitrogen removal efficiency from 29% to 52% (for secondary treated effluent - influent TN = 15 mg/L). They also report that on a stronger effluent (TN=360 mg/L) nitrogen removal efficiency was a sizeable 97%. While the first system requires a recirculation pump, this latter system operates under gravity.

As well as economies of scale, it is apparent that the clustering of on-site systems will lead to more labour efficient maintenance. In NSW the Multiple Occupancy and Community Title structures offer a framework which would support clustering. In these cases the body corporate would be responsible for system construction and maintenance. Reed (*pers. comm*) reported that the preference in the US has been for municipal management of cluster systems. Indeed, Otis (1998) has suggested that public health and environmental outcomes can be optimised when decentralised systems are centrally managed.

In Australia, recent problems with the level of maintenance of both septic tank and aerated wastewater treatment systems have highlighted the issue of on-site system management generally. A difference in the structure of the two reed bed systems described in the present study may offer a useful insight into the structuring of a management routine. The Mature System reed bed consists of five modules and the effluent flow needs to be redirected on a daily basis. The Young System consists of two large modules and loading is alternated on a weekly basis. It was observed that the daily operation in the Mature System was more than occasionally overlooked with detrimental consequences to the level of treatment. Perhaps the lesson is that weekly tasks are more likely to be performed regularly than daily ones.

5 Conclusions and Recommendations

- The treatment performance of the two reed beds was in line with the findings of previous researchers for the pollutants studied.
- The effective reduction in TSS, BOD and nitrogen loadings achieved by reed beds can lead to smaller more sustainable disposal / irrigation areas. More work needs to be done to fully identify and quantify these gains.
- Nitrogen removal in the Young System was considerably enhanced by the presence of the pond (80% removal) following the reed bed (40-50% removal). This reduction in TN has considerable implications for the sizing of irrigation disposal areas. More work needs to be done on the issue of TSS resurgence in ponds caused by algal blooms.
- The Young System was found to be operating efficiently within six months of commissioning.
- There was no evidence of significant seasonal variation in treatment by the reed beds.
- The reed bed / pond system appears to offer excellent buffering against peak loadings.
- The *Phragmites australis* reeds were found to have a summer crop factor of 1.6, and 40% of the reed bed hydraulic load was removed by evapotranspiration. This fact provides opportunities for resting parts of a segmented disposal area in summer.
- Cluster systems may offer several economic, operational, environmental and lifestyle advantages, over individual systems, in certain situations. By spreading the cost of TN reducing refinements such as ponds, trickling filters and vertical flow reed beds, considerable reductions in disposal area can be achieved. Further work needs to be done to identify obstacles (*e.g.* cultural, economic, regulatory) to the more widespread adoption of the clustering approach.

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