TREATMENT BY REED BED AND SAND FILTER: RESULTS FROM A TEST FACILITY

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Abstract

Three reed beds and one intermittently dosed single-pass sand filter were subjected to loadings of primary settled sewage at a specially constructed test facility at the South Lismore Sewage Treatment Plant in Northern NSW. Two of the reed beds are identical, being 5.5 m long by 1.6 m wide and 0.6 m deep with a substrate of 10 mm gravel (porosity approximately 40%). The third reed bed is 4.4 m long by 1.1m wide with a depth of 0.5 m and a substrate of Bioblock®, a plastic media with porosity of 90%. All three reed beds are planted with *Phragmites australis*. The sand filter has a plan area of 5 m by 1.6 m and contains a depth of 0.6 m of local river sand.

All four treatment devices easily achieved secondary treatment levels. All devices achieved TSS removal rates of 95% or better. The sand filter provided the best removal for BOD (95%), FC (3.4 logs) and TP (77%) at a hydraulic loading rate of 74 L/m^2/d. The two gravel media reed beds achieved extremely high TN removal rates of 84% (5.7 days HRTn) and 87% (9.1days HRTn) as well as producing 95% reductions in BOD loading. With a nominal hydraulic residence time of 10.9 days the plastic media reed bed removed only 22% of its TN load, probably because of the low specific surface area of this media compared to that of gravel. Crop factor with respect to ET_o appeared to vary in proportion to the amount of above-surface biomass with one reed bed consistently producing a crop factor of 2.5

Keywords

Constructed wetland, reed bed, sand filter, evaporative performance, treatment performance, total nitrogen

1 Introduction

In the immediate post World War II years on-site wastewater management systems in Australia consisted simply of a collection device such as a small septic tank and a disposal field, typically an absorption trench. Until the late 70's in many parts of the country it was often common practice to collect only the blackwater in the septic tank. Greywater tended to be released untreated either into the absorption trench or even above ground. Under ideal conditions the treatment afforded by this approach was considered to be sufficient to avoid major public health and environmental problems.

However with the expansion of peri-urban populations and rural villages in the last two decades it became apparent that additional treatment of domestic effluents was necessary. The early 80's saw the advent of the Aerated Wastewater Treatment System (AWTS) a generic technology which replicates large scale sewage treatment approaches such as activated sludge or biological filtration to produce a nitrified effluent low in BOD and SS with pathogen indicators reduced by chlorine disinfection. While the AWTS approach has proven quite popular in Australia, a number of studies (eg Khalife and Dharmappa, 1996) have indicated that there are problems. The relatively high-tech mechanical nature of AWTS technology often puts do-it-yourself maintenance beyond the reach of the average householder.

Most states in Australia now require AWTS owners to commit to a maintenance contract that involves a recurrent expense of up to five hundred dollars per year. In Europe and North America other approaches to on-site wastewater treatment have been more popular. In the US sand filtration has been a rapidly developing technology. In Europe constructed wetlands (reed beds) are increasingly being adopted. Advocates of these two approaches claim that they offer the combination of acceptable treatment and a level of technology that falls within the maintenance capability of the average householder. A number of reed beds have been incorporated into on-site systems on the NSW Far North Coast in recent years and studies have indicated performance comparable to that reported elsewhere (Davison *et al.*, 2000).

In response to a perceived need for more intensive, research-oriented monitoring of small reed beds loaded with domestic wastewater a test facility, funded under the NSW Department of Local Government's Septic Safe Program, has been constructed at the South Lismore Sewage Treatment Plant (STP). The broad aim of the test facility is to observe the performance of natural treatment devices such as wetlands and sand filters, under more controlled conditions than can be achieved in a normal domestic situation, with a view to making design recommendations to regulators and system designers. The test facility currently contains three reed beds (horizontal subsurface flow wetlands) and a single pass sand filter, which are dosed with primary settled municipal sewage. This paper describes the treatment performance of all four devices obtained in an initial five-week monitoring period. It also presents the results of eleven weeks of analysis of the evaporative performance of the three wetlands.

2 Site Description and Methods

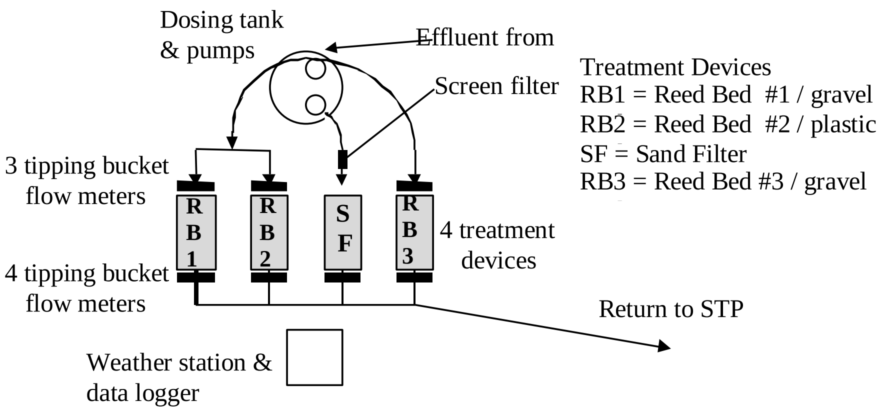


Figure 1:Test Facility Site Layout

Figure 1 depicts the layout of the test facility. Primary settled municipal sewage is siphoned from the STP's sedimentation tank outlet and gravity fed to a 2,300 L polyethylene dosing tank. A float valve controls the level in the tank is controlled by. Devices RB1 and RB3 are identical reed beds (horizontal sub-surface flow wetlands) 1.6 m wide x 5.5 m long containing 10 mm gravel (porosity 40%) to a depth of 0.6 m (Figure 2). Device RB2 is a reed bed 1.2 m wide x 4.4 m long containing Bioblock®, an artificial plastic media with a porosity of 90%, as the substrate. All three reed beds are contained in a 0.75 mm polypropylene liner. *Phragmites australis* seedlings were planted into the three reed beds in mid September 2000. Wetted depth is set at 55cm in the gravel reed beds and 50cm in the plastic media bed.

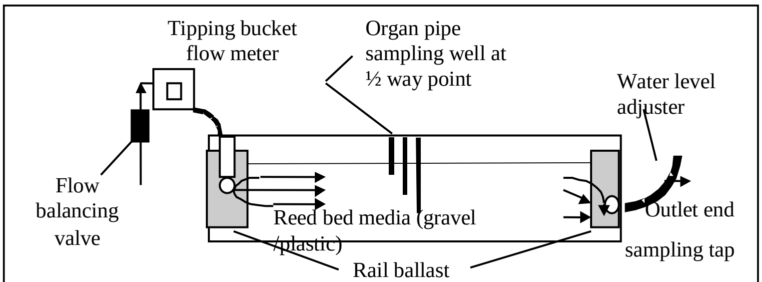


Figure 2: Longitudinal Section of Reed Bed

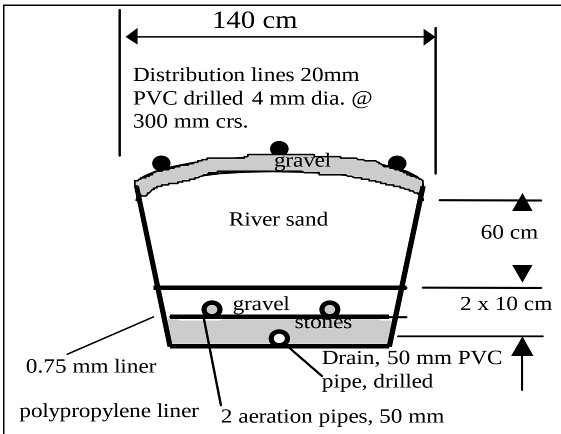
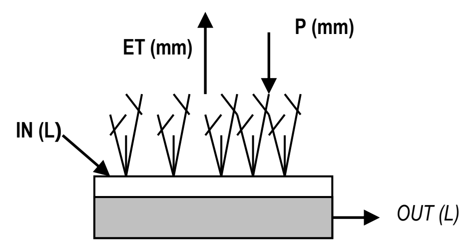


Figure 3: Cross-section of Sand Filter (Element SF)

Device SF is a sand filter, shown in cross-section in Figure 3. It consists of a 60 cm deep layer of river sand (Effective Size = 0.16 mm, Uniformity Coefficient = 1.5) overlain by 10 cm of 10mm gravel. The filter is 5 m long and 1.4 m wide at the top tapering to 1.1 m at the bottom of the sand column. It is dosed through three parallel distribution pipes with 4mm holes drilled at 30 cm centres in the top of the pipe. Below the sand is a layer of 10 mm gravel containing two slotted aeration pipes (50 mm PVC) above a bottom layer of 100 mm stones. A tipping bucket flow meter measures volume of flow from the sand filter.

Influent is pumped to the inlet end of the three reed beds by a submersible pump, located in the dosing tank. Flow balancing valves on each inlet line allow for the individual fine-tuning of influent flow rate to each device. As indicated in Figure 2, after passing through the inlet tipping bucket, the influent drops into the inlet device consisting of a horizontal 100 mm diameter slotted PVC pipe placed 200 mm below the surface of the media extending the width of the reed bed. The inlet device is surrounded by rail ballast (basalt stones between 40mm - 100mm). The outlet device is similar with the exception that the horizontal pipe is placed just above the reed bed floor to enable water level lowering. Each reed bed contains three "organ pipe" sampling wells located ¼, ½ and ¾ of the way between inlet and outlet devices. Each organ pipe consists of three 20 mm diameter PVC tubes constructed so that samples can be taken from the top, middle or lower third of the water column.

An automatic weather station and data logger records meteorological data, calculates a reference evapotranspiration rate, ET_o, based on measured parameters such as relative humidity, wind speed, solar intensity and temperature using the Modified Penman Monteith Equation. The data logger also records the number of tips made by the seven calibrated tipping bucket flow meters located at the inlet and outlet ends of the test devices. Thus accurate water balances can be performed on each test device.



ET = P + (IN – OUT)/A

where A = reed bed surface area (m^2)

Figure 4: Water Balance to Determine Reed Bed ET

Weekly monitoring of the performance of the four treatment devices was conducted over a five-week period starting on 7th March 2001. The inlet flow rates to all four treatment devices had been set 10 days earlier and were held constant for the duration of the five week trial. Table 1 summarises the design parameters of each device as well as the hydraulic loading rate (HLR) and nominal hydraulic residence time (HRTn) imposed on each during the trial. A composite sample representative of influent to all devices was taken from the dosing tank. Effluent samples were taken from a sampling tap at the outlet end of each device. Halfway samples were also taken from the mid-section of the water column in each of the three reed beds. Flow data and meteorological data were downloaded from the data logger weekly. Samples were analysed for total suspended solids (TSS), five-day biochemical oxygen demand (BOD), total phosphorus (TP), total nitrogen (TN) and Faecal Coliforms (FC). Sand filter samples were also tested for NH4-N, NOx-N and ortho-phosphate.

Analytical methods in accordance with APHA (1992) were used. The mean concentration for each parameter at each sampling point for each of the five one-week sampling periods was taken as the average concentration at the beginning and end of that week. Halfway flows were evaluated by averaging influent and effluent flows. Treatment performance was estimated on the basis of percent load removal and areal removal rate. Daily and weekly evapotransporation (ET) rates from the reed beds were determined by performing the water balance illustrated in Figure 4. The evaporative performance of each reed bed was assessed by calculating its crop factor ($CF = ET/ET_o$) over the eleven weekly periods from 1^{st} January 2001 for which accurate data was obtained.

Table 1: Mean Values (n=5) of Key Parameters for Four Treatment Devices Studied

Treatment device	RB1	RB2	SF	RB3
media	10 mm gravel	plastic	Sand	10 mm gravel
properties	Porosity 40%	Porosity 90%	ES 0.16, UC 1.5	Porosity 40%
dimensions (m)	5.5 x 1.6 x 0.55	4.4 x 1.1 x 0.5	5 x 1.25 x 0.6	5.5 x 1.6 x 0.55
surface area (m^2)	8.8	4.8	6.2	8.8
Pore volume (m^3)	1.94	2.16	-	1.94
HLR (mm/d)	39	45	71	24
HRTn (days)	5.7	10.9	-	9.2

3 Results and Discussion

Table 2 is a summary of treatment device performance based on mean values for the five one-week sampling periods. All treatment devices performed well with respect to TSS, BOD and FC removal. The two gravel reed beds (RB1 and RB3) and sand filter achieved TSS load reduction rates of over 97% while the plastic media reed bed (RB2) achieved 95%.

The sand filter proved most effective at removing BOD loading with a removal rate of 98.5%, ahead of the three reed beds at approximately 94%. The sand filter was superior with respect to FC loading, achieving a reduction 3.35 logs (99.96%).

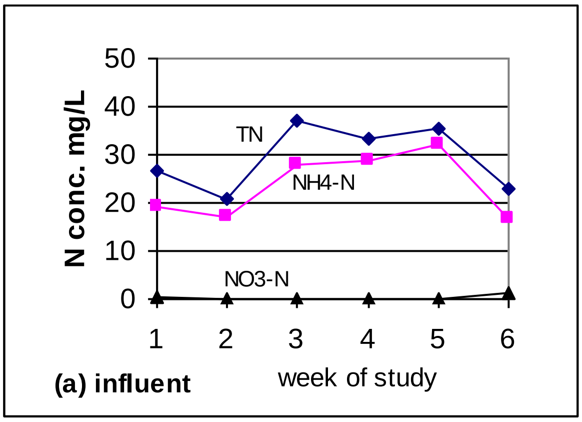
The reed beds achieved FC reduction rates of between 2.5 logs and 3 logs which is at the top end of the range commonly reported in studies on sub-surface flow wetlands. For example Reed *et al.* (1995) report FC removal rates of 1-2 logs with residence times of 3-7 days and 3-4 log removal at HRT's in excess of 14 days.

TN reduction in the two gravel reed beds was excellent, with effluent concentrations consistently around 5 mg/L. Load removals for TN of 84.5% (HRTn = 5.7 days) and 87.4% (HRTn = 9.1 days) were achieved for RB1 and RB3 respectively. Previous studies on the NSW North Coast have reported TN removal rates as high as 66% (Davison *et al.*, 2000) and 80% (Craven and Davison, 2001). Further monitoring will attempt to ascertain what combination of factors (eg effluent composition, reed bed structure etc.) leads to such high TN removal rates. By contrast, the plastic media reed bed, RB2 removed only 22% of the TN load with an HRTn of 10.9 days. This performance should improve with time as the reed roots develop to provide increased area for colonisation by nitrifying and denitrifying microbial communities.

The sand filter achieved no TN removal. However, Figures 5(a) and 5(b) show that it consistently oxidised most of the influent ammonium to produce a highly nitrified effluent. Future trials will determine the extent to which this effluent can be subsequently denitrified in one of the gravel based reed beds.

Table 2: Overall Mean Treatment Performance for the Four Devices (n=5)

	Variable	Reed Bed 1 HRTn=5.7d	Reed Bed 2 HRTn=10.9d	Reed Bed 3 HRTn=9.2d	Sand Filter 71 mm/d
TSS	Inf. Conc. mg/L	58	58	58	58.4
	Eff. Conc. mg/L	1.2	22	1.8	1.9
	removal rate (g/m²/d)	4.2	2.08	2.59	2.6
	% load removal	97.8	94.9	97.3	97.0
BOD	Inf. Conc. mg/L	107	107	107	89
	Eff. Conc. mg/L	5.9	12.6	5.8	1.4
	removal rate (g/m²/d)	7.61	3.89	4.76	4.43
	% load removal	93.8	93.9	94.7	98.5
TP	Inf. Conc. mg/L	5.6	5.6	5.6	6.3
	Eff. Conc. mg/L	4.9	6.2	2.7	1.59
	removal rate (mg/m²/d)	18.05	-8.8	114.2	235
	% load removal	3.8	-3.7	43.2	76.7
TN	Inf. Conc. mg/L	29.7	29.7	29.7	29.9
	Eff. Conc. mg/L	4.4	25	4.8	32.1
	removal rate (mg/m²/d)	942	251	331	-36.8
	% load removal	84.5	21.9	87.4	-2.4
FC	Inf. Conc. cfu/100ml	7780000	7780000	7780000	10280000
	Eff. Conc. cfu/100ml	22320	300000	14240	4600
	% load removal	99.71	99.89	99.64	99.96
	log reduction	2.54	2.96	2.44	3.35



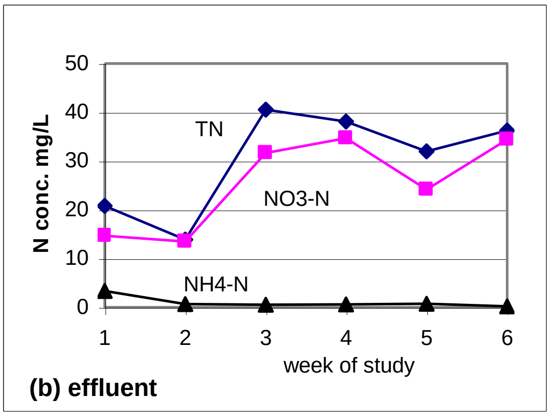


Figure 5: N Species Concentrations in Sand Filter Influent and Effluent

Samples taken from the halfway points of RB1 and RB3 gave an indication of the level of treatment achieved in the gravel media reed beds at HRTn's of 2.8 and 4.6 days respectively. This data is combined with the full treatment data in Figure 6 to give an indication of treatment response against HRTn for some key parameters. Figure 6(a) shows that TSS concentration declines very rapidly within the first two days. Physical processes such as filtration and settling are mainly responsible. Figure 6(b) shows that BOD concentrations decline almost as rapidly, with RB1 reaching a BOD of 15 mg/L in under three days. As much of the carbonaceous material contributing to BOD is associated with solids, this early removal can be attributed to physical processes prior to microbially mediated breakdown (Kadlec and Knight, 1996).

Figure 6(c) shows that TN concentration declines somewhat more slowly. Most researchers (eg Reed *et al.*, 1995) suggest that nitrification followed by denitrification is the primary removal pathway for nitrogen and that there is insufficient DO for complete nitrification at the front end of the wetland due to the oxygen demand posed by the carbon breakdown reactions.

Figure 6(d) indicates that TN load is still being removed after seven days. This finding is in line with those of other authors. For example Huang *et al.* (2000) report TN removal rates of 46%, 55% and 67% from septic tank effluent subjected to residence times of four, eight and twelve days respectively in pilot scale gravel-based reed beds.

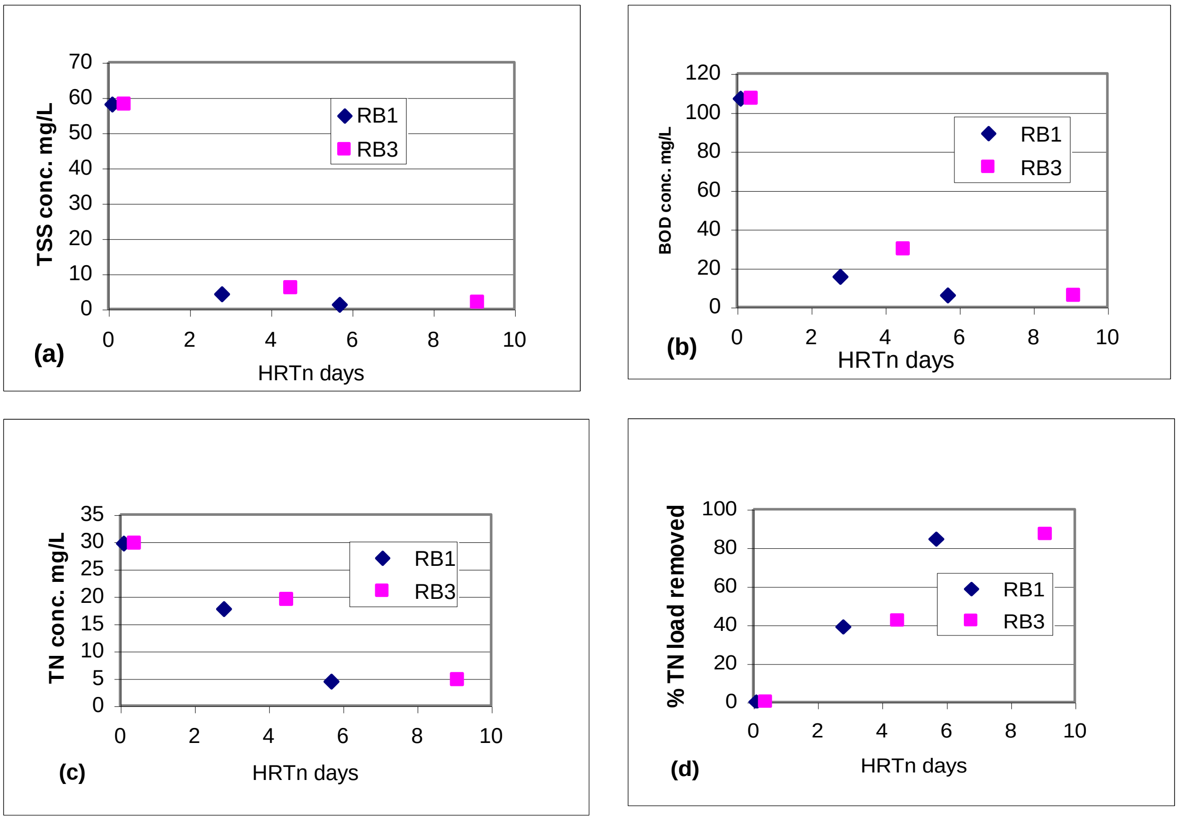


Figure 6: Variation in effluent quality vs residence time in RB1 and RB3

The sand filter removed 77% of TP load indicating that the local river sand used in this device was still effectively immobilising phosphate six months after dosing commenced, probably as a result of precipitation with calcium ions associated with the sand particles. This figure compares with a TP load removal of 51% reported by Craven and Davison (2001) in a sand filter of similar age and design. The plastic media reed bed RB2 produced no removal of TP load indicating that this media has no P-immobilising capacity. Of the two gravel reed beds, RB3 produced a TP load reduction of 43% which is in line with reductions of 49%-70% reported by Davison *et al.* (2000) for young gravel based reed beds. At the time of writing there was no explanation for the low TP removal of 3.8% in RB1.

The evaporative performance of constructed wetlands is of interest because, in dry (eg inland) areas, there may be a need to reuse treated water for irrigation or other non-potable purposes. In such situations there would be an interest in minimising evaporative losses. In wetter (eg coastal) areas where land tends to be more expensive and area of land available for disposal may be scarce, there could be a desire to minimise hydraulic loading on disposal area and hence to maximise evaporative losses from both disposal area and treatment devices. A common measure of evaporative performance is the crop factor (CF), defined (for a given crop) as the ratio of evaporative loss from that crop to a given reference evaporation rate. While Class A Pan evaporation has been used traditionally as the reference, Grayson *et al.* (1996) advocate the use of ET_o, an estimate of the evapotranspiration generated by a well watered crop of grass 0.12 m high calculated using the Modified Penman-Monteith Equation.

Of the three reed beds, the reeds in RB2 showed the best early growth from time of planting in September until early January when growth tapered off. Above–surface biomass in this reed bed did not appear to change significantly over the subsequent three months. Figure 7 is a plot of weekly ET for RB2 vs ET_o performed using water balances from the eleven weeks commencing 1st January 2001 for which reliable hydraulic data was available. The data points in Figure 7 are strongly correlated ($r=0.84$, $p<0.005$). The slope of the line of best fit gives the crop factor, CF which in this case is 1.8.

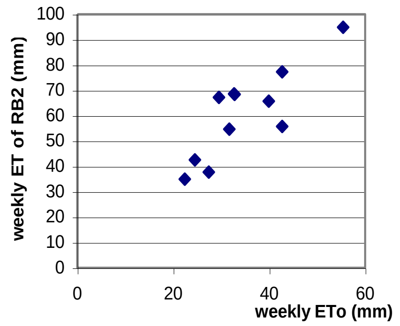


Figure 7: weekly ET for RB2 vs Eto

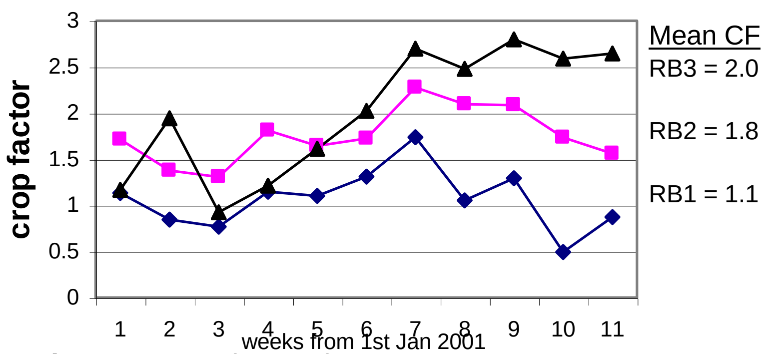


Figure 8: Crop factors for RB1, RB2 & RB3

Figure 8 is a plot of the crop factors for all three reed beds, calculated weekly over the 11-week hydraulic monitoring period. There is considerable variability in the value of crop factors both within and between reed beds with RB2 showing the least variability, probably because of lack of plant growth during the monitoring period. Overall mean CF values for RB1, RB2 and RB3 were found to be 1.1, 1.8 and 2.0 respectively with RB3's crop factor consistently exceeding 2.5 towards the end of the monitoring period. While RB1 and RB3 are structurally identical reed beds, RB3 has shown superior reed growth and, at the time of writing, appeared to have at least twice as much above-surface biomass as RB1. While this difference in leaf mass explains the difference in evaporative performance, the reason for the difference in growth rates is not clear.

4 Conclusions

All four treatment devices easily achieved concentrations lower than the 20mg/L and 30 mg/L for BOD and TSS respectively specified by AS/NZS 1547:2000 (Standards Australia, 2000) as the limit for secondary treatment. All devices achieved TSS removal rates of 95% or better. The sand filter provided the best removal for BOD (95%), FC (3.4 logs) and TP (77%) at a loading rate of 74 $L/m^2/d$. The two gravel media reed beds achieved extremely high TN removal rates of 84% (5.7 days HRTn) and 87% (9.1days HRTn) as well as producing 95% reductions in BOD loading. With a nominal hydraulic residence time of 10.9 days the plastic media reed bed removed only 22% of its TN load, probably because of the low specific surface area of this media compared to that of gravel.. Crop factors with respect to ET_o for the three reed beds, averaged over eleven weeks in late summer - early autumn, were 1.1, 1.8 and 2.0 for RB1, RB2 and RB3 respectively. RB3, with the greatest amount of above-surface biomass, consistently produced a crop factor of 2.5 during the final five weeks of monitoring. The results presented here are the first in a planned series of studies aimed at tracking long term hydraulic and treatment performance of the devices described in this paper.

Acknowledgments

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