PERFORMANCE EVALUATION OF A SMALL DOMESTIC SAND FILTER

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Abstract

As part of the NSW Department of Local Government *SepticSafe Program*, funding was obtained to construct a low cost sand filter to treat domestic effluent. The construction of the domestic facility, which incorporated a septic tank, dosing siphons, sand filter (with a layer of additional filter media of zeolite to remove ammonium), collection well and drip irrigation system, has previously been described by Geary *et al* (2001) at the On-site '01 Conference. Some of the preliminary monitoring results from the innovative sand filter design were also presented.

In this paper the first twelve months of monitoring undertaken between May 2001 and April 2002 are presented. The results indicate that the low cost alternative treatment system has performed exceptionally well and consistently produced an effluent of high quality with only minor system maintenance requirements. The results of chemical analysis suggest that intermittently dosed sand filters do have a significant capacity to consistently treat domestic effluent from a septic tank to a secondary standard. Significant levels of biochemical oxygen demand and total suspended solids removal were achieved and high rates of nitrification resulted in most of the organic nitrogen and ammonia being converted to nitrate. The full description of the project and the monitoring results are contained in the recently prepared project report for the *SepticSafe* program (Geary *et al*, 2003).

Keywords

Ammonia, effluent, nitrogen, phosphorus, sand filter, zeolite

1 Introduction

Sand filters can produce a high quality effluent for on-site disposal and recent innovations in sand filter design have resulted in renewed interest in their potential for wastewater treatment. They are however not a new technology and have been employed since the late 1800's. They have been used extensively in the USA and New Zealand and guidelines are available for both Victoria and South Australia which deal with their construction (including media size selection), and operation and maintenance (Victorian EPA, 1996; South Australian Health Commission, 1995). In NSW there are very few sand filters which have been constructed for domestic wastewater treatment and the reasons for this are unclear. Perhaps part of the reason for their lack of acceptance in NSW may stem from the fact that they were previously not an "approved" system and little effort was made to promote them, however, the revisions to the on-site wastewater guidelines (Department of Local Government, 1998) now mean that they can be approved for use where it is demonstrated that they will produce a final effluent of acceptable quality. As a result of the previous approvals system and lack of awareness within local government, the installation, use and monitoring of sand filters in on-site domestic wastewater treatment systems is very limited in NSW.

Under the *SepticSafe* Research Grant Program, funding was obtained to construct and monitor an intermittently dosed aerobic sand filter. The simple filter which contained a layer of zeolite (clinoptilolite) was constructed at a domestic residence at Martinsville, NSW and the performance of the filter in reducing the concentrations of a number pollutants in effluent monitored. Both prefilter and postfilter effluent samples were collected and analysed between May 2001 and April 2002.

2 Design and Technology

Lake Macquarie City Council approved the sand filter at a private household containing four residents in May, 1999. The system design included a septic tank to collect wastewater and perform primary treatment. Outgoing wastewater passed through a 1 mm effluent filter, and then flowed via a dosing siphon to the sand filter. The siphon triggered approximately four times per day, although this depended on the incoming hydraulic load. The effluent was collected from the sand filter and drained to a second dosing siphon, which charged a header tank and then gravity discharged via sub-surface emitters. The inclusion of the zeolite layer in the design of the sand filter was an attempt to remove ammonium nitrogen from the wastewater through ion exchange. A cross-section through the aerobic sand filter is shown in Figure 1. The effective size and uniformity coefficient of the sand media were 0.325 and 2 respectively.

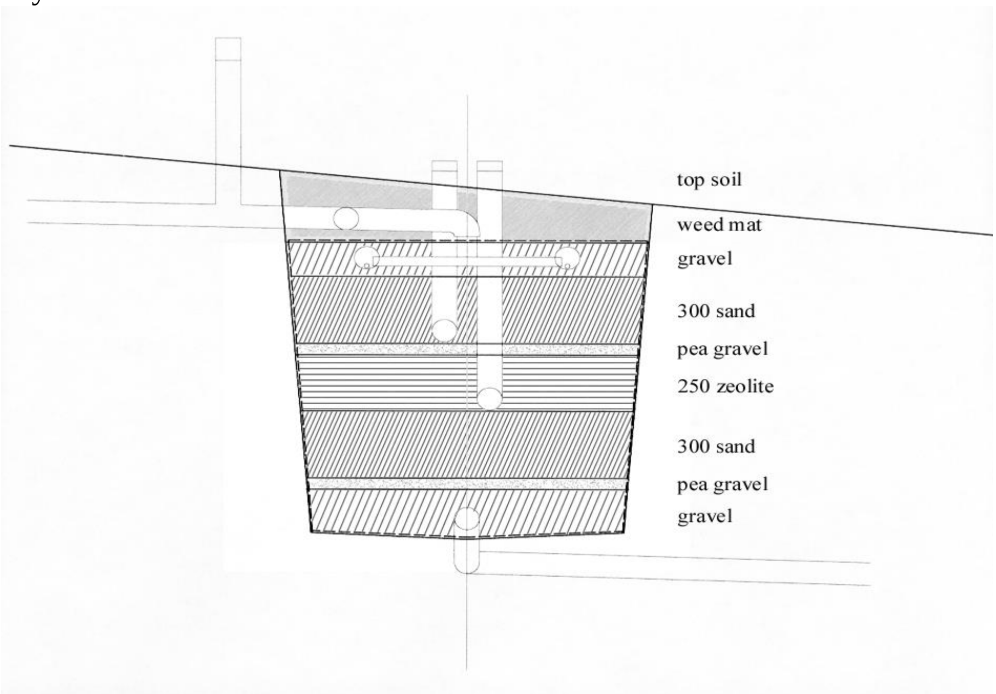

Figure 1: Section Through Aerobic Sand Filter

Sampling commenced on 22nd May, 2001, and after 12 months, concluded on 30th April 2002. Pre and postfilter samples (influent and effluent) were taken fortnightly during the first five months of monitoring (May – October 2001) and monthly thereafter (November 2001 – April 2002). Analyses of the pre and postfilter samples taken from the Martinsville sand filter were conducted at the University of Newcastle and at Hunter Water Laboratories, Warabrook. Analyses conducted at the University included the physico-chemical parameters and major cations and Hunter Water Laboratory conducted an analysis of selected wastewater chemical and microbiological parameters. Full details of test methods are provided in Geary *et al* (2003).

3 Results and Discussion

The results of pre and postfilter monitoring of the intermittently dosed filter for a number of water quality parameters (BOD_5, pH, electrical conductivity, suspended solids, dissolved oxygen, total Kjeldahl nitrogen, total oxides of nitrogen, total phosphorus, dissolved oxygen and major cations) are contained in Appendix 1 of Geary *et al* (2003). A summary providing mean concentrations and the recorded ranges for each parameter is shown in Table 1.

Table 1: Summary of Sand Filter Prefilter/Postfilter Concentrations

	N	Mean		Minimum		Maximum	
		Pre filter	**Post filter**	**Pre filter**	**Post filter**	**Pre filter**	**Post filter**
BOD_5 (mg/L)	18	194	4	104	< 2	271	13
TSS (mg/L)	18	77.1	6.5	15.7	0.5	156	14.5
TKN (mg/L) as N	18	67.7	2.9	46.9	< 0.5	81.8	8.2
TON (mg/L) as N	18	0.11	53.1	< 0.03	0.68	0.26	113.0
Total P (mg/L) as P	18	8.49	4.97	4.80	1.40	10.20	10.30
Ammonia (mg/L) as N	17	50.5	2.15	38.5	0.07	60.4	8.2
Dissolved Oxygen (mg/L)	17	1.27	7.42	0.23	5.82	2.40	10.00
pH	18	7.78	7.23	7.14	6.65	8.68	7.76
EC (uS/cm)	18	1226	1110	1006	756	1495	2600
Sodium (mg/L)	17	155	195	118	107	253	632
Calcium (mg/L)	17	15.2	32.1	8.6	17.8	28.5	92.0
Magnesium (mg/L)	17	4.7	12.7	2.6	8.1	7.6	35.7
Potassium (mg/L)	17	27.0	19.7	21.3	10.1	34.3	43.5

3.1 Hydraulic loading

Monitored household water consumption was between 13-15 kL per month (350-500 L/day), which is quite low for a family of four. With the inclusion of direct rainfall on the filter and the water usage data, the hydraulic loading rate to the sand filter varied between 19 and 27 $L/m^2/d$ during the monitoring period. Even during the wettest month (February 2002), the hydraulic loading was only approximately 34 $L/m^2/d$ which was significantly less than the design loading for the filter of 50 $L/m^2/d$.

3.2 Physico-chemical parameters

Sand filters typically provide substantial reductions in both BOD_5 and TSS, not only because of the physical effect of filtering, but also because the oxidising environment is suitable for breakdown of organic carbon by micro-organisms. The Martinsville sand filter showed significant reductions in the effluent concentrations for both parameters (Figures 2 and 3). The final effluent was consistently reduced to below common '20/30' standards (20 mg/L BOD, 30 mg/L TSS) recommended by the Department of Local Government (1998) and was close to always meeting 10/10 standards. The average BOD_5 concentration of the influent (approximately 190 mg/L) was consistently reduced to low levels between 4-5 mg/L (Table 1) as a result of treatment processes occurring in the sand filter. Initial concentrations of total suspended solids in the influent quickly increased as the household and wastewater system became fully operational. Influent suspended solids concentrations averaged around 70-80 mg/L lower than is typically expected (Figure 2). In this installation, an effluent filter was installed in the new plastic septic tank at the starat of the project and this appears to have had a marked impact in reducing TSS concentrations entering the sand filter. The post-filter effluent samples also exhibited significant reductions in the concentrations of TSS. The final effluent quality produced by the sand filter was clear of organic materials and solids.

Dissolved oxygen concentrations consistently increased from less than 2 mg/L to between 6–8 mg/L in the postfilter effluent which is typical of an intermittently dosed aerobic sand filter. The aerobic conditions in the sand filter result from the entrainment of oxygen as effluent passes through the filter. Electrical conductivity (EC) gradually increased over the sampling period to between 1000 - 1400 uS/cm, within the range expected for domestic septic effluent.

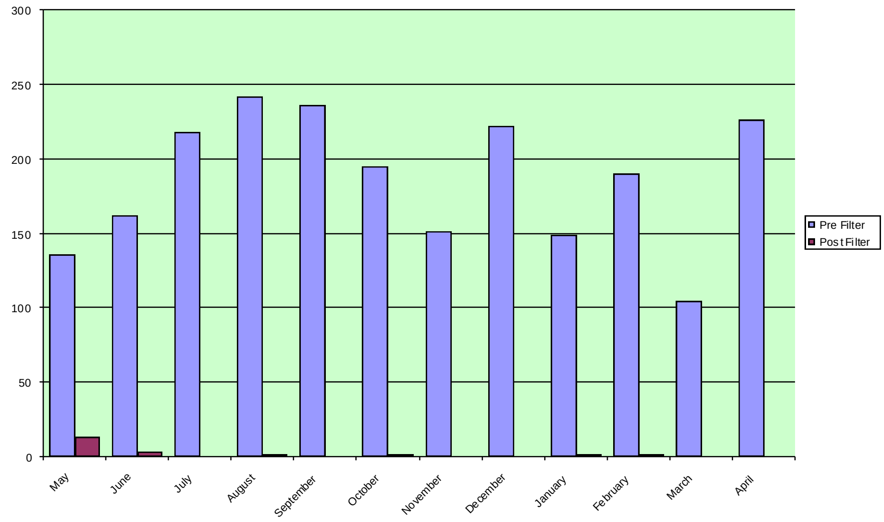

Figure 2: Biochemical Oxygen Demand (mg/L)

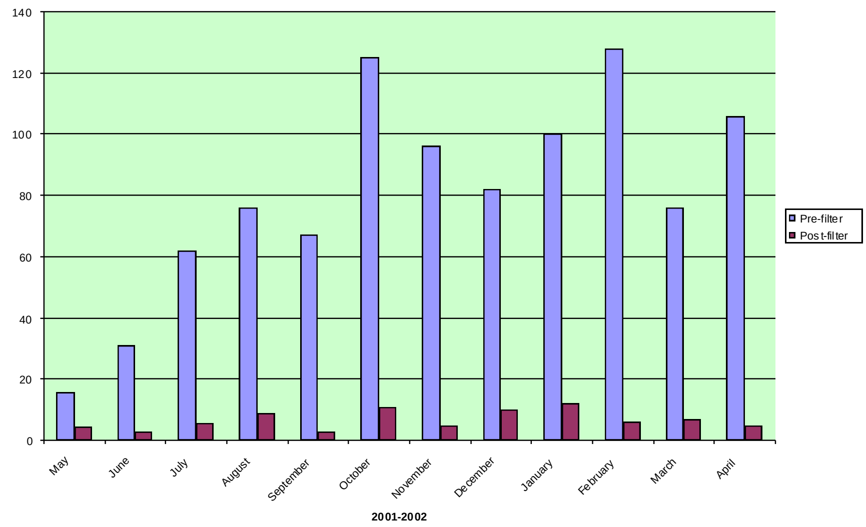

Figure 3: Total Suspended Solids (mg/L)

3.3 Nitrogen and phosphorus

The majority of the nitrogen in septic tanks is present as Total Kjeldahl Nitrogen (TKN) (organic nitrogen and ammonia) with the oxidized forms such as nitrate being negligible as there is little free oxygen available. The TKN results for septic tank effluent passing through the sand filter show a significant reduction of organic and ammonia nitrogen (Figures 4 and 5). Of the total nitrogen present in the Martinsville prefilter influent, ammonia typically makes up about 60 - 80% of the TKN, although on some occasions it is greater than 90%. The substantial reductions in TKN after passage through the filter are associated with nitrification and this is reflected in the typically high dissolved oxygen results in the postfilter effluent (mean 7.42 mg/L) and the minor reductions in pH (nitrification is an acid forming process). After an initial delay associated with the development of a biomat and population of micro-organisms in the sand filter, it appears as though the ammonium oxidizer bacteria began to work efficiently. In terms of the very low TKN concentrations in the postfilter effluent, most of the remaining nitrogen appeared as ammonia as the organic fraction has been mostly converted in the treatment process.

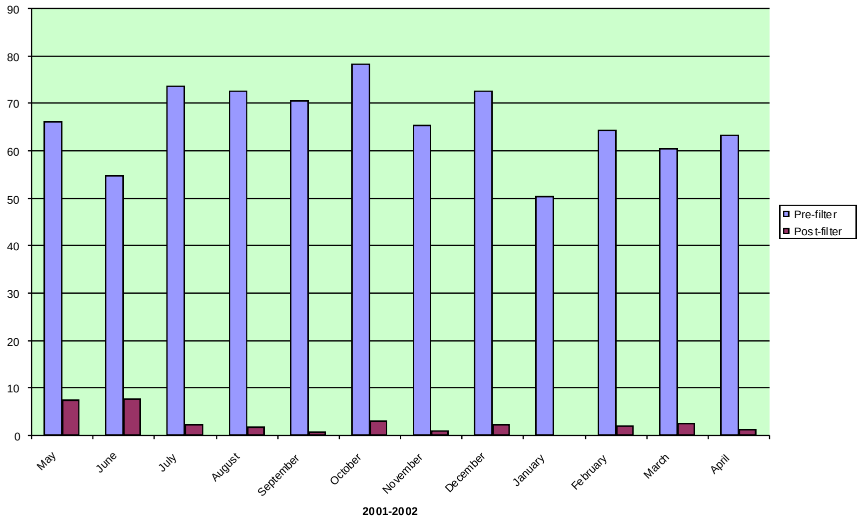

Figure 4: Total Kjeldahl Nitrogen (mg/L) as N

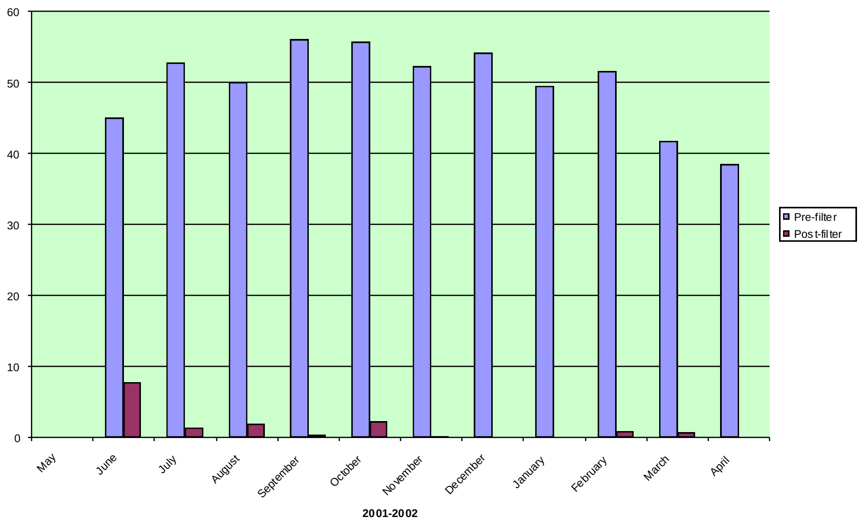

Figure 5: Ammonia (mg/L) as N

The results for the Total Oxides of Nitrogen (Nitrite and Nitrate) are shown in Figure 6. After an initial delay the intermittent sand filter produced highly nitrified postfilter effluent. Most of the nitrogen present in the final effluent is as TON with very small concentrations of organic nitrogen and ammonia. The organic nitrogen is typically removed in the treatment process and only very small concentrations of ammonia sometimes remain (mean ammonia concentration of 2.15 mg/L with the mean organic N concentration of 0.75 mg/L). The final

TON concentrations averaged approximately 53 mg/L, although concentrations were variable and on one occasion up to 113 mg/L was recorded. The lowest result for TON was recorded just after the sand filter commenced operation and prior to the establishment of a population of micro-organisms in the sand filter. Total Nitrogen is the sum of the TKN and TON. The changes in the nitrogen totals after passage through the sand filter are shown in Figure 7. It is clear that there are some reductions in total Nitrogen except in October 2001 and January 2002 when there was a net export from the system. The role of the zeolite in reducing ammonium and total nitrogen concentrations in the effluent is very difficult to ascertain as a result of the final design and the fact that samples could not be collected from within the sand filter. This is partly due to the placement of the zeolite layer below the surface of the filter as most ammonia oxidizes within the top few centimetres of the sand filter. The failure of sampling ports which were constructed above and below the zeolite layer also hampered the interpretation of the collected data. It does however appear that total nitrogen reductions as a result of passage through the sand filter are quite variable and during 2001/2002 were often not substantial.

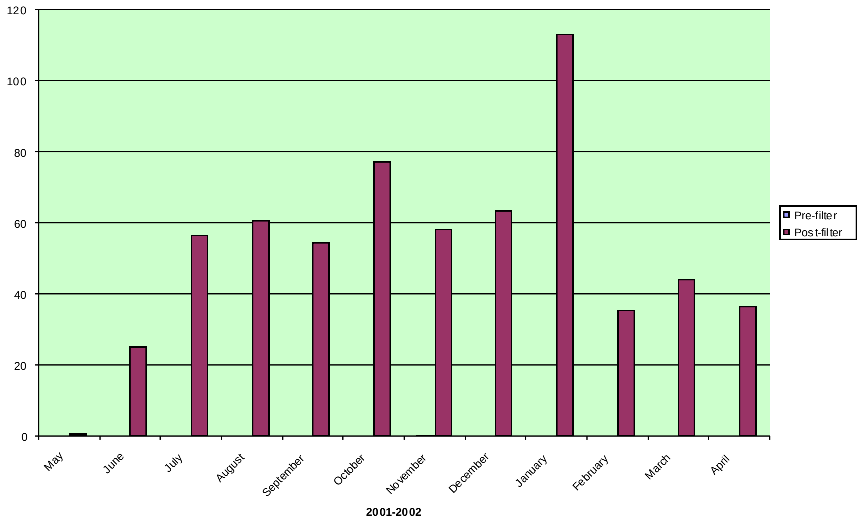

Figure 6: Total Oxides of Nitrogen (mg/L) as N

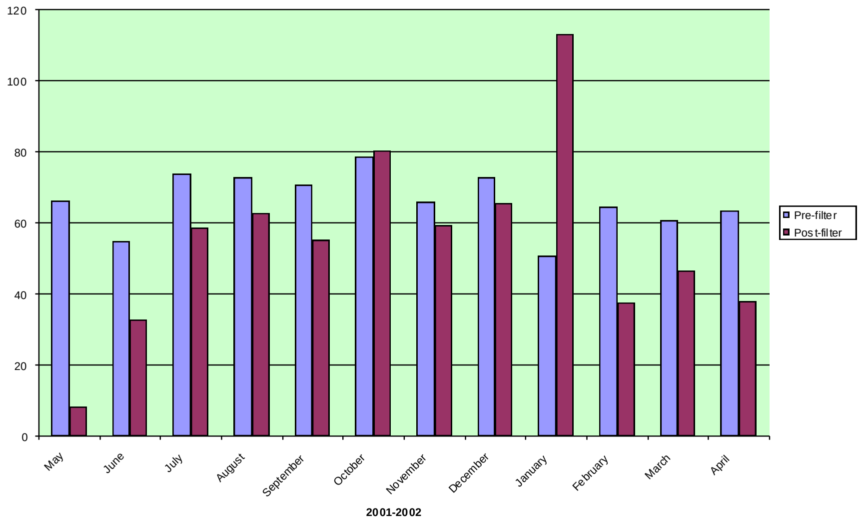

Figure 7: Total Nitrogen (mg/L) as N

The impact of the sand filter on Total Phosphorus is shown in Figure 8. Phosphorus concentrations are overall relatively low (average 8 mg/L) compared to other households, and reflect the selective use of more environmentally friendly household products for washing. Perhaps surprisingly, the sand filter appeared to be removing often significant amounts of phosphorus in effluent, however, there is a clear breakthrough in January 2002 with the post-filter concentration exceeding the prefilter concentration by 23%. The removal of phosphorus in a standard sand filter is unexpected, however, other research on phosphorus removal by Sakadevan and Bavor (1998) found that clinoptilolite can remove 50% of phosphorus from wastewater when the concentration of the influent is below 200 mg/L. In this case some of the phosphorus removal may be associated with the zeolite layer in the filter.

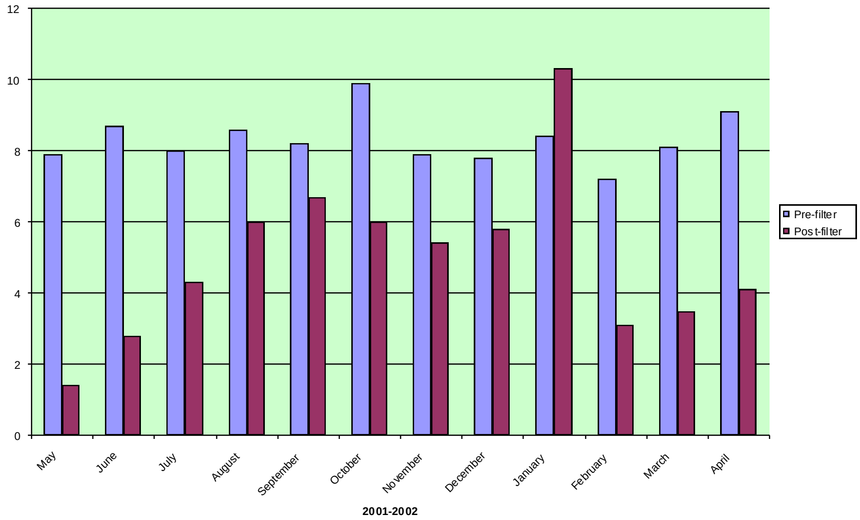

Figure 8: Total Phosphorus (mg/L) as P

The percentage reductions of sand filter effluent have been calculated for BOD_5, TSS, total nitrogen and total phosphorus and these are contained in the report by Geary *et al* (2003). Table 2 shows a comparison between the 2001/2002 results of the Martinsville sand filter and the results from other recent studies on sand filters. The comparisons indicate that the Martinsville system was well performed with respect to both BOD_5 and TSS, a performance which is typical of intermittently dosed sand filters. The 98% BOD_5 removal rate is consistent with other sand filters, as were the high TSS reductions.

Table 2: Sand Filter Pollutant Reductions (Means as %)

	Martinsville System (2001/2002)	**McCarthy *et al* (1998)**	**Jantrania *et al* (1998)**	**Davison and Bayley (2001)**
BOD_5	98	96-99	94	98
TSS	90	89-96	89	97
Total N	16	12-32	19	-2.4
Total P	41	39-53	27	77
Loading Rate ($L/m^2/d$)	19-27	32	88	71

(McCarthy *et al* (1998) and Jantrania *et al* (1998) both cited in Craven and Davison, 2001)

The total nitrogen removal of the Martinsville system was generally very low, but all filters shown in Table 2 performed poorly in this respect as only in recirculating sand filters is a higher overall nitrogen reduction likely. Intermittent sand filters produce a highly nitrified effluent and the limited nitrogen removal achieved is usually attributed to denitrification, and possibly some ion exchange. While ion exchange is clearly occurring in this sand filter, it is difficult to determine how much of the ammonium ion is being removed by ion exchange processes. Overall the zeolite in the Martinsville filter did not appear to have enhanced nitrogen removal, certainly in comparison with those other filters shown which did not incorporate a zeolite layer. The excellent phosphorus removal in the sand filter may be due to the presence of the zeolite as other studies have also reported capabilities in this regard. The longer-term performance with respect to phosphorus removal could decrease however as sorption is the principal short-term removal mechanism.

4 Conclusions

The Martinsville sand filter, like all intermittent sand filters, produced a high quality secondary wastewater effluent. One important feature associated with this accepted technology is that the lower organic and total suspended solids content of the effluent may allow a reduction in the land area requirements for land disposal systems. Sand filters are an excellent option for the onsite treatment of domestic wastewater in NSW and their installation and use in unsewered areas should be encouraged. The overall nutrient removal rates in the sand filter were quite variable. Almost all organic and ammoniacal nitrogen were converted to nitrate with only a minor amount of Total Nitrogen removed or lost from the system. The Martinsville design removed moderate amounts of phosphorus over the short-term monitoring undertaken in this study. The reductions in BOD_5 and TSS concentrations were excellent, with the results significantly better than the recommended 20/30 standards. The final effluent produced from the sand filter was clear, with neutral pH and no odour. The effluent produced is of much higher quality than that required by local government regulations. Further, the Martinsville system, incorporating a sand filter and automatic dosing siphons, has no moving or electrical parts and has the advantage of not requiring specialist maintenance. It also has a long life expectation.

Acknowledgements

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