Environment Waikato Technical Report 2004/15

Evaluation of the Performance of Constructed Wetlands Treating Domestic Wastewater in the Waikato Region

Prepared by:
James Sukias & Chris Tanner (NIWA)
NIWA Client Report: HAM2004-013
NIWA Project: EVW04202

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

ISSN: 1172-4005

March 2004

Document #:926261

Reviewed by: *Approved for release by:*

Rupert Craggs Long Nguyen

Contents

Figures

Tables

1 Introduction

Constructed wetlands are an established technology for secondary or tertiary treatment of wastewaters, with over 80 systems in operation in New Zealand (Tanner, Sukias et al. 2000, appended to this report). In addition to their treatment role, they appeal to communities because of their "naturalness" and function as a refuge to wetland plants and birdlife, and also the intimate contact of the wastewater with the wetland substrate, which helps meet Maori cultural requirements for wastes to be cleansed by passage through the earth.

There are a wide range of constructed wetland designs in use, which reflect the diversity of engineering approaches and treatment objectives at different sites. Factors such as the quality of construction, success of plant establishment, and level of operational maintenance can all affect treatment performance. Performance is also influenced by the age of the system. Constructed wetlands include a number of "treatment compartments" (e.g., plant biomass, bacterial biomass, soil matrix) which change in their ability to process nutrients as they mature. For instance, a gaseous removal mechanism for phosphorus is generally absent, thus phosphorus removal is limited to plant uptake and storage within the soil matrix. Once initial soil adsorption and plant biomass compartments are filled, phosphorus removal occurs only as a result of accretion of sediments and organic matter. Thus performance of constructed wetlands, like all stages of waste treatment systems, requires regular monitoring and assessment.

Environment Waikato requested NIWA to undertake an assessment of the performance of constructed wetlands treating domestic wastewater in the Waikato Region. Data for the assessment was provided by Environment Waikato, supplemented by data supplied by treatment plant operators.

2 Wetland Specifications

The seven wetlands included in this study were: Ngaruawahia, Huntly, Te Kauwhata, Cambridge, Waikeria, Otorohanga and Pukekohe. The specifications of each wetland are detailed in Table 1.

Table 1: Specifications of 7 wetlands in the Waikato Region.

Site	Type	Size (ha)	Mean Flow (m^3 d^{-1})	Mean Hydraulic loading (mm d^{-1})	Plant species
Huntly	SF[i]	4.0	1065	27	*Glyceria maxima*
Ngaruawahia	Combined SF and SSF[ii]	4.3	302	7	*Glyceria maxima*
Te Kauwhata	SF	2.4	414	17	*Glyceria maxima*
Cambridge	SF	6.6	3234	50	Mixed native and adventive aquatic grasses and herbs.
Waikeria	SSF	0.4	382	96	Mixed native species.
Otorohanga	Combined SF and SSF	3.0	1512	50	Mixed native aquatic grasses and herbs.
Pukekohe	SF	9.0	2541	28	*Glyceria maxima* and mixed native species.

SF = Surface Flow wetland. A shallow (0.1 – 0.3 m deep) planted pond.
SSF = Sub-Surface Flow wetland. Water flows beneath a gravel or soil media.

3 Treatment performance

The performances of 7 constructed wetlands treating domestic wastewater in the Waikato Region for which data were available were assessed and compared against results from other New Zealand wetlands as well as data from the NADB (North American Data Base). Data from each wetland consisted of regular monitoring reports (generally monthly) undertaken by the treatment plant operators, usually for the purposes of compliance monitoring. The frequency of monitoring and types of analyses undertaken depended on the consent conditions for the particular wetland treatment system. Available data was compiled in Tables 2 – 6 to allow comparisons between each wetland system for major performance indicators. Specific data were not available for separate wetland components, such as surface and sub-surface flow sections, and thus we have not attempted to distinguish between wetland types in this evaluation. In addition, some of the data was provided already sorted into "ordinal" format (from highest to lowest with no dates attached). This prevented more in-depth analysis of the data.

3.1 BOD

Average BOD inflow concentrations varied between 30 and 66 g m^{-3}, which is fairly typical of secondary treated domestic wastewater. The areal mass loading rate of the wetlands was highly variable, due to differences in the area of the wetlands relative to the daily inflow volume. Outflow BOD concentrations were, however, quite uniform (7 – 13 g m^{-3}), representing 59 – 84% removal (assuming a neutral water balance, i.e., no loss or gain in water in the wetland from rainfall or evapo-transpiration).

Table 2: Mean influent and effluent BOD concentrations, areal loading rate, and % removal for each wetland.

	Huntly	Ngaruawahia	Te Kauwhata	Cambridge	Waikeria	Otorohanga	Pukekohe
Inflow (g m^{-3})	30	33	30	52	-	-	66
Load (g m^{-2} d^{-1})	0.79	0.23	0.51	2.6	-	-	1.9
Outflow (g m^{-3})	12	11	7	13	-	9*	10
% Removal	59	67	76	75	-	-	84

*Otorohanga data is described in Council records as being taken at point of effluent outfall (Jul 02 – Feb 03), which may differ from the wetland outlet.

Figure 1 shows the performance of these wetlands in relation to SF and SSF wetlands in New Zealand and North America (NADB = North American Data Base) also treating domestic sewage.

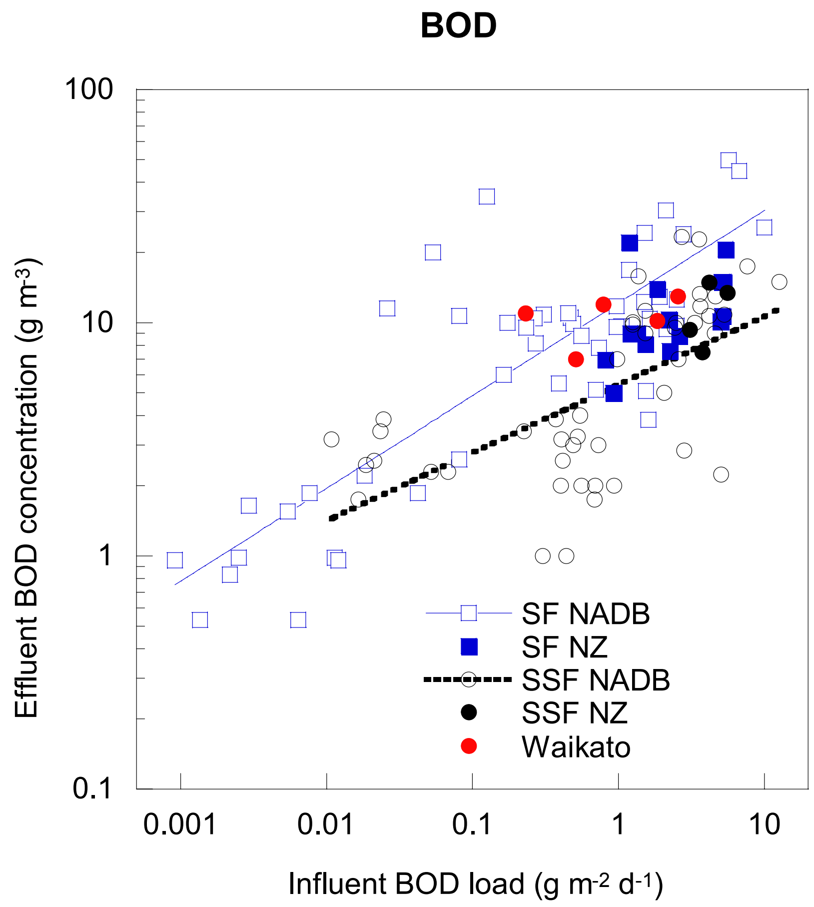

Figure 1: Mean annual BOD loading and effluent concentrations from constructed wetlands in Waikato, the rest of New Zealand, and from North America.

The performance of sub-surface flow wetlands is generally better than surface flow wetlands, which is due to their superior filtration capabilities (see trend lines for NADB wetlands). The mass removal (per unit area) by both wetland types increases as loading rate is increased, although effluent concentrations increase and efficiency (percentage removal) declines.

New Zealand wetlands (solid symbols) tend to typically have higher loading rates than the North American wetlands. BOD removal performance of the Waikato wetlands falls in the middle of the range for surface flow wetlands, and is therefore reasonable.

3.2 Suspended Solids

Inflow concentrations (22 – 84 g m^{-3}) and loading rates (0.51 – 2.24 g m^{-2} d^{-1}) for suspended solids (SS) were more variable than for BOD (30 – 66 g m^{-3}; 0.23 – 1.85 g m^{-2} d^{-1} respectively). This reflects differing levels of pre-treatment at the different sites, as well as the variation in algal SS in oxidation ponds, which preceded the wetlands at most of the sites. Outflow concentrations were low (3 – 23 g m^{-3}) representing 67 – 84 % removal.

Table 3: Mean influent and effluent suspended solids concentrations, areal loading rate, and % removal for each wetland.

	Huntly	Ngaruawahia	Te Kauwhata	Cambridge	Waikeria	Otorohanga	Pukekohe
Inflow (g m^{-3})	84	73	75	40	22	-	77
Load (g m^{-2} d^{-1})	2.24	0.51	1.30	1.95	2.12	-	2.16
Outflow (g m^{-3})	23	13	12	13	3	-	23
% Removal	73%	83%	84%	67%	85%	-	70%

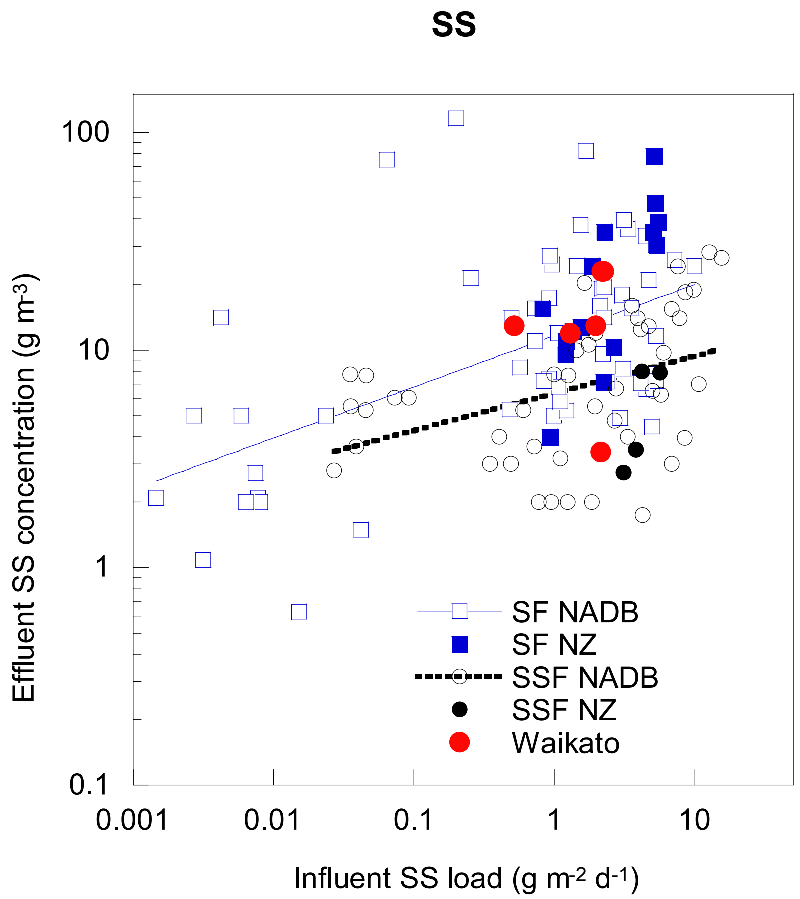

Figure 2: Mean annual suspended solids loadings and effluent concentrations from constructed wetlands in Waikato, the rest of New Zealand, and from North America.

Loadings for suspended solids range over 4 orders of magnitude, illustrating varying wetland design approaches and treatment expectations. Trends are similar to that seen for BOD, with effluent concentrations increasing with higher loading. The performance of the Waikato wetlands again is in the middle of the performance range (note, the symbols for Huntly and Pukekohe sites over-lie each other). Performance for the sub-surface flow Waikeria system is notably better than for the others. This may also be influenced by higher levels of pre-treatment steps at this site, which include activated sludge and sand filtration.

3.3 Total Kjeldahl Nitrogen

The wetlands showed modest removals (17 – 33 %) of total kjeldahl nitrogen (TKN, which is comprised of organic nitrogen and ammoniacal-N, see Table 4). Much of the organic nitrogen will be in particulate forms, which can be filtered or settle within a wetland. This retained organic N can subsequently be remineralised and hydrolysed, to ammoniacal-N. Ammoniacal-N can be removed by plant uptake (generally a small, finite pool), volatilisation (which requires elevated pH levels), or sequential nitrification and denitrification. This last route is considered the major avenue of nitrogen removal from constructed wetlands (Kadlec and Knight 1996). Generally, anaerobic or anoxic conditions prevail within the soil:water matrix, so nitrification is the limiting step in this process. As a result, reductions of nitrogen above the levels seen in these wetlands may require either additional pre-treatment steps that include significant amounts of aeration, larger wetland areas, or different plant types (see below).

Table 4: Mean influent and effluent total Kjeldahl nitrogen concentrations, areal loading rate, and % removal for each wetland.

	Huntly	Ngaruawahia	Te Kauwhata	Cambridge	Waikeria	Otorohanga	Pukekohe
Inflow ($g\ m^{-3}$)	11	23	16	-	-	-	14
Load ($g\ m^{-2}\ d^{-1}$)	0.30	0.16	0.28	-	-	-	0.39
Outflow ($g\ m^{-3}$)	9	15	11	-	-	-	11
% Removal	17%	30%	33%	-	-	-	24%

Figure 3 shows the Waikato wetlands falling in the general range of TKN removal, although slightly above the trend line (i.e., worse than average) for surface flow wetlands. Although % removal at the Ngaruawahia was 30% (second highest), its performance lies well above the trend line, due to the low loading at this site. It may be that performance is hindered by the use of *Glyceria maxima* at this site, as it is considered to have relatively poor oxygen release characteristics.

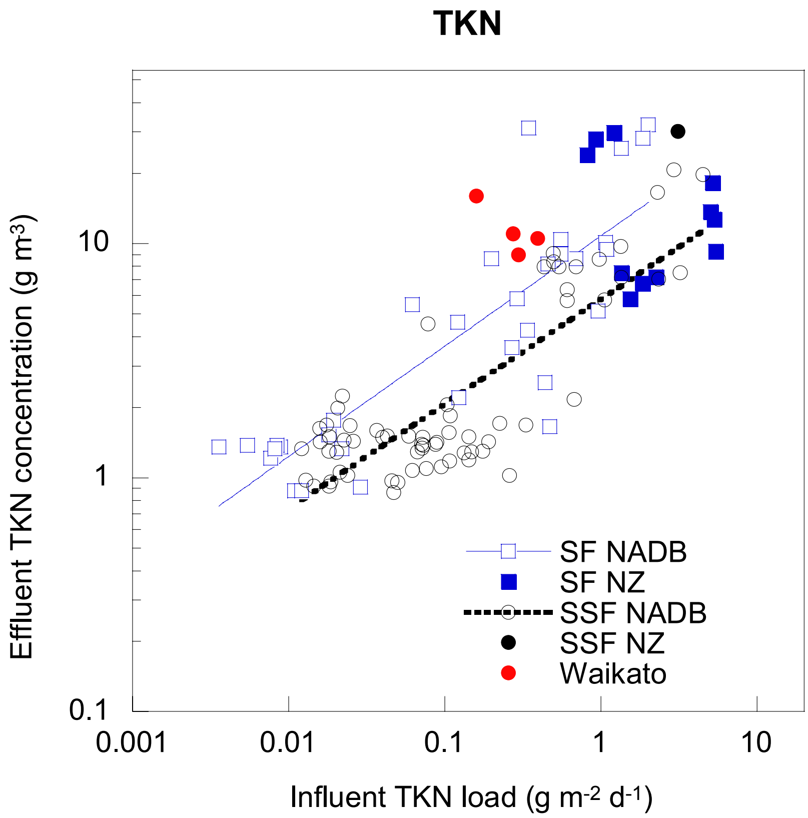

Figure 3: Mean annual total kjeldahl nitrogen loadings and effluent concentrations from constructed wetlands in Waikato, the rest of New Zealand, and from North America.

3.4 Ammoniacal-N

Evaluation of ammoniacal-N removal is complicated, due to the release of additional ammoniacal-N from organic-N retained in the wetland. Little reduction in ammoniacal-N is evident in Table 5, except at the Cambridge site, where influent concentrations were high. Although removal was good at this site (46%), effluent concentrations were relatively high. Apparent increases in ammoniacal-N occurred at the other sites, particularly Huntly. However overall decreases in TKN (Table 4) at these sites show that the ammoniacal-N increases were likely to be due to mineralisation of organic-N deposited in the wetland.

Table 5: Mean influent and effluent ammoniacal-N concentrations, areal loading rate, and % removal for each wetland.

	Huntly	Ngaruawahia	Te Kauwhata	Cambridge	Waikeria	Otorohanga	Pukekohe
Inflow ($g\ m^{-3}$)	0.9	12.0	6.6	47	-	-	3.1
Load ($g\ m^{-2}\ d^{-1}$)	0.02	0.08	0.11	2.29	-	-	0.09
Outflow ($g\ m^{-3}$)	5.1	12.1	7.4	25	-	20.2*	3.5
% Removal	-463%	-1%	-13%	46%	-	-	-14%

* Otorohanga data taken at point of effluent outfall (Jul 02 – Feb 03).

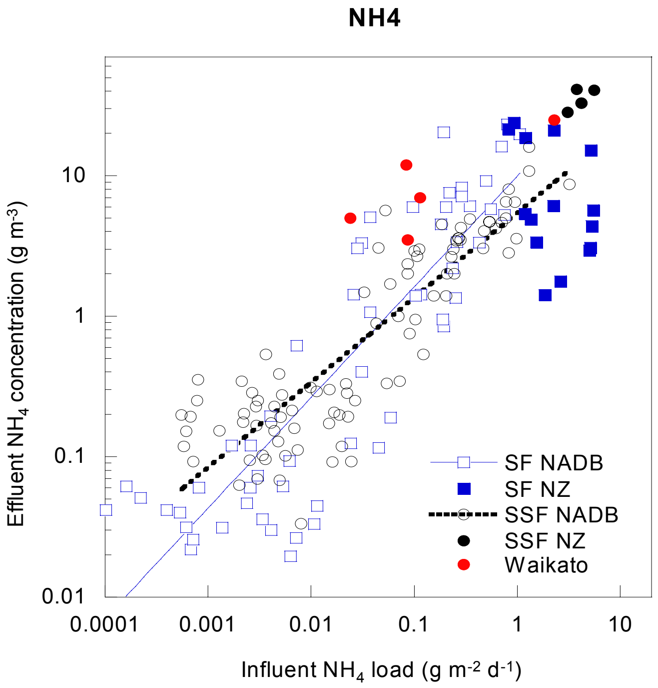

Figure 4: Mean annual total ammonia loadings and effluent concentrations from constructed wetlands in Waikato, the rest of New Zealand, and from North America.

It can be seen from figure 4 that the ammoniacal-N loadings at the four sites (with available data) were lower than typical of New Zealand constructed wetlands, and that removals were also generally lower.

The crossing of the trend lines in the graph indicates that surface flow wetlands are better at removing ammoniacal-N at low influent loadings, while sub-surface flow wetlands are better at high influent loadings.

3.5 Phosphorus

Phosphorus removal in constructed wetlands is generally by storage in various compartments, such as plant matter, settling and sorption in the soil/gravel matrix, or incorporation into microbial biomass. The storage of P in each of the compartments should be regarded as finite, as phosphorus removal by wetlands generally decreases over time. In some wetlands sediment accretion can be an on-going process, allowing phosphorus removal to continue for many years (Nguyen 2000), but P saturated wetland sediments can act as a source for phosphorus release.

All the studied wetlands only removed small amounts of total phosphorus (Table 6), indicating minimal additional capacity in the storage compartments. Note: Phosphorus is measured in the intake and outlet of the Otorohanga wetland as Dissolved Reactive Phosphorus and Total Dissolved Phosphorus. Slight increases were evident in these parameters, indicating negligible removal (assuming a neutral water balance) at this site. This is similar to the performance of the other wetlands studied.

Table 6: Mean influent and effluent total phosphorus concentrations, areal loading rate, and % removal for each wetland.

	Huntly	Ngaruawahia	Te Kauwhata	Cambridge	Waikeria	Otorohanga	Pukekohe
Inflow (g m^{-3})	6.7	7.3	6.9	12.6	-	(6.6)*	8.5
Load (g m^{-2} d^{-1})	0.18	0.05	0.12	0.62	-	(0.33)*	0.239
Outflow (g m^{-3})	6.5	6.3	6.1	12.1	-	(6.7)*	8.1
% Removal	2%	14%	12%	4%	-	+2%*	4%

* Otorohanga data for Total Dissolved Phosphorus.

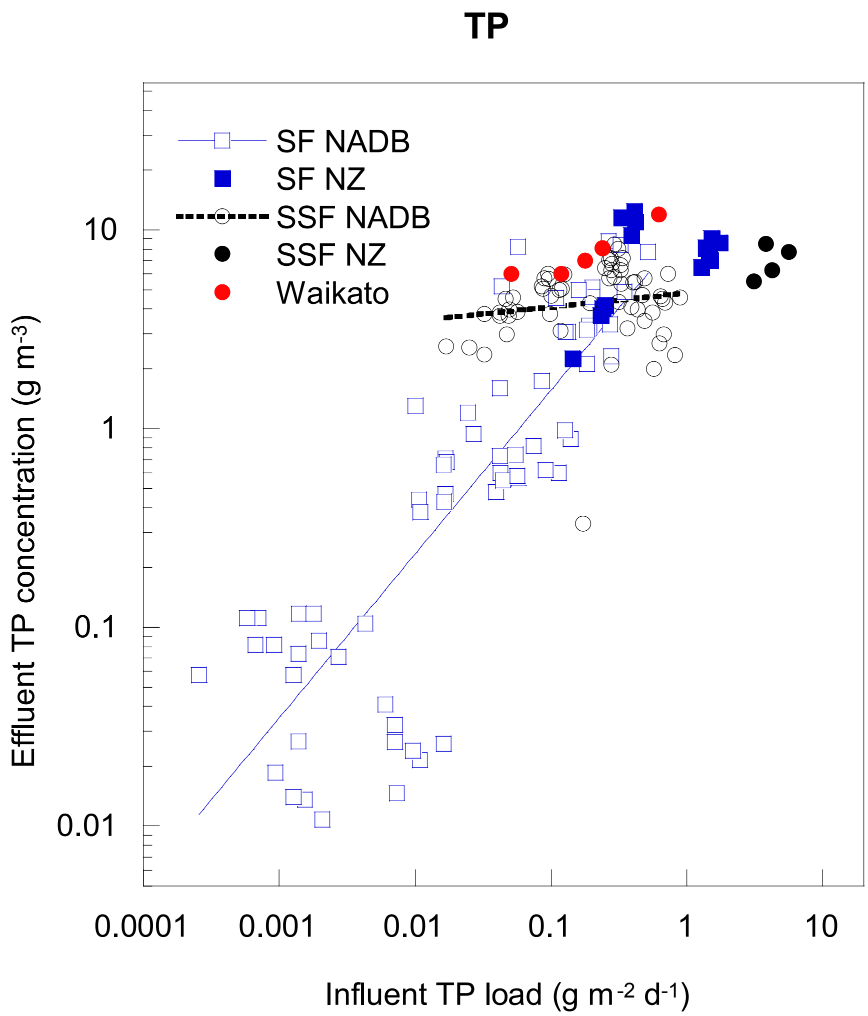

Figure 5 : Total phosphorus loadings and effluent concentrations from constructed wetlands in Waikato, the rest of New Zealand, and from North America.

Figure 5 again illustrates the general trend in New Zealand of total constituent loading to constructed wetlands more highly than in North America. While Table 6 indicates only low levels of removal, the performance of these wetlands is not significantly worse than other sites. If phosphorus removal is an important treatment requirement, it should be undertaken by alternative preceding or post wetland treatment steps, e.g., induced phosphorus precipitation, or enhanced biological P-removal systems.

4 Individual wetland assessment

4.1 Huntly

The constructed wetland at Huntly is a 4 ha surface flow system planted with *Glyceria maxima*. Removal of BOD and SS (59% and 73% respectively) were good at this site. Effluent concentrations of SS however are higher than average (23 g m^{-3}), probably attributable to the high SS loading rate. TKN showed reasonable reductions (17% removal), although total ammonia increased to around 5 g m^{-3}.

4.2 Ngaruawahia

This 4.3 ha wetland, which combines surface and sub-surface flow sections, is also planted with *Glyceria maxima*. Removal of BOD and SS (67% and 83% respectively) were good. TKN showed 30% removal, which was about what would be expected for the loading rate in this wetland (see fig. 3). TP also showed some improvement (14% removal). Faecal coliform removal (data not provided, but stated in District Council reports on wetland performance) was apparently 95%, which is also a good level. Overall this wetland is performing well.

4.3 Te Kauwhata

The Te Kauwhata wetland is a 2.4 ha surface flow system. The levels of BOD and SS removal (76% and 84% respectively) were similar to the other wetlands assessed, and about what would be expected from figs 1 and 2. TKN removal was 33%, also about what would be expected based on the loading rate. TP showed similar improvement to the Ngaruawahia site. Overall this wetland is performing well.

4.4 Cambridge

The 6.6 ha surface flow Cambridge wetland had a much higher loading than the other sites (see particularly Tables 2, 5 and 6), however BOD and SS removal (75% and 67% respectively) were similar to the other wetlands. TKN data was not available, but good removal of ammoniacal-N was evident (46%). This was the only site to show improved ammonia concentrations. This may be disguised somewhat by the high effluent concentrations of ammoniacal-N (avg. 25 g m^{-3}), however, fig. 4 clearly demonstrates that this removal rate is typical for the loading rate at this site. Aeration in preceding treatment systems is used to reduce ammoniacal-N concentrations, although until recently it appears to have been inadequate, as high ammoniacal-N and nitrite concentrations (nitrite = 3.5 g m^{-3}) entered the wetland. The recent addition in March, 2002 of extra aerators is an appropriate response to the high effluent ammoniacal-N concentrations evident in this data. Faecal coliforms are also sampled at the wetland outflow, and are reduced up to 2 orders of magnitude (99%) in the wetlands.

4.5 Waikeria

The 400-m^2 sub-surface flow wetland at Waikeria had the lowest influent SS concentration of the sites assessed (22 g m^{-3}). SS loading (2.12 g m^{-2} d^{-1}) however was similar to Pukekohe and Huntly (2.24 and 2.16 g m^{-2} d^{-1} respectively), due to the high hydraulic loading rate at Waikeria. Removal at this site was similar to the other sites (85%) demonstrating that even at low influent concentrations, good removal is possible, especially in sub-surface flow wetlands, as discussed earlier. Inclusion of additional analyses (BOD, phosphorus and nitrogen) in the monitoring of this site would enable a more thorough assessment of the treatment systems performance.

4.6 Otorohanga

The combined surface and sub-surface flow wetland at Otorohanga is preceded by an aerated sewage treatment pond, and is followed by an “Earth Contact” Outfall Trench. Monitoring at this site focuses upon the actual discharge, and effects in the stream receiving the discharge. The wetland is monitored at the inlet and outlet for conductivity, pH, dissolved reactive phosphorus (DRP), total dissolved phosphorus (TDP) and turbidity, but not SS, BOD etc. Therefore it could not be adequately assessed or compared with the other sites. Small decreases were evident for conductivity (7 %) and pH. As noted, both DRP and TDP increased slightly, either due to reductions in water volume from evapo-transpiration in the wetland, or release of P from sediments and plant litter in this wetland. Turbidity of the effluent as it passed through the wetland decreased from 66 to 28 NTU, a significant improvement.

Analysing the wetlands for DRP and TDP indicated a certain amount of dissolved organic P entering the wetland from the preceding pond system. High turbidity also enters the wetland at times (which may contain particulate P fractions). However, given the low expected removal of DRP or TDP in this system, the usefulness of analysing not only DRP but also TDP is questionable.

4.7 Pukekohe

In terms of wetland performance, the 9 ha surface flow Pukekohe site is clearly performing well, with good reductions in BOD and SS (84% and 70% respectively). Effluent concentrations of SS however are higher than average (23 g m^{-3}). This may be attributed to the SS loading rate, as Huntly has similar loadings and effluent concentrations. Other effluent quality indicators such as TKN and TP were about average for these wetlands.

5 Summary

All the studied wetlands appeared to be performing adequately, when compared with data from the NADB and from other NZ wetlands. Removal of BOD and SS by the wetlands were typically good, both on a loading per unit area and % removal basis. Removal of TKN was only moderate (17-33%), and phosphorus removal was generally negligible (which is typical in well-established constructed wetlands). Ammoniacal-N removal appears poor, possibly attributable to the plant species (*Glyceria maxima*) that is used in several of these wetlands. This wetland species has relatively poor oxygen release characteristics, and may not be suitable for use in wetlands where the incoming water is low in oxygen; has a high oxygen demand and/or ammoniacal-N. Further investigations are required on the suitability of this species for use in wetlands.

The performance of the wetlands was difficult to assess in some instances, where the range of analyses was limited, or where data was not ordered by date. In general this appeared to be due to a focus by the wetland operators on “whether they had achieved the consent requirements” rather than on monitoring their treatment systems for trend analysis or enhancing the performance of the systems, of which the wetlands form only a single component. We would recommend a greater degree of standardisation in monitoring and reporting of wetland performance.

References

Kadlec, R.H. & Knight, R.L. (1996). Treatment Wetlands. Boca Raton, CRC Press.

Nguyen, L.M. (2000). Phosphate incorporation and transformation in surface sediments of a sewage-impacted wetland as influenced by sediment sites, sediment pH and added phosphate concentration. *Ecological Engineering 14*: 139–155.

Tanner, C.C.; Sukias, J.P. et al. (2000). Constructed wetlands in New Zealand - evaluation of an emerging "natural" wastewater treatment technology. *Water 2000 "Guarding the global resource",* Auckland, New Zealand, NZWWA.

(Appended overleaf)