Praat, J-P. Sukias, J., Wright-Stow, A., Bichan, A. Perrie, A., 2019. Changes in water quality through a constructed wetland on a Wairarapa dairy farm – mitigation in action. In: *Nutrient loss mitigations for compliance in agriculture*. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8 pages.

CHANGES IN WATER QUALITY THROUGH A CONSTRUCTED WETLAND ON A WAIRARAPA DAIRY FARM

– MITIGATION IN ACTION

John-Paul Praat[1], James Sukias[2] Aslan Wright-Stow[3], Aidan Bichan[4] and Alton Perrie[5]

[1]Groundtruth Ltd, 104 Turere Lane, Te Awamutu and PO Box 52 Paekakariki
[2]National Institute of Water and Atmosphere, Hamilton, [3]Dairy NZ, Hamilton
[4]Kaiwaiwai Dairies Ltd, Featherston and [5]Greater Wellington Regional Council, Masterton
Email: jp.praat@groundtruth.co.nz

Abstract

A constructed wetland was installed on a Wairarapa dairy farm in October 2014. The wetland features a serpentine flow at three levels in the landscape, has a permanent metered inflow and is planted with emergent native aquatic plants. It demonstrates a design which conforms well with the Overseer® wetland module. Initial flow through the wetland was increased to 14 Litres/second in January 2016. The quality of the water entering and leaving the wetland has been sampled on a monthly basis since February 2015. Electronic monitoring of wetland flow has also been installed.

Nitrate-N removal in the wetland averaged 48%, with average net removal of 626 kg N per year over the two years from January 2016 to March 2018. This is significant as the average farm nitrogen loss is (as calculated by Overseer) 13 kg N/ha/yr or 6024 kg N in total. The wetland effectively reduces total N loss from the farm by more than 10% while intercepting approximately 15% of the water exiting the farm.

Other results - total N has been reduced by ~36%, mostly associated with nitrate-N removal since the wetland was installed. A recent report by the National Institute of Water and Atmosphere (NIWA) stated that total N removal at Kaiwaiwai wetland was higher than most NZ constructed wetlands of this size relative to their inflowing catchment area. Results for Total Phosphorus were similar in that 14.3% was removed, again above the 10% removal normally expected.

Introduction

Significant capital has been invested in the Wairarapa on upgrading dairy effluent management systems to comply with regulations requiring storage to avoid land application to saturated soil. The purpose of the regulation is to reduce the risk of contaminants reaching surface and groundwaters and subsequently entering the water of Wairarapa Moana. There are other investments a landowner can make in this regard which are outside the compliance envelope and may be a more efficient use of capital earmarked for water quality improvement.

In 2014 a 0.75 hectare “wet” part of a paddock at Kaiwaiwai Dairies Ltd was converted to a wetland with a permanent water source. Detail of construction and initial performance in terms of water quality impacts were described in Praat et. al. (2015). Here we update and expand on water quality results from the monitoring which has continued as part of a Sustainable Farming Fund project.

Flow monitoring

Harvest Electronics (NZ) Ltd installed water height monitors on the inlet and outlet of the wetland to reflect water flow through the wetland. The system is monitored remotely with set points to alert the landowner of reduced flows due to inlet blockages. A water conductivity meter was also installed to investigate how this might be used in the future to record contaminants in the drainage water.

Water Quality Sampling

Monthly sampling of inflow and outflow from the wetland was carried by a technician from Greater Wellington Regional Council (GWRC). Hill Laboratories completed the analysis which was paid for by the landowner. Analysis of water quality included a standard set of parameters including nitrogen (N), phosphorus (P), turbidity, total suspended solids (TSS), total organic carbon (TOC) in the wetland inflow and outflow. This paper reports the results for N and P for the period January 2016 to March 2018. A full report assessing all results was completed by the National Institute of Water and Atmosphere (NIWA) and is available from the corresponding author of this paper.

Results

Flow monitoring

Figure 1 shows an example of inlet and outlet water depths for Kaiwaiwai wetland along with conductivity of the water coming into the wetland. Rainfall events (data not shown) were reflected in the height of water at the outlet from direct rainfall on the water surface of the wetland and by the increase in conductivity, presumably as sediment and water turbidity increases. Monthly sampling did not coincide with these peaks in conductivity so this could not be verified on site. Data from the inlet and outlet heights showed reduced flow towards the end of the month. This was within the set alert points, so no action was taken at the time. The issue was rectified in early April by removing aquatic weed from the intake in the open drain.

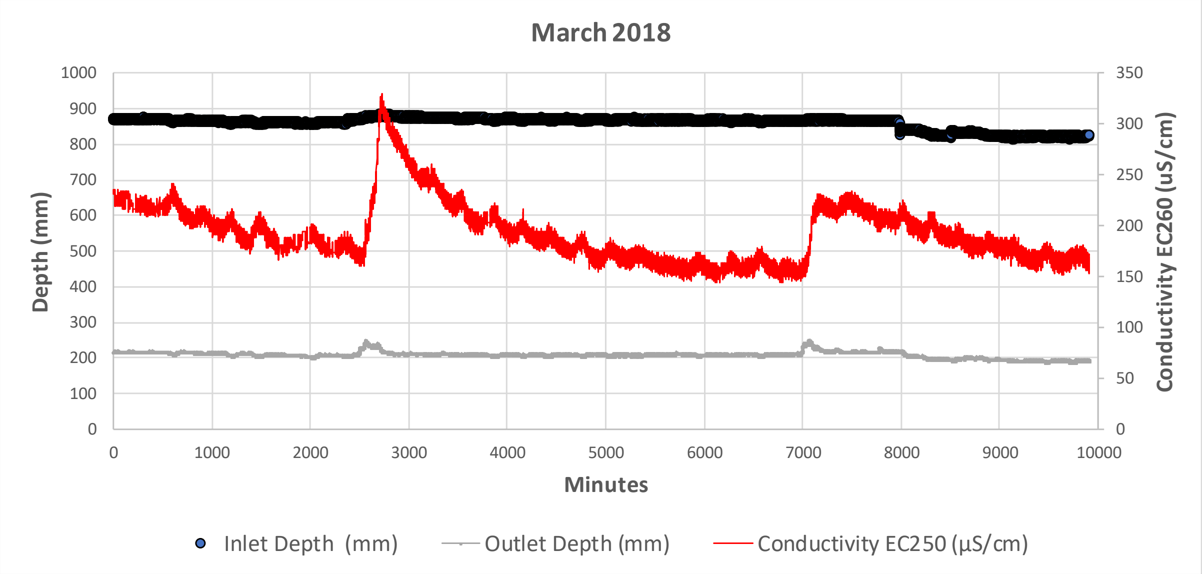

Figure 1 **Water depth at the inlet and outlet and inlet water conductivity of Kaiwaiwai wetland during March 2018**

Nitrogen reduction

Statistical analysis for inflow and outflow nitrogen concentrations and percent reduction efficiencies of nitrate nitrogen (NO_3-N) and total nitrogen (TN) are summarised in Table 1. Concentrations of NO_3-N in inflow and outflow of the Kaiwaiwai wetland are shown in Figure 2. The wetland achieved a mean ~48% reduction of NO_3-N (from 3.1 to 1.6 mg N/L, Table 1) over the 28-month monitoring period despite the relatively short nominal hydraulic retention time of approximately 1.24 days. Other species of nitrogen were also measured but changes were negligible. For example, maximum concentration of ammoniacal nitrogen (NH_4-N) inflow and outflow was only 0.19 mg N/L compared with NO_3-N maximum conc. of 5.2 mg N/L.

Overall, the Kaiwaiwai wetland achieved ~36% TN reduction (from 4.2 to 2.7 mg N/L) mainly through the reduction of NO_3-N (Table 1). The major removal mechanism was likely via microbial denitrification (reducing NO_3-N to N_2 gas under anoxic conditions). In addition to this removal pathway, some of the nitrate removal was probably occurring via plant uptake, with increased organic nitrogen (possibly floating plant debris) at the outflow. The wetland had almost complete NO_3-N reduction (outflow <0.5 mg N/L, Table 1) in summer months (December to February, Figure 2) when microbial activities and plant nutrient uptake are enhanced by warmer temperatures, .

Table 1 **Statistical analysis for inflow and outflow nitrogen concentration and percent reduction efficiencies in the Kaiwaiwai wetland *(reproduced from NIWA September 2018 report)***

	TN (mg/L)			NO_3-N (mg/L)		
	In	Out	reduction	In	Out	reduction
Median	4.5	2.8	35.6 %	3.4	0.9	73.5 %
Mean ± s.d.	4.2 ± 1.6	2.7 ± 1.8	35.7 %	3.1 ± 1.3	1.6 ± 1.5	48.4 %
Max.	7.2	6.0		5.2	4.3	
Min.	1.0	0.6		0.6	0.0	
# of data points	28	28		28	28	

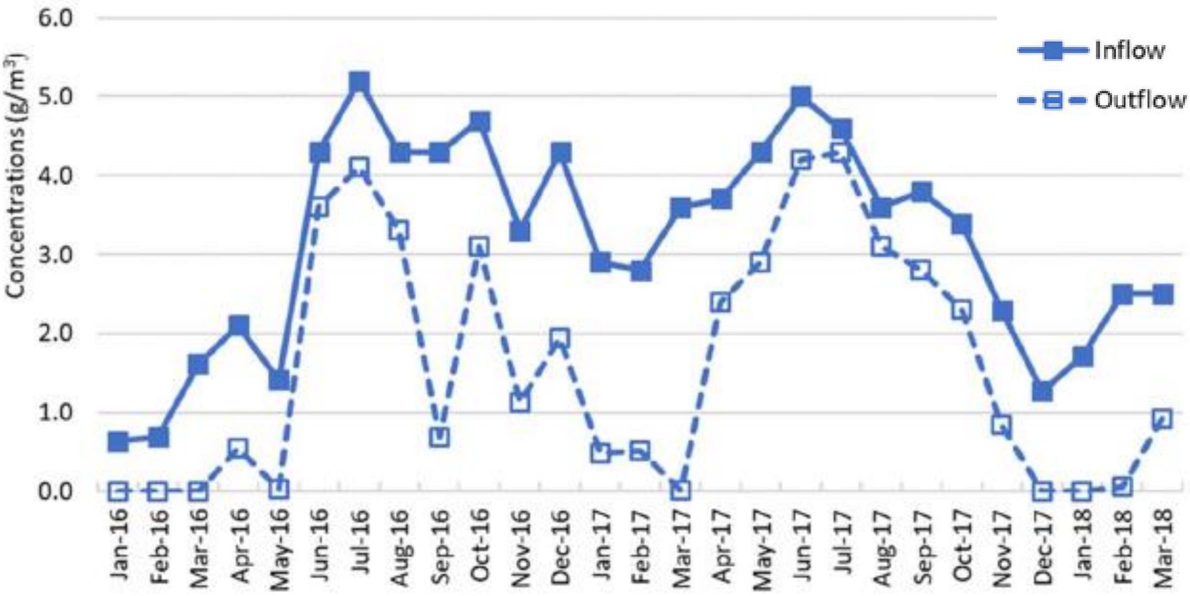

Figure 2 **Concentrations of nitrate nitrogen (NO_3-N) in inflow and outflow of the Kaiwaiwai wetland. Monthly water quality monitoring January 2016 to March 2018.**

Mass nitrogen reduction (kg N per month or year) based on TN, NH_4-N and NO_3-N, calculated on the basis of water flow through the wetland and monthly concentration, is summarised in Table 2. The wetland removed 613 and 640 kg TN, and 679 and 639 kg of NO_3-N from the farm drain water in Years 1 and 2 (2016 and 2017) respectively. The farm total N loss value from Overseer (2014 analysis) was 6024 kg so the wetland has reduced nitrogen loss by ~10-12%. These results were obtained by transforming only ~0.7 ha wet pasture land to constructed wetland which intercepts approximately 15% of the water exiting the farm (estimated based on catchment area of 70ha).

Table 2 Mass nitrogen reduction in the Kaiwaiwai wetland based on TN and NO_3-N since January 2016. calculated based on the daily flow rate of 1209.6 m^3/day (14L/s

	Year 1 (2018)		Year 2 (2017)		Year 3 (2018)	
	TN	NO_3-N	TN	NO_3-N	TN	NO_3-N
Month	Kg N reduction per month					
Jan	14.2	23.9	114.0	90.7	67.1	64.0
Feb	18.0	23.3	71.1	77.6	78.9	82.7
Mar	48.7	60.7	136.1	134.4	55.1	59.2
Apr	44.6	56.6	47.2	47.2		
May	85.9	52.0	26.2	52.5		
Jun	14.5	25.4	29.0	29.0		
Jul	45.0	41.2	15.0	11.2		
Aug	18.7	37.5	26.2	18.7		
Sep	87.1	131.0	32.7	36.3		
Oct	56.2	60.0	41.2	41.2		
Nov	105.2	79.1	51.2	52.6		
Dec	75.0	88.1	50.2	47.5		
Yearly total (kg N/yr)	**613**	**679**	**640**	**639**		

Phosphate reduction

Statistical analysis for inflow and outflow TP and DRP concentrations and percent reduction efficiencies are summarised in Table 3. Mass flow of total phosphorus (TP) and dissolved reactive phosphorus (DRP) in the inflow and outflow of the Kaiwaiwai wetland are shown in Table 4. Total phosphorus removal within the wetland during the monitoring period was 14.3% TP, with 25.0% DRP reduction. Low final effluent TP (0.06 mg/L) and DRP (0.03 mg/L) concentrations were maintained throughout the monitoring period. The wetland removed 6.8 and 3.9 kg of TP in Years 1 and 2 respectively (Table 4).

Outflow values were sometimes higher than recorded for the inflow on that particular day (Table 4). This is likely associated with a variety of factors. Firstly, the hydraulic retention time of the wetland is 1.24 days so the outflow on any sampling occasion relates to the inflow of approximately that amount of time previously when inflow concentrations may have been higher. Also constructed wetlands which have not had addition of phosphorus adsorbing minerals have modest phosphorus removal rates, as reduction process are limited to physical and biological processes such as biotic uptake, sorption onto soil particles and through the accretion of wetland soils.

Table 3 Statistical analysis for inflow and outflow phosphorus concentrations and percent reduction efficiencies in the Kaiwaiwai wetland

	TP (mg/L)			DRP (mg/L)		
	In	Out	reduction	In	Out	reduction
Median	0.06	0.05	16.7 %	0.03	0.02	33.3 %
Mean ± s.d.	0.07 ± 0.04	0.06 ± 0.03	14.3 %	0.04 ± 0.02	0.03 ± 0.01	25.0 %
Max.	0.17	0.13		0.09	0.05	
Min.	0.03	0.02		0.01	0.01	
# of data points	28	28		28	28	

Table 4 Mass phosphorus reduction in the Kaiwaiwai wetland based on TP and DRP since January 2016. Calculated based on the daily flow rate of 1209.6 m^3/day (14L/s)

	Year 1 (2018)		Year 2 (2017)		Year 3 (2018)	
	TP	DRP	TP	DRP	TP	DRP
Month	Kg P reduction per month					
Jan	-0.11	0.94	3.19	0.19	1.5	0.75
Feb	1.08	1.25	1.90	1.15	-0.34	-0.17
Mar	0.00	1.57	-0.37*	-0.56	-0.45	-0.56
Apr	0.51	0.8	0.8	0.22		
May	3.34	1.69	-0.71	-0.07		
Jun	0.04	0.36	-0.15	-0.22		
Jul	0.75	0.67	-0.22	-0.11		
Aug	-0.15	0.30	0.56	0.04		
Sep	-2.07	0.11	0.18	0.07		
Oct	0.07	0.04	0.04	0.22		
Nov	3.19	2.18	-0.22	-0.29		
Dec	0.11	0.04	-1.09	-0.52		
Yearly total (kg N/yr)	**6.8**	**10.0**	**3.9**	**0.1**		

*Note: Negative values are due to the outlet concentration being higher than inlet

Discussion

A 0.5 ha wetland was constructed at Kaiwaiwai Dairies Ltd in southern Wairarapa to treat farm drainage water from an open drain. The wetland was constructed in three cells, each with a long winding path length. Flows into the wetland were controlled to 14 L/s giving a residence time for water in the wetland of 1.24 days.

Measurement of water depth to reflect flow through the wetland was effective at monitoring the performance of the wetland although set points for alert should be fine-tuned so that target flow is maintained. This is especially important in summer when the wetland is working at maximum capacity and removing all the NO_3-N from the incoming drainage water. Water conductivity appeared to reflect rainfall events and may be useful also in alerting the landowner when wetland parameters are outside expected norms at other times.

Overall, the wetland achieved ~36% TN reduction (from an average of 4.2 down to 2.7 mg N/L). Sukias and Park (2018) noted that this was higher than most NZ constructed wetlands that occupy 0.5-1.0% of a catchment. Removal was via reduction of nitrate, which was almost 100% in summer months (December to February, effluent concentration <0.5 mg N/L). They also found that nitrate removal was partially offset by accumulation of some organic nitrogen and ammonia nitrogen, probably associated with floating aquatic weeds in the wetland.

The wetland removed 613 and 640 kg TN (equivalent to 117 and 122 g N/m^2/y) from the farm drainage water in Years 1 and 2 (2016 and 2017) respectively. In terms of overall nitrogen losses from the farm, (calculated by Overseer as 6024 kg N), the wetland reduced these losses by ~10-12%.

The wetland removed 6.8 and 3.9 kg TP in Years 1 and 2 respectively, and achieved phosphorus reductions of 14.3% TP. This was also a little higher than a modelled prediction which was 10% (Sukias and Park 2018). Low final outflow TP (0.06 mg/L) and DRP (0.03 mg/L) concentrations were maintained throughout the monitoring period. As this wetland did not have an addition of phosphorus sorption materials, reduction would have been mainly through physical and biological processes such as biotic uptake, sorption onto soil particles solids deposition, and through the accretion of wetland soils.

Costs and Benefits

At a capital cost of $55,000 and nitrogen removal of around 626 kg N the wetland reduced N loss for $88/kg N ($55,000/625kg N). This is considerably cheaper when compared with the cost of upgrading effluent systems. Two Wairarapa examples of dairy effluent upgrade indicate a range of $724 to $1680/kg N where capital costs ranged from $400,000 to $780,000. Reduction in N loss was estimated to be 552 and 463 kg respectively by Overseer. The addition of a constructed wetland is considerably more cost-efficient in reducing N loss from the farm and has brought with it increased biodiversity in terms of additional plant, bird and fish species and improved aesthetic values on the farm.

Conclusion

The constructed wetland at Kaiwaiwai Dairies is very successful in terms of removing N from drainage water. Removal of P is also very valuable in terms of improving water quality but should not be considered as a sustainable mechanism as P storage cells will eventually be filled. The relative capital cost of removal of contaminants in water from farms should be considered when rules and regulations are developed. As shown here, an outcomes-based approach to reduce N and P loss from the farm has been more efficiently achieved by methods other than that required by rules. When other benefits like improvements to biodiversity and aesthetic values are considered, then flexible rules and regulations which recognise a range of approaches to improving environmental outcomes achieve more in the long-term than a rigid simple rules-based approach. The creation of an integrated network utilising a variety of approaches specific to the individual farming operation is more likely to reduce capital costs and improve environmental outcomes. For example, on this farm 14 more wetlands could have been established on this farm for the same capital that was spent upgrading the farm dairy effluent system. Other complimentary activities like using green water wash for yards, riparian planting, management of laneway run-off and increased monitoring of drainage water could form a more integrated and effective solution.

Acknowledgements: Continued monitoring and reporting from the wetland has been made possible by funding from a Sustainable Farming Fund (SFF-MPI) project, administered by Sustainable Wairarapa Inc.. Dairy NZ and Pāmu are co-funding partners. The awesome effort of the owners and managers at Kaiwaiwai Dairies Ltd in establishing and maintain the wetland to the benefit of the wider community is greatly appreciated.

References

Guide on constructing a wetland for nitrogen removal can be found at https://www.groundtruth.co.nz/news/guide-constructing-wetland-farm-nitrogen-removal

Park. J., Sukias. J., 2018: Performance of Kaiwaiwai constructed wetland. Unpublished NIWA Client report No 2018285HN. September 2018 pp 23

Praat, J-P. Sukias, J. Faulkner, T. Bichan, A., 2015: Benefits and costs of a constructed wetland on a Wairarapa dairy farm. *In* Journal of New Zealand Grasslands 77: 173-176