Second Australian Stream Management Conference
8-11 February 1999, Adelaide, South Australia

Riparian Wetland Processing of Nitrogen, Phosphorus and Suspended Sediment Inputs from a Hill Country Sheep-Grazed Catchment in New Zealand

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SUMMARY: We investigated the ability of a riparian wetland to strip nitrogen (N), phosphorus (P) and suspended sediment (SS) from surface runoff and ground water over a 6-month period when most of the annual water flows from a sheep-grazed pasture catchment to the wetland occurred. Water flows into and out of the wetland were monitored daily. Concentrations of SS, ammonium (NH_4^+), nitrate (NO_3^-), total Kjeldahl N (TKN), dissolved reactive phosphate (DRP), total P (TP), and natural oxygen-18 (^{18}O) in these waters as well as seepage flows from ground water were analysed periodically. Rainwater was also sampled weekly for O^{18} analyses. Differences in ^{18}O between all water inputs and outputs from the studied wetland indicated that groundwater was the source of base flow events and was a major contributor (66-72%) of water export during the high flow events (>75m^3/day). Over a 6-month period, the wetland was a significant sink for P (26% retained mainly as DRP) and N (54% removed mainly as NO_3^-). However, it was a source of NH_4^+ and particulate N. Their concentrations in the wetland outflows were respectively, 50% and 44% higher, than in the wetland inflows. Nitrate and TN outputs showed a linear increase (r^2 = 0.965-0.971; P < 0.01) with an increase in water flow within the wetland, suggesting an inadequate soil-water contact time for nitrate denitrification at high flow rates (>75 m^3/day). In addition, suspended sediment retained in the wetland under low flow conditions was probably washed out at these high flow rates.

MAIN POINTS

- The studied riparian wetland removed 27% phosphorus (mainly as dissolved phosphate) and 54% nitrogen (mainly as nitrate) from surface runoff and groundwater seepage in a grazed pastoral catchment over a 6-month period.
- The wetland was a source of suspended solids, ammonium and particulate forms of nitrogen.
- Wetland nitrogen removal by denitrification probably decreased at high water flows (75 m^3/day).
- Sediment retained in the wetland under low flow conditions was probably washed out when surface flows exceeded 75 m^3/day.
- Implications of results to the management of riparian wetlands for removing agricultural pollutants will be discussed.

1. INTRODUCTION

Surface runoff and subsurface (ground water) drainage from agricultural land can contribute significant amounts of suspended sediment (SS), nitrogen (N) and phosphorus (P) to receiving waters in New Zealand (The Ministry for the Environment 1997). In this paper, we present preliminary findings that demonstrate the role of riparian wetlands in trapping and removing these agricultural pollutants from surface runoff and ground water drainage from a hill-country sheep-grazed pasture catchment at Whatawhata, near Hamilton.

2. EXPERIMENTAL SITE

The study catchment (3 ha) is located at Whatawhata Research Centre, approximately 30 km west of Hamilton, New Zealand (latitude 37° 48’ S latitude; longitude 175° 5’ E). The basin topography is dominated by a steeply incised gully surrounded by active slump areas. The elevation ranges from 72 to 146 m above sea level, and the slope ranges from flat near the outlet to 60^o on the gully sides. The soil in the catchment is a well-drained brown granular loam of the Naike Clay Series, 1-1.5 m deep, over up to 2 m of weathered bedrock. It has a high clay content (>50% mainly as halloysite), high total porosity (60% by volume) and medium-high macroporosity (10-12% by volume). Catchment pastures are predominantly ryegrass (*Lolium perenne*)-clover (*Trifolium repens*), which has annually received long-term superphosphate applications (200-300 kg/ha/year). Pastures are grazed by sheep throughout the year, with an average stocking rate of 13 stock units per hectare (SU/ha). One SU is equivalent to a ewe (55 kg liveweight at mating) plus one weaned lamb per year. Each SU consumes 550 kg dry matter annually (Metherell and Morrison, 1984).

The natural wetland (62 m^2) located in the gully (Figure 1) intercepts both surface runoff (normally occurring after heavy rainfall events of over 20 mm/day) and groundwater seepage flow from the catchment.

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3. EXPERIMENTAL METHODS

Weekly rainfall, catchment surface runoff to the wetland, ground water seepage and water outflows from the wetland were monitored over 6 months (August 1997-March 1998).

Flows and concentrations of suspended sediment (SS), ammonium (NH_4^+), nitrate (NO_3^-), total Kjeldahl N (TKN), dissolved reactive phosphate (DRP), and total P (TP) in water discharged from the wetland were measured. Seepage flows from ground water were sampled periodically for NH_4^+, NO_3^-, TKN, DRP, and TP.

Particulate P (PP) and particulate N (PN) in water inputs and outputs from the wetland (i.e., surface runoff from catchment, ground water seepage and water outflows from the wetland) were determined as the difference between TP and DRP and between TKN and NH_4^+, respectively. This determination was probably accurate for PP since there was no significant dissolved organic P. However, the PN concentrations would have included some dissolved organic N.

The proportion of surface runoff and ground water which flow through the wetland was determined from the concentration of natural isotopic tracer (^{18}O) in 'new' water (weekly-sampled rainwater and surface runoff from catchment) and 'old' water (ground water seepage and water in the studied wetland prior to a rainfall event).

4. PROPORTIONS OF SURFACE RUNOFF AND GROUND WATER IN THE WETLAND

Table 1 shows the concentration of ^{18}O in 'new' and 'old' water. For low (14-20 mm) rainfall events, 72-100% of ^{18}O in wetland outflows was contributed from the old water (ground water). Surface runoff from the upper catchment accounted for <28% of water outflows from the wetland.

At the 45 mm rainfall event with a high peak runoff (30 L/sec), the old water contribution to the wetland outflows was 46-66%, while surface runoff from the upper catchment accounted for 34-54% of wetland outflows.

For a similar rainfall event (45 mm) but at a low peak runoff (3 L/sec), over 90% of the wetland outflows were contributed from 'old' ground water, which was displaced by infiltrating water within the soil profile. Surface runoff from the upper grazed pastoral catchment accounted for less than 9% of wetland outflows. This probably reflects a higher amount of infiltration and water abstraction to wet the soil as a consequence of lower soil moisture content after a prolonged summer (March 1998), compared with that which occurred after receiving a similar rainfall amount in the previous spring (September 1997).

(**A**)

(**B**)

(**C**)

Figure 1: The studied wetland with a weir to measure water outflows and automatic sampling for water collection (**A**). Wetland vegetation consists mainly of floating sweet grasses (*Glyceria declinata*), with rush (*Juncus effusus*) around the wetland margins and sedge *(Carex geminata*) on the top half of the wetland (**B**). The wetland (**A-B**) receives surface runoff and subsurface drainage from a sheep-grazed pastoral catchment (**C**).

Table 1. ^{18}O concentration in old and new waters measured during four rainfall events

Rainfall (mm)	Peak runoff (L/sec)	^{18}O concentration (‰)			Old water contribution (%)
		Old water	Rain water	Wetland outflows	
20	5	-5.2	-8.2	-6.0	72
45	30	-5.2	-7.1	-5.9-6.2	46-66
12	0.6	-5.2	-0.1	-5.1-5.3	100
45	3	-5.3	-8.8	-5.4	92

5. WETLAND REMOVAL OF NITROGEN AND PHOSPHOROUS FROM THE SHEEP-GRAZED CATCHMENT

Nutrient removal by the wetland is the net balance between nutrient inputs and outputs. Nutrient outputs are calculated from the product of water outflows from the wetland (m^3/day) with concentrations of N and P in these waters. A similar approach was used to calculate input loads of nutrients to the wetland, assuming that the amount of water inputs equates to that of water outflows.

5.1. Total nitrogen and phosphorus

Generally, the TN inputs to the wetland exceeded TN outputs. In contrast, TP inputs were similar to TP outputs over most of the sampling time (Figure 2). Approximately 54% of TN and 26% of TP from wetland inputs were estimated to be retained in the wetland over the 6-month period. This suggests that some N and P forms in input loadings may not be effectively removed by the wetland, particularly under high flow conditions ($\geq 75\ m^3$/day).

5.2. Ammonium, nitrate and dissolved phosphate

Figure 3 shows that the studied wetland is a source of NH_4^+, but is a sink for NO_3^- and DRP. Approximately 51% of NO_3^- entering the wetland over the study period was effectively removed by the wetland. This is attributed to the high nitrate denitrification potential (10-15 mg N/kg soil/hour) in the Whatawhata riparian soils (Nguyen and Downes, 1997a). The export of NH_4^+ from the wetland may be attributed to the relatively low potential for oxidation of NH_4^+ (nitrification) from organic N mineralisation in the studied wetland soil (Nguyen and Downes, 1997a, b). Dissimilatory reduction of NO_3^- to NH_4^+ may also occur within the wetland soil (Schipper et al. 1994). This would be expected to lead to the high accumulation of NH_4^+ in the wetland, which may be washed out off the wetland under high flow events.

Similar to NO_3^-, 43% of DRP inputs to the wetland was not accounted for in wetland outflows over the 6-month period. This may be a result of P retention and microbial immobilisation in the wetland (Nguyen and Downes, 1997a, b).

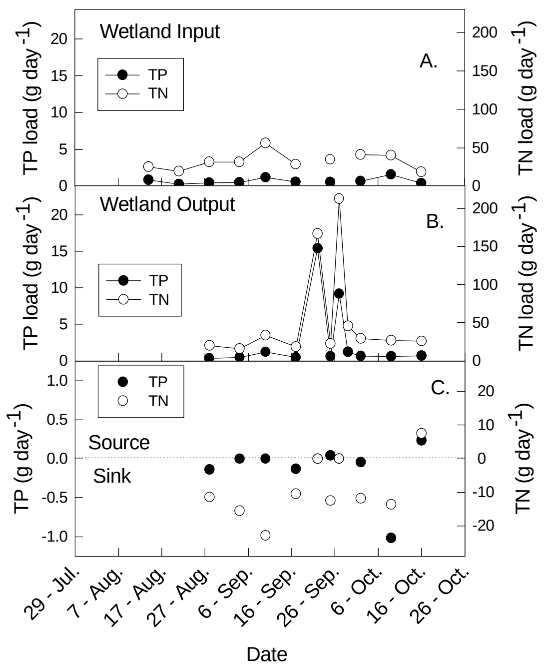

Figure 2: Daily amounts of total nitrogen (TN) and total phosphorus (TP) inputs (**A**) to and outputs (**B**) from the wetland and the net balance (**C**) between inputs and outputs.

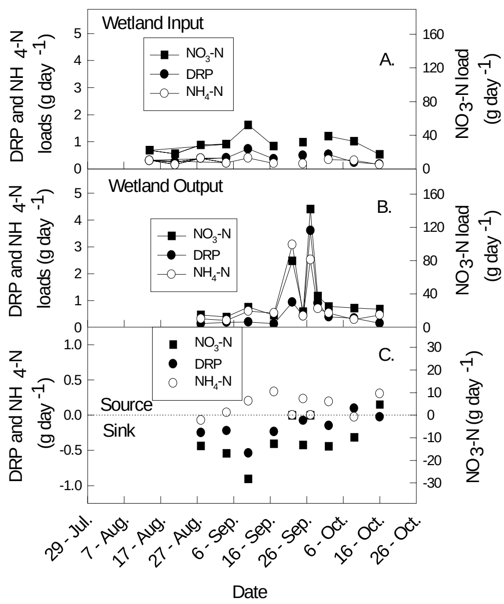

Figure 3: Daily amounts of nitrate (NO_3^-), dissolved reactive phosphate (DRP) and ammonium (NH_4^+) inputs (**A**) to and outputs (**B**) from the wetland and the net balance (**C**) between inputs and outputs.

5.3. Particulate nitrogen and particulate phosphorus

PN and PP data are not shown here. Over the 6 month-period, approximately 44% of PN inputs to the wetland was released to the receiving stream. This suggests that the wetland was a significant source of PN in water outflows.

The wetland was also inefficient at trapping PP, since only 1.2% of PP inputs was retained within the wetland. The sedimentation and deposition of PN and PP (bound to sediment and organic matter) is probably ineffective in this small and narrow (62 m^2) wetland. The resuspension of fine particulates and organic N and P fractions originating from the death and decay of wetland plants may also be a contributing source of PN and PP in wetland outflows (Uusi-Kampala et al. 1997).

6. SEDIMENT REMOVAL BY THE WETLAND

The wetland was the source of SS during the period between 6 September-6 October, when wetland outflows often exceeded 75 m^3/day (Figure 4). This indicates that the velocity of water flow within the wetland during this period is likely to cause a wash-out of fine SS and particulate organic matter which have accumulated in the wetland.

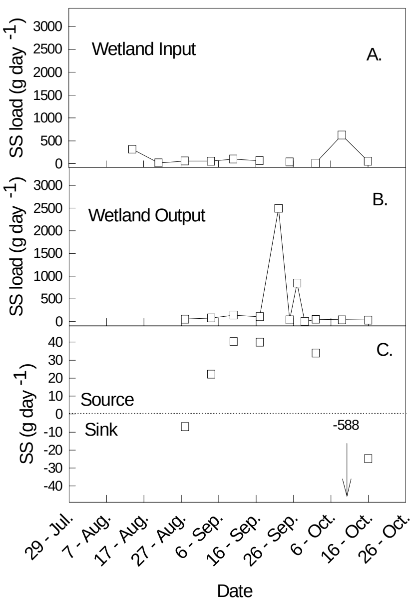

Figure 4: Daily amounts of suspended sediment inputs (**A**) to and outputs (**B**) from the wetland and the net balance (**C**) between inputs and outputs.

7. GENERAL DISCUSSION AND CONCLUSIONS

The studied wetland was a significant sink for P and N (mainly as DRP and NO_3^-). However, it was not effective at trapping particulate P and was a significant source of NH_4^+ and particulate N. To enhance the trapping of these pollutants, additional buffer zones in the upper catchment to intercept both water and particulate runoff may be necessary.

In catchments where runoff of NH_4^+, particulate N and particulate P is a predominant feature, the use of wetlands as a trapping function may be limited unless catchment and riparian wetland management practices that promote water infiltration within the catchments and reduce water flows within riparian wetlands are adopted. These practices may include grazing management strategies which avoid or minimise animal treading damage in the runoff-sensitive areas of the catchment, particularly during the winter months (Nguyen et al. 1998) and the maintenance of a riparian corridor around the wetlands to intercept water runoff and to maintain sheet flows (Nguyen and Downes, 1997b). Research is required to evaluate the effect of these practices on nutrient and sediment removal efficiencies in riparian wetlands.

Some of the practices outlined above may also be beneficial for NO_3^- and DRP removal, since they reduce the water flow rate through the wetland and enhance the contact time between NO_3^-/DRP-containing water and the wetland soil for optimum denitrification (Hill 1996) and phosphate retention (Nguyen and Downes, 1997a; Nguyen et al., 1997). The importance of contact time and flow rate is further demonstrated by the fact wetland outputs of DRP, NO_3^- and TN showed a linear increase with an increase in wetland water flow rate (r^2 of 0.802, 0.965 and 0.971, respectively; $P < 0.01$) over a 6 month period.

In order to provide farmers, land users and resource managers with information that can be used to design and manage riparian wetlands to minimise SS, N and P inputs to receiving waters, further research is required to investigate the interactions between water flow and pollutant removal processes within riparian wetlands and the long-term sustainability of these wetlands in mitigating agricultural pollutants.

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