Water Quality of a stream recently fenced-off from deer

Report prepared for DEEResearch

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1. Abstract

Water quality monitoring was conducted on a tributary of the Dow Stream on the AgResearch Invermay deer farm near Mosgiel. The aim was to see if fencing-off an area of the stream channel with a known contaminant source (a wallow) and riparian planting improved water quality as measured by the fortnightly concentrations and annual loads of nitrogen (NH_4^+-N, NO_3^--N), phosphorus (P; dissolved reactive P, particulate P and total P) species, suspended sediment (SS) and the faecal indicator bacteria, *Escherichia coli* (*E. coli*). Measurements were taken two years before and after fencing-off and riparian planting. Analysis of the data indicated that a significant improvement occurred in the mean concentrations of NO_3^--N, NH_4^+-N, SS and TP after fencing-off and planting compared to those beforehand. As a result, loads of these constituents decreased by 44 to 97%. Mean concentrations of *E. coli* and DRP showed no significant difference with fencing-off and planting. Mitigation effects were attributed (i) to the setting-out of SS and associated NH_4^+-N and PP in an area formerly used by deer for wallowing and (ii) the absence of direct excretal input by deer. Hence, fencing-off and riparian planting is recommended for areas where known sources of contaminant loss occur (e.g., wallows or degraded areas of a stream channel). However, this must be balanced with the cost of fencing and potential loss of land from production and the suitability of the stream, or area, for fencing. For instance, the potential mitigation performance of fencing-off and planting is likely to be poorer in areas without large contaminant sources or already good water quality.

Keywords *E. coli*; nitrogen; phosphorus; sediment; riparian; wallow

2. Introduction

It is well established that when deer have access to a waterway water quality can decline. For instance, McDowell (2007) examined concentrations and loads of the contaminants nitrogen (N) and phosphorus (P) fractions, faecal indicator bacteria (*Escherichia coli*) and sediment in headwater catchments with wallows. This work showed that concentrations were often well in excess of the ANZECC (2000) guidelines for water quality in disturbed (i.e. farmed) lowland streams. Furthermore, P loads, sediment and *E. coli* were close to or exceeded the greatest loads thus far measured for New Zealand catchments in pastoral agriculture. However, the presence of deer and wallowing accounted for the majority of contaminants (about 60% of N, 80% of P, 60% of *E. coli* and up to 90% of sediment) found in the draining streams. Other studies have also found a significant increase in concentrations of *E. coli* and sediment immediately downstream of deer farms and deer farmed areas with a proportion of the stream unfenced (de Klein et al. 2002; Environment Southland and Otago Regional Council, McDowell et al. 2006a; unpublished data). Consequently, it is obvious that by fencing-off access to a waterway water quality would improve. Indeed, fencing-off streams from dairy cattle in the Cannonsville watershed in New York State caused a 32% decrease of in-stream P loads (James et al. 2007).

In addition to fencing-off streams, in many instances regional councils and territorial authorities charged with environmental stewardship encourage planting stream banks to improve shade and shelter. This decreases summer water temperature and may also retain some sediment and sediment-associated P and N. However, the effectiveness of riparian areas and buffer strips to act as a filter of sediment and nutrients, especially in dissolved form, is questioned (Verstraeten et al. 2006).

Despite anecdotal evidence that fencing-off streams from deer is beneficial for water quality, little data exists. Obviously, it is important to establish if fencing-off a waterway from deer improves water quality before many farmers would consider undertaking this (Payne & White 2006). Consequently, the opportunity was taken to conduct a study on a small stream that had been earmarked for fencing due to the presence of an unsightly, and probably polluting, wallow. The objective of this study was to determine if mean concentrations and loads of contaminants were different two years before and after fencing-off and riparian planting.

3. Materials and methods

3.1 Site and sampling

The AgResearch Invermay deer farm near Mosgiel, Otago, New Zealand covers about 160 ha split amongst 90 paddocks of rolling to steep hill country at an altitude of 150 to 300 m. The farm has been running deer since 1972, but about half of the paddocks have only been farmed with deer since 1991. Mean annual rainfall is 687mm that falls, on average, over 153 days of the year. Currently about 1200 deer are farmed with a pasture (mixed ryegrass - *Lolium perenne* L and white clover - *Trifolium ripens* L.) rotation of 21-56 days, depending on the time of year. The predominant soil type is a Warepa silt loam (mottled fragic Pallic soil) with outcrops of Cargill hill soils (acidic mafic Brown soil) at higher elevations.

The study catchment covered approximately 4.1 ha, separated into 4 paddocks on the Invermay deer farm (Figure 1). It was a tributary of the Dow stream and in-turn a tributary of the Silver stream. Slope in the study catchment ranged from 5% near the outlet and at high elevations to 15% at mid slope. The catchment received about 25 kg P ha^{-1} as superphosphate in early summer to maintain soil Olsen P concentration at 20-25 mg kg^{-1}. Applications of superphosphate during summer in this region usually contribute only a small amount (0.1 kg P ha^{-1} y^{-1}) to P losses (McDowell & Catto 2005). Additional applications of lime were made in early summer when soil tests indicated pH had dropped below 5.8.

The largest paddock was downslope and contained a second-order stream constantly fed by two seeps (i.e. first order waterways) that drained 50 and 100 m upslope (Figure 1). The stream also contained a wallowing area (approximately 30 m^2 and 1 m deep) about 50 m from the outlet. At the outlet, flow was channelled through a culvert (Flume in Figure 1), which had a stilling-well and level recorder installed to monitor flow rates every 30 minutes. Flow within the stream channel was characterised by low base flow of < 0.2 litre s^{-1} and periodic storm events up to 30 litre s^{-1}.

Beginning at the start of March 2003, grab samples (1 litre) of water were taken on a fortnightly basis at the outlet. These were supplemented by samples taken during flood events when flow reached > 1.5 litre s^{-1}. In late autumn 2005, approximately 100 m of deer proof fencing was installed around the wallow and stream channel, removing about 300 m^2 from deer access. Over a period of two weeks the wallowing area was planted in a combination of 200 Red Tussock (*Chinochloa rubra* sp.) and 100 Swamp Sedge

(Carex virgata sp.) in and near the wallowing area and stream channel, and 100 Manuka (Leptospermum scoparium sp.), 50 Totara (*Podocarpus totara* sp.) and 50 Wineberry (*Aristotelia serrata* sp.) on the mid- and high-banks.

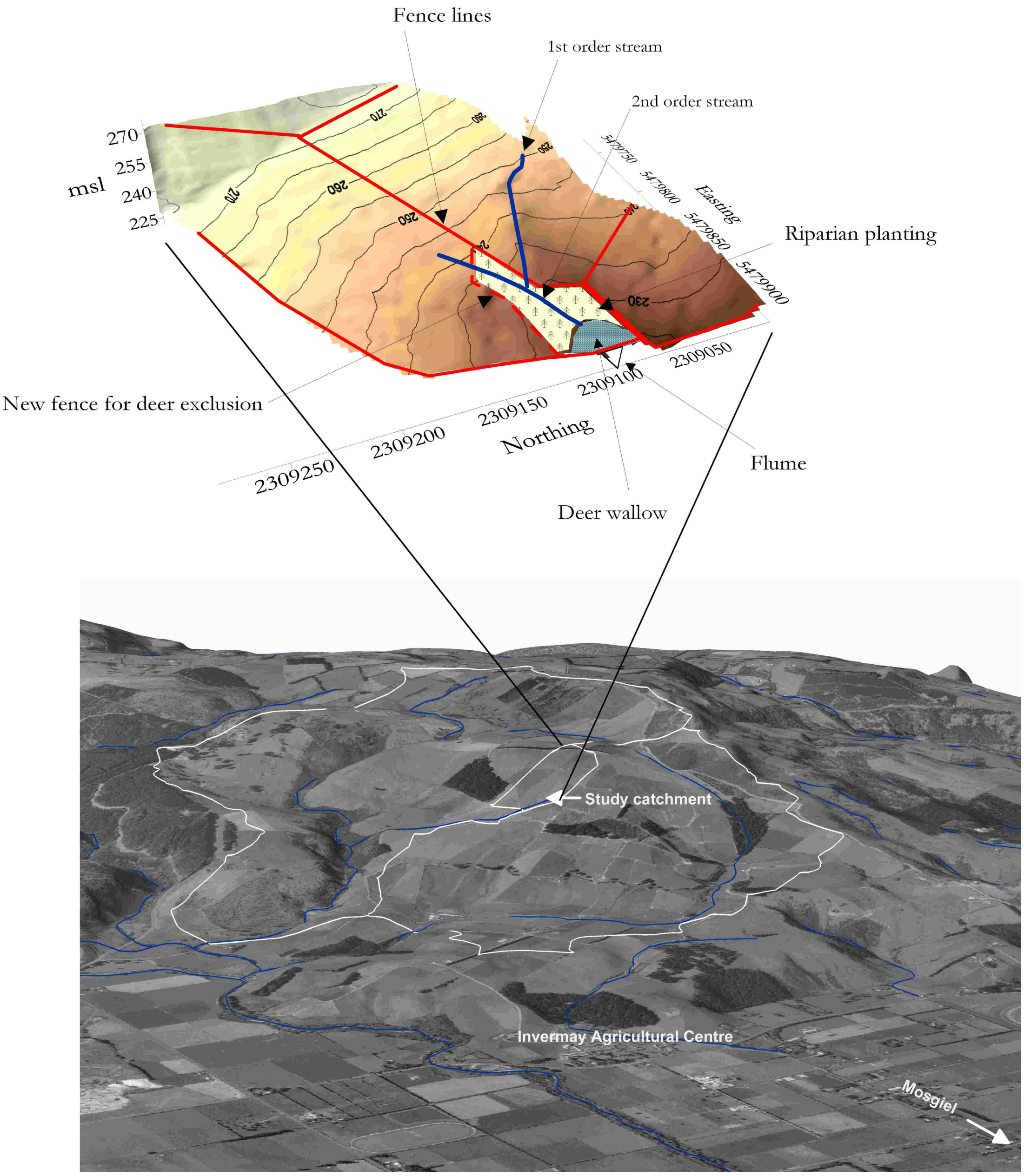

Figure 1. Location and topographical data of the study site within the Invermay catchments.

4. Analysis

Water samples were analyzed for dissolved (filtered through a 0.45 µm membrane) reactive P (DRP) within 24 hours and total dissolved reactive P (TDP) after Kjeldahl digestion (Eisenreich et al. 1975) within 48 hours. An unfiltered sample was also digested and total P (TP) measured within 7 days. Particulate P (PP) was determined as the difference between TP less TDP. All P analyses used the colorimetric technique of Watanabe & Olsen (1965). Suspended sediment (SS) was determined by weighing the residue left after filtration through a Whatman GF/F glass fibre filter paper of a shaken 250 mL sub-sample. *Escherichia coli* was measured as the preferred faecal indicator bacteria for freshwater in New Zealand (Ministry for the Environment 2003). Live *E. coli* were counted as coliform forming units (cfu) in 100 mL samples of flow using the Colilert® media and the Quanti-Tray® enumeration system (IDEXX Laboratories, Maine, USA). Nitrogen fractions, ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N) were made using standard auto-analyzer techniques.

Annual loads on a kg (or cfu) ha^{-1} basis of N and P fractions, SS, and *E. coli* were calculated via interpolation of measurements taken during base flow and flood events (Robertson & Roerish 1999).

Data was split into two sets either side of planting. An unpaired comparison of means was done with a simple *t*-test after first confirming that the data was normally distributed via a Shalipro-Wilk test. Data for *E. coli* and SS required $\log_{10}$ transformation before analysis. In order to better account for variation due to climate, concentration data for each constituent was plotted against flow for both before and after data sets. Where significant relationships ($P < 0.05$) were obtained, an F-test was used to determine if the slope of the two regression equations were significantly different from one another (Striffler 1965). This was possible for SS, TP and NH_4^+-N, but not for other constituents, whose comparison of means must be interpreted with caution.

5. Results and discussion

Summary statistics of some measured constituents are given in Figure 2. Using a *t*-test significant differences were noted between mean concentrations of SS, PP, TP, NH_4^+-N and NO_3^--N before and after planting. For all constituents except NO_3^--N these differences were supported by significant differences in the slopes of paired regression equations comparing concentrations and flow before and after planting; thereby removing most of the variation due to climate. Other sources of possible variation such as grazing and fertiliser management were thought to be minimal as neither changed during the study.

Much of the climatic variation is due to different rainfall and flow patterns. Rainfall in the 2004, 2005, 2006 and 2007 years (measured from September the previous year to August) was 610, 685, 719 and 530 mm, respectively. Although many of the constituents measured generally exhibit a relationship with flow (e.g., Webb & Walling 1985; Galeone 1999), this does not guarantee that enriched concentration of, for example, P could occur at low flow. By establishing that a relationship with flow did exist both before and after planting, variation with flow regime could be accounted for.

Figure 2 shows median concentrations of *E. coli*, SS and TP before planting were well in excess of guidelines (given as dashed lines in each graph) for lowland streams in disturbed ecosystems (i.e. agricultural; ANZECC 2000). After planting, both SS and TP were within recommended guidelines, whereas DRP had increased to beyond its guideline concentration (0.009 mg $litre^{-1}$). Loads of *E. coli*, SS and NH_4^+-N were either near or in-excess of the maximum load measured to date in deer farmed catchments (Table 1). The same could be said compared with other pastoral land uses for SS and NH_4^+-N: too few data exist for *E. coli.* However, after planting, all constituents were within the range of loads measured for deer and other land uses (Table 1).

Table 1: Loads of potential contaminants in the two years before (2004 and 2005) and after fencing off and planting along with the range of loads for deer catchments and other catchments in pastoral agriculture (all kg ha^{-1} except *E. coli*, which is presented in coliform forming units ha^{-1})

Constituent	2004	2005	2006	2007[A]	Mean % decrease after fencing-off and planting	Deer catchments only[B]	All other pastoral catchments in New Zealand[C]
E. coli	6.0×10^{11}	3.4×10^{11}	2.2×10^{10}	7.4×10^{10}	90	6.9×10^{8} - 3.4×10^{11}	-
SS	2230	4482	100	67	97	20-4480	20-2000
DRP	0.10	0.30	0.02	0.06	80	0.01-0.04	0.010-0.300
PP	0.98	0.96	0.21	0.31	73	0.19-2.99	-
TP	1.18	1.87	0.27	0.13	87	0.21-3.00	0.10-5.20
NH_4^+-N	1.30	1.40	0.10	0.05	44	0.30-1.03	0.03-1.10
NO_3^--N	1.90	2.76	0.73	0.95	64	0.12-22.0	0.5-29.0

[A] Load for 2007 based on 10 months and extrapolated to a 12 month period using median flow rates and concentrations.

[B] Taken from McDowell (2007), McDowell & Paton (2004), McDowell & Stevens (2006) and McDowell et al. (2006a).

[C] Taken from Cooper & Thomsen (1988), Quinn & Stroud (2002), Wilcock (1986), Wilcock et al. (1999), Wilcock et al. (2007) and Vant (2001).

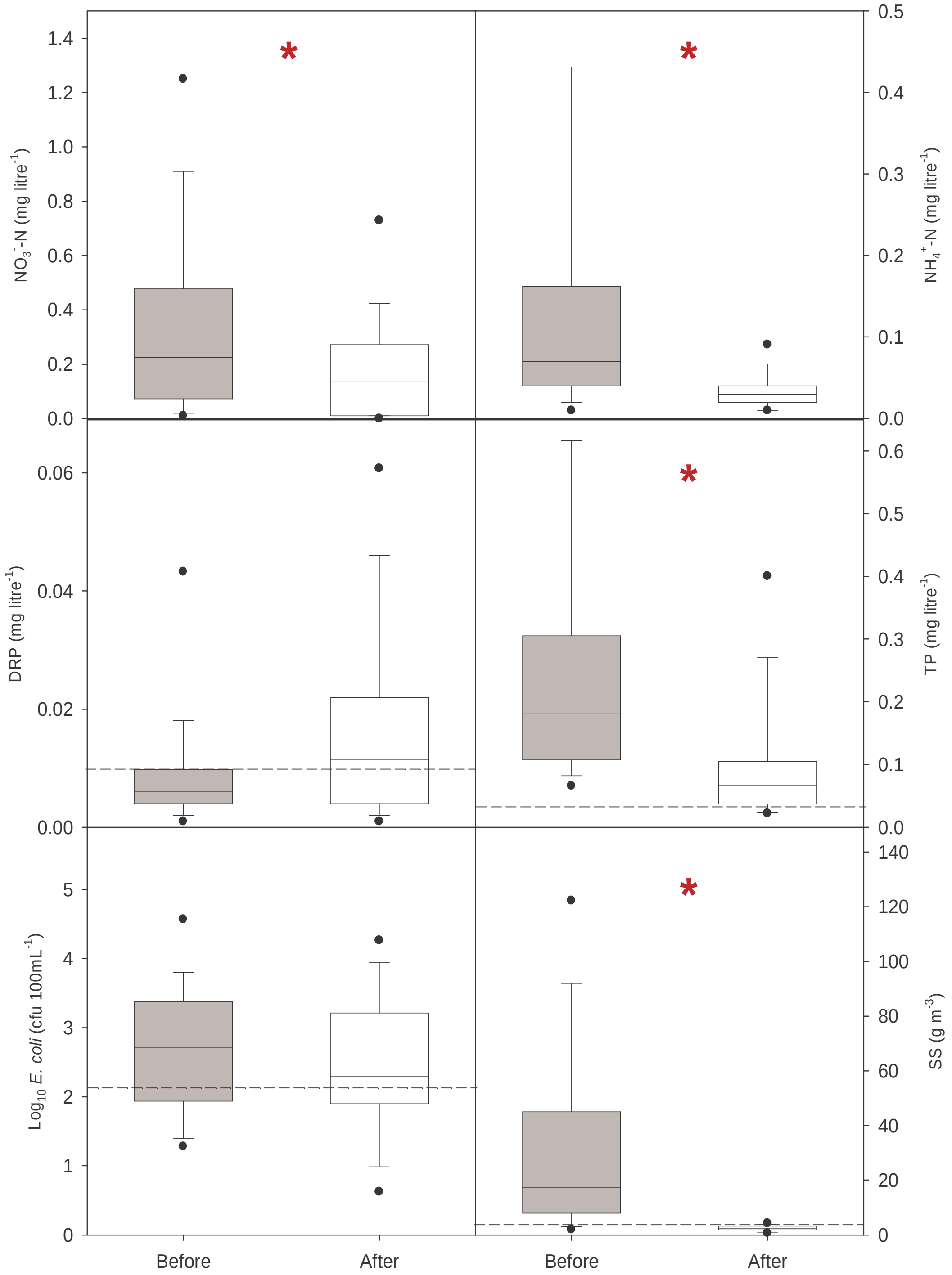

Figure 2. Box and plots whisker plots of *E. coli*, SS, DRP, TP, NH_4^+-N, and NO_3^--N before and after the stream and wallow were fenced-off and planted. Upper and lower boundaries are the 25th and 75th percentiles, the line within the box is the median, the whiskers are the 10th and 90th percentile, and the circles the 5th and 95th percentiles. The dashed lines are the respective guideline for lowland water quality in disturbed ecosystems (ANZECC 2000). Asterisks indicate significant difference between mean concentration before and after fencing and riparian planting. Note, guideline for NH_4^+-N (0.9 mg L^{-1} at pH 8.0) is in-excess of maximum concentration measured.

Enriched concentrations and loads in water before planting were probably associated with direct excretal deposits, runoff and the presence of a wallowing area not far from the catchment outlet (Figure 1). In a study of water quality in headwater catchments with deer wallows, McDowell (2007) found that loads and concentrations of N and P species, SS and *E. coli* were largely (60-90%) associated with deer wallowing even though deer were only present in the catchment for half the year. When wallowing, deer deposit excreta enriched with N, P, *E. coli* and, to a lesser extent, SS. Add to this the N, P and SS stirred up from the bed of the wallow and it is of no surprise that loads were at the upper end of the range measured for pastoral catchments.

As a result, the recommendation by McDowell (2007) was to fence-off wallowing areas from deer, and also to provide an area where deer could wallow that wasn't connected to the stream. If a new wallowing area was not created it was hypothesized that deer would create a new wallow just beyond the fence.

At the start of this trial this effect was unknown, but a survey of pasture cover at the end of the trial (A. Rutherford *personal communication*) indicated that bare spots were already being created immediately upslope of the fenced-off area. It will be interesting to see in the coming years if this negates the remedial effort undertaken.

Apart from wallowing, another likely source of potential contaminants will be runoff, both surface runoff (overland flow) and sub-surface flow (associated with leaching and interflow). The contaminants most affected by surface runoff are P species, SS and NH_4^+-N due to their sorption in topsoil or dislodging due to treading damage and denuded pasture. McDowell et al. (2004; 2006b) have noted that enhanced losses of these species occur due to deer traffic associated with fence-line pacing. As a result of compaction, decreased infiltration rates and little pasture to maintain soil integrity, fence-line pacing has been suggested as a major source of contaminant loss (New Zealand Deer Farmers' Association 2004). While the study catchment had about a dozen fence-lines, some of which intersected the streams, it was not possible to tell how much fence-line pacing contributed to contaminant loss.

Data suggests that fencing-off the stream and planting did decrease the concentration and load of some contaminants. While separating the effects of fencing-off the wallow and planting is not possible, it would be uncommon for a wallow area not to be planted if fenced-off. Compared to unfenced areas, areas that are fenced-off from deer will always decrease contaminant loss by preventing channel and bank disturbance and excretal returns. In terms of mitigating contaminant loss, it is a common belief that riparian areas and buffer strips would mitigate contaminant loss further by filtering out particulate material and sorbed NH_4^+-N and P in surface runoff (i.e. particulate P). However, Verstraeten et al. (2006) summarized their performance and concluded that they're often bypassed by flow that has converged and either goes straight through or over them. One such incidence would be for fence-lines, which would act as a channel for flow, and a direct influencer of water quality if intersecting a stream channel. In contrast, the wallowing area planted in Red Tussock and Swamp Sedge would have acted as a setting basin with the plants buffering high flow events and allowing SS and sorbed NH_4^+-N and P to settle out. It will also enhance stream biodiversity and help regulate stream temperature. However, this area, like many buffer strips and riparian areas, will have a finite lifespan and can eventually silt up, no longer being a sink for sediment and P (Reddy et al. 1999). This will depend on sediment delivery rates and topography.

In contrast to SS and TP, *E. coli* losses showed no significant decrease in concentration after fencing-off and riparian planting: loads did decrease due to less flow. Recent work by Muirhead et al. (2006) has shown that most *E. coli* are not retained by grass swards and hence any surface runoff reaching the stream from areas outside the fenced-off area would carry within it a similar load of *E. coli* as if no buffer or riparian area existed. Furthermore, McDowell & Stevens (2006) established that there was a considerable reservoir of *E. coli* contained within wallow sediments that would be mobilized in storm events.

Compared to surface runoff losses, sub-surface losses are largely restricted to either mobile constituents such as NO_3^--N, or some macropore losses of *E. coli* and sorbed species like P or NH_4^+-N. Much more NO_3^--N is lost via sub-surface flow than surface runoff, provided a conduit exists between subsurface flow and the hyporheic zone and thereby stream flow (Pionke et al. 1988). In the study catchment, sub-surface flow is largely restricted to the A-horizon since sub-soil is poorly drained (saturated hydraulic conductivity is < 1mm h^{-1}: J. Paton, *personal communication*). Since NO_3^--N decreased after planting, this would suggest that NO_3^--N was being retained by the plant biomass. However, it should be reiterated that this decrease was unable to be supported by additional statistical analysis and that the median NO_3^--N concentration before and after planting already met ANZECC (2000) guidelines.

After fencing-off and planting, DRP concentrations did not change (Figure 2). This is common for riparian areas and buffer strips since DRP is neither trapped nor settles out. However, this does suggest that much of this P is associated with natural release from sediments and not excretal returns since direct deposits were mitigated by fencing. It will be interesting to see if DRP increases via reducing (anoxic) conditions as silt fills the wallowing area (Cooke 1992). However, anoxic conditions will also aid in the removal of N from surface water via denitrification (Clough et al. 2006).

As a mitigation strategy, the data suggest that fencing-off and planting was beneficial for water quality. However, this has to be balanced with the cost of fencing and planting and the potential loss of production from some land, albeit mostly used as a wallow. Currently deer fencing costs around \$20 m^{-1} (including parts and labour) and about \$1500 was spent on planting, giving a total of \$3500. Hence, it cost between 36 and 88 dollars per percentage decrease in loads of contaminants (Table 2). Cost kg or cfu mitigated (i.e. load), costs varied from \$ <1 to \$25000. Furthermore, the cost per hectare to meet the ANZECC (2000) guidelines ranged from about 750 to 1200 \$ ha^{-1}. While some of these figures may look expensive, this has to be put into context. The catchment was small (4.1 ha) and it is likely that larger catchment areas contributing to the fenced-off and planted area would make the mitigation strategy more cost efficient. Additional but unpublished data (M. Srinivasan, *personal communication*), suggest that the fenced-off area contributes most of the P and sediment lost from a larger catchment area (Figure 1) hence the effectiveness of this mitigation strategy on a per hectare basis is good. However, it should be noted that the effectiveness of fencing-off an area and planting will vary. It is likely that the study site represented an area where this mitigation strategy would have had the best possible effect, i.e. a stream on sloping land with an established deer wallow. Flatter land with different climatic patterns and without known wallowing areas may not respond so well.

Table 2. Cost (\$) per cfu or kg mitigated due to fencing and riparian planting and the cost per hectare to meet ANZECC (2000) guideline concentrations.

Constituent	\$ per cfu or kg ha^{-1} mitigated	\$/ha to meet guideline concentration [A]
E. coli	<1	748
SS	<1	923
DRP	25000	- [B]
PP	5000	-
TP	2600	1211
NH_4^+-N	2750	-
NO_3^--N	2350	-

[A] assumes a pro-rata cost proportional to difference before and after fencing-off and planting (i.e. median TP before and after = 0.155 and 0.069 mg L^{-1} respectively, but guideline is 0.033 mg L^{-1} meaning that an additional decrease of 42% is required - \$3500 × 1.42 = \$4965/4.1ha = \$1211/ha.

[B] median concentration before fencing-off and planting already less than ANZECC (2000) guideline.

6. Conclusions

Water quality data indicated that riparian planting and fencing-off a stream from deer access caused significant decreases in the mean concentrations of NO_3^--N, NH_4^+-N, SS, PP and TP. This also translated into decreases in the loads of these constituents, varying from 44 to 97%. Mean concentrations of both *E. coli* and DRP showed no significant difference with fencing-off and planting. Median concentrations of SS and TP before fencing-off and planting did not met with ANZECC (2000) guidelines, but did after fencing-off and planting. Mitigation effects were attributed to a combination of SS and associated NH_4^+-N and PP settling out in the former wallowing area and the prevention of direct excretal input by deer. The use of fencing-off and planting mitigated a major proportion of P and SS lost from the study catchment and hence is recommended as a strategy for areas where known sources of contaminant loss occur (e.g. wallows or degraded areas of a stream channel). This has to be balanced with economic considerations and the suitability of the stream or area for fencing, i.e. the effectiveness of fencing-off and planting is likely to be less in areas without large sources of contaminants or if stream water quality is already good.

7. Acknowledgements

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8. References

ANZECC 2000: Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volumes 1 and 2. Canberrra, ACT, Australia. Australian and New Zealand Environment and Conservation Council.

Clough, T. J.; Bertram, J.; Sherlock, R. R.; Lenoard, R. L.; Nowick, B. L. 2006: Comparison of measured and EF5-r-derived N_2O fluxes from a spring-fed river. Global Change Biology 12: 352-363.

Cooke, J. G. 1992: Phosphorus removal processes in a wetland after a decade of receiving sewage effluent. Journal of Environmental Quality 21: 726-732.

Cooper, A. B.; Thomsen, C. E. 1988. Nitrogen and phosphorus in streamwaters from adjacent pasture, pine, and native forest catchments. *New Zealand Journal of Marine and Freshwater Research 22*: 279-291.

de Klein, C. A. M.; Drewry, J. J.; Nagels, J. W.; Scarsbrook, M.; Collins, R.; McDowell, R. W.; Muirhead, R. 2002: Environmental impacts of intensive deer farming in New Zealand – a review. The Nutrition and Management of Deer on Grazing Systems. New Zealand Grassland Association, Wellington, 79-88.

Eisenreich, S. J.; Bannerman, R. T.; Armstrong, D. E. 1975: A simplified phosphorus analysis technique. *Environmental Letters 9*: 43-53.

Galeone, D. G. 1999: Calibration of paired basins prior to streambank fencing of pasture land. Journal of Environmental Quality 28: 1853-1863.

Hicks, M.; Quinn, J.; Trustrum, N. 2004: Stream sediment load and organic matter. In Harding, J.; Mosley, P.; Pearson, C.; Sorrell, B. Freshwaters of New Zealand. New Zealnad Hydrological Society and New Zealand Limnological Society, Christchurch, New Zealand. Pp. 12.1-12.16.

James, E.; Kleinman, P.; Stedman, R.; Sharpley, A. 2007: Phosphorus contributions from pastured dairy cattle to streams of the Cannonsville Watershed, New York. *Journal of Soil and Water Conservation 62*: 40-47.

McDowell, R. W. 2007: Water quality in headwater catchments with deer wallows. *Journal of Environmental Quality 3X*: In press.

McDowell, R. W.; Catto, W. 2005: Alternative fertilizers to prevent incidental phosphorus loss. *Environmental Chemistry Letters 2*: 169-174.

McDowell, R. W.; Drewry, J. J.; Paton, R. J. 2004: Effects of deer grazing and fence-line pacing on water and soil quality. Soil Use and Management 20: 302-307.

McDowell, R. W.; McGrouther, N.; Morgan, G.; Srinivasan, M. S.; Stevens, D.; Johnson, M.; Copland, R. 2006a: Monitoring of the impact of farm practices on water quality in the Otago and Southland deer focus farms. Proceedings of the New Zealand Grasslands Association 68: 183-188.

McDowell, R. W.; Steves, D. R.; Cave, V.; Paton, R. J.; Johnson, M. 2006b: Effects of shelter belts on fence-line pacing of deer and associated impacts on water and soil quality. Soil Use and Management 22: 158-164.

McDowell, R. W.; Paton, R. J. 2004: Water and soil quality in an Otago deer farm. Proceedings of the New Zealand Grasslands Association 66: 187-193.

McDowell, R. W.; Stevens, D. R. 2006. Experiments examining soil and water quality in a New Zealand deer farm. pp. 235-257. In: focus on environmental research. Ed. Davis, E. B. Nova Science Publishers, Hauppauge, New York.

Muirhead, R. W.; Collins, R. P.; Bremer, P. J. 2006: The interaction of *Escherichia coli* and soil particles in runoff. *Applied and Environmental Microbiology* 72: 3406-3411.

Ministry for the Environment. 2003: Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Wellington, Ministry for the Environment. (www.mfe.govt.nz/publication/water/microbiological-quality-jun03), accessed June 2006.

New Zealand Deer Farmers' Association 2004. The New Zealand Deer Farmers' Landcare Manual. New Zealand Deer Farmers' Association and Deer Industry New Zealand, Wellington, New Zealand.

Payne, T.; White, T.; 2006: Understanding deer farmer's level of environmental awareness. A report prepared for the Ministry and Agriculture and Forestry's Sustainable Farming Fund, AgResearch – Ruakura Research Centre, Hamilton. 24 p.

Pionke, H. B.; Hoover, J. R.; Schnabel, R. R.; Gburek, W. J.; Urban, J. B.; Rogowski, A. S. 1988: Chemical-hydrologic interactions in the near-stream zone. Water resources Research 24: 1101-1110.

Quinn, J. M.; Stroud, M. J. 2002. Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research 36*: 409-429.

Reddy, K. R.; Kadlec, R. H.; Flaig, E.; Gale, P. M. 1999: Phosphorus retention in streams and wetlands: a review. Critical Reviews in Environmental Science and Technology 29: 83-146.

Robertson, D. M.; Roerish, E. D. 1999: Influence of various water quality sampling strategies on load estimates for small streams. *Water Resources Research 35*: 3747-3759.

Striffler, W. D. 1965: The selection of experimental watersheds and methods in disturbed forest areas. Publication number 66, I.A.S.H. Symposium of Budapest. Pp. 464-473.

Vant, W. N. 2001. New challenges for the management of plant nutrients and pathogens in the Waikato River, New Zealand. *Water Science and Technology 43*: 137-144.

Verstraeten V, Poesen J, Gillijns K, Govers G 2006. The use of riparian vegetated filter strips to reduce river sediment loads: an overestimated control measure? Hydrological Processes: 20, 4259-4267.

Watanabe, F. S.; Olsen, S. R. 1965: Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Soil Science Society of America Proceedings 29*: 677-678.

Webb, B. W.; Walling, D. E. 1985: Nitrate behaviour in streamflow from a grassland catchment in Devon, UK. Water Research 8: 1005-1016.

Wilcock, R. J. 1986. Agricultural runoff: a source of water pollution in New Zealand? *New Zealand Agricultural Science 20*: 98-103.

Wilcock RJ, Monaghan RM, Thorrold BS, Meredith AS, Betteridge K, Duncan MJ 2007. Land-water interactions in five contrasting dairying catchments: issues and solutions. Land Use and Water Resources Research, www.luwrr.com 7: 2.1 - 2.10.

Wilcock, R. J.; Nagels, J. W.; Rhodda, H. J. E.; O'Connor, M. B.; Thorrold, B. S.; Barnett, J. W. 1999. Water quality of a lowland stream in a New Zealand dairy farming catchment. *New Zealand Journal of Marine and Freshwater Research 33*: 683-696.