Monitoring the impact of farm practices on water quality in the Otago and Southland deer focus farms

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Abstract

Research on the soil and water quality of deer farms is minimal. However, the perception is that many deer operations may be detrimental to soil and water quality. To address this problem two deer focus farms (DFF, 1 each in Otago and Southland) were established to showcase how productivity and environmental objectives can coincide. Managements implemented by the farmers included a sedimentation pond, fencing off waterways and retiring land under a QEII covenant. A detailed soil and water quality testing regime occurred for each farm: data were collected at the Southland DFF for three tributaries (one fenced off, one partially fenced and one unfenced) which fed into a stream and through a tussock covered area retired from grazing. Water quality in the unfenced and partially fenced tributaries was poor with no water quality parameters meeting ANZECC guidelines, whereas water quality in the fenced-off and planted tributary was better. Water exiting the retired area met ANZECC guidelines. Although water quality on parts of both deer farms did not meet ANZECC guidelines, when management practices such as fencing off and the creation of a pond were used water quality improved. More importantly, an area retired from grazing and further development on the Southland DFF showed that water quality could be significantly improved and could be better than that entering the farm.

Keywords: fencing-off, QEII covenant, sedimentation pond, water quality

Introduction

Sustainable deer farming in New Zealand requires profitable and well producing farms with minimal impact on the environment. Past studies have suggested that natural behaviour by deer such as fence-line pacing and wallowing can cause significant erosion and input of nutrients, sediment and faecal bacteria into waterways (e.g. McDowell & Stevens 2006; Eyles *et al*. 2002). With this in mind, two deer focus farms (DFF) were established to identify, trial and showcase best management practices (BMPs). In addition to benchmarking and improving production, environmental objectives were also included to improve our knowledge of the impact of deer on the environment. These objectives included determining the effect of BMPs on soil and water quality, and investigating alternative management strategies to accommodate deer behaviour on-farm. At present, each DFF has strategies to minimise the impact of deer on soil and water quality. These include the establishment of a sedimentation pond, fencing off the waterway and wallowing areas and planting the riparian area to prevent fence-line pacing, and the establishment of an area of land under a covenant. The covenant protects the landform and vegetation in perpetuity, stock access is no longer allowed nor is further development of the land. This paper examines the effect of these strategies on soil and water quality in each DFF.

Materials and Methods

Site description

Each deer focus farm (Fig. 1) formed part of a larger catchment. The Otago DFF (Glenomaru, about 20 km south of Balclutha) was contained within a 190 ha catchment, of which about 100 ha was deer farmed, 15 ha in scrub and the remainder, at the headwaters, occupied by sheep and beef. The Southland DFF (Waimea, about 10 km east of Lumsden) occupied about half of a 290 ha catchment with the remainder forming part of a sheep and beef farm. Annual rainfall was about 1100 mm at the Glenomaru DFF and 850 mm at the Waimea DFF. Soils in both catchments were dominated by Brown silt loams (Owaka at Glenomaru and Wendon at Waimea). About 250 soil samples were taken (0-75 mm) from each catchment on a 50 m grid in October and analysed for Olsen P, pH, sulphate-S, and MAF Quicktest K. Water quality was monitored at four sites in each catchment. At Glenomaru, three sites were located on the main waterway flowing through the DFF; one before the stream entered the deer farm, one before a sedimentation pond and one at the catchment outlet after the pond (Fig.1a). An additional site (outside of the catchment) monitored the drainage from a paddock used for a winter crop and a self-feeding silage pit. At Waimea, three creeks were monitored on the south side of the main stream: one was

Figure 1 Map showing an aerial photograph and the paddock layout (transparent light-grey), catchment boundary, streams and the location of each water sampling site (circles) at the Glenomaru) and Waimea DFFs.

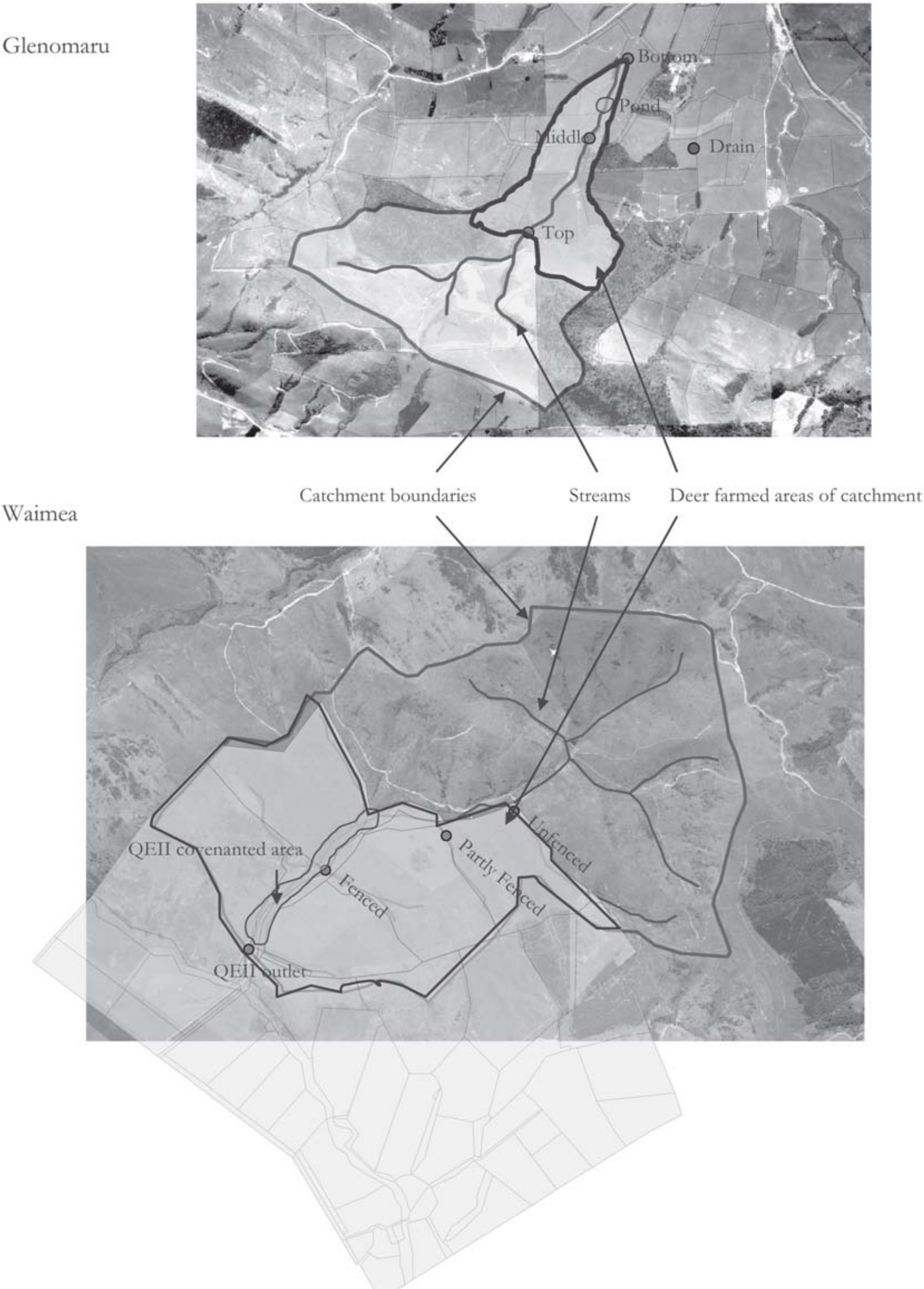


Table 1 Mean and, in parentheses, range of soil test values for both DFF, deer farms in the Otago/Southland region and the recommended range.

Test	Glenomaru	Waimea	Otago/Southland[1]	Recommended range[2]
pH	5.9 (5.4 – 6.2)	5.7 (5.4 – 6.2)	5.8	5.8-6.0
Olsen P (mg/kg)	38 (4 – 120)	33 (3 – 109)	26	20-30
K	13 (8 – 33)	19 (6 – 36)	12	5-8
SO_4^{3-}-S	20 (13 – 44)	12 (8 – 18)	13	10-12

[1] Data for all deer farms up to Jan 2006 tested at Hill's laboratories (F. Calvert, pers. comm.).
[2] From Roberts & Morton (1999)

unfenced and located farthest from the catchment outlet, while another, near the catchment outlet, was fenced-off from stock near the bottom and planted with poplars (Fig.1b). A third creek was only partly fenced-off. All three creeks were from sub-catchments on the south side of the main catchment and had approximately the same slope. All three fed into a stream, which at the bottom end went through a 5 ha area covered in tussock and under a Queen Elizabeth II Trust (QEII) covenant preventing stock access and future land development. A permanent gauge was located here to measure the water flow rate and volume in the stream. At Glenomaru, a gauge was maintained at the catchment outlet and another at the site before the stream entered the deer farm. Water samples (2 L) were taken for 1 year from each site on a monthly basis beginning in July 2005 and whenever additional site visits occurred and flow was occurring: at the Glenomaru DFF about 20 samples were taken at each site and about 12 at the Waimea DFF.

Flow sampling and analysis

In the field, dissolved oxygen, pH and temperature were measured before samples were transferred back to the lab. They were immediately filtered (< 0.45 µm) and analysed for dissolved reactive phosphorus (DRP) within 24 h, and total dissolved P (TDP) after persulphate digestion within 48 h. An unfiltered sample was also digested and total P (TP) measured within 7 days. Fractions defined as dissolved unreactive (largely organic) P (OP) and particulate P (PP) were determined as TDP less DRP and TP less TDP, respectively. All P analyses were made using the colorimetric method of Watanabe & Olsen (1965). Suspended sediment (SS) was determined by weighing the oven dry (105°C) residue left after filtration through a GF/A glass fibre filter paper. Samples were also analysed for NH_4^+-N and NO_2^{2-}N/NO_3^--N (NO_x) concentrations using standard auto-analyser procedures (APHA 1998). *Escherichia coli* (*E. coli*) was measured as the preferred faecal indicator bacteria for freshwater in New Zealand (MfE 2003) using the Colilert® media and the Quanti-Tray® system (IDEXX Laboratories, Maine, USA). Data were $\log_{10}$ transformed before an analysis of variance was done to indicate a significant difference in mean concentrations between sites within a catchment at $P<0.05$.

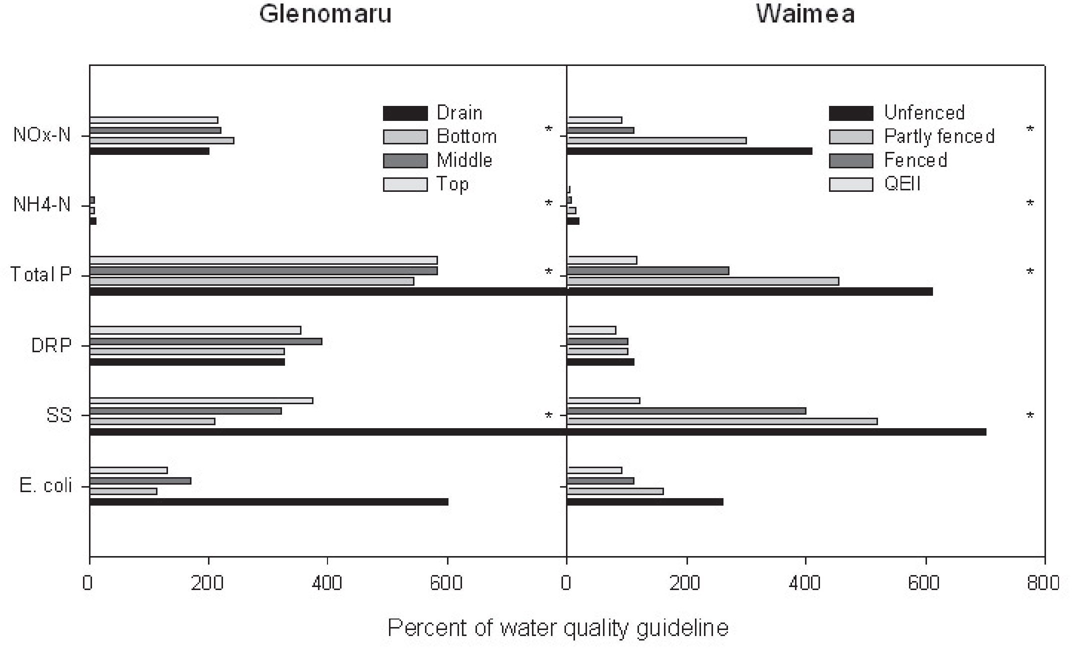
Loads of nutrients, SS and *E. coli* were calculated via interpolation techniques (e.g. Robertson & Roerish 1999). Where not measured, flows were estimated as proportional to the area of the catchment occupied by the sub-catchment. This estimate was improved by a regression relationship generated between sub-catchment flow measured during sampling (by gauging the main channel before and after the confluence) and continuous flow measurements at the catchment outlet.

Results

Means of each soil test are given in Table 1 together with the recommended range and mean value for deer farms in the Otago/Southland regions (Roberts & Morton 1999). In general, soil pH was near optimum at both farms, while P, K, and S were significantly in excess of the recommended range at the Glenomaru DFF (one-sample T-test $P<0.001$) but near to that recommended (except K) for optimal pasture production at the Waimea DFF. This also meant that Olsen P and K in both DFF were significantly greater than average fertility for deer farms in the Otago/Southland region.

Median water quality data at both DFFs are summarised in Figure 2 and expressed relative to recommended ANZECC (2000) guidelines for lowland water quality (eutrophication for NO_x – 0.444 mg N/L, DRP – 0.01 mg P/L and TP – 0.03 mg P/L; fish toxicity for NH_4^+-N – 0.9 mg N/L; and contact recreation for *E. coli* – 260 cfu/100 mL). At the Glenomaru DFF (Fig. 2A), only NH_4^+-N met its respective guideline at any site. For NO_x-N, concentrations generally increased downstream (top to bottom) reflecting increasing contributions via drainage of grazed pastures. However, DRP and *E. coli* increased from the top to the middle site, commensurate with travel through the deer farm. On average, concentrations of most species decreased from the middle to bottom site (paired comparison T-test indicated significant differences for SS, NH_4^+-N and NO_x-N), which was sampled after water had traveled through a pond allowing sediment and entrained P to settle-out and for increased exposure and possible death of *E. coli* from UV light (Vinten *et al*. 2004). Median concentrations were greatest in drainage water from the

Figure 2 Median concentrations of water quality variables expressed as a percentage of the ANZECC (2000) and MfE (2003) guidelines for lowland water quality and contact recreation at the Glenomaru and Waimea DFF. An asterisk indicates a significant difference in mean concentrations (P<0.05) between sites in a catchment for mean contaminant concentrations.



tile drain. At the Waimea DFF (Fig. 2B), the overall situation was different with all parameters meeting recommended guidelines at the catchment outlet (QEII outlet). Again, as for the Glenomaru DFF, NH_4^+-N concentrations in outflow waters were generally less than 20% of the recommended limit for fish toxicity. Of each of the three tributaries feeding the main stem at the QEII outlet, the unfenced tributary exhibited the greatest median concentrations for all water quality variables, while the fenced tributary exhibited the least: median concentrations in the partly fenced tributary was intermediate between the other two.

Catchment specific loads for nutrients, sediment and *E. coli* are given in Table 2 along with the range of loads for grazed pastoral catchments including those thus far measured from deer farms. A similar picture emerged for loads from the Waimea tributaries as for median concentrations: greatest in the unfenced tributary and lowest in the fenced tributary. Loads were generally in the lower end of the range for NZ pastoral catchments. The exception was for NO_x-N which exhibited wide variation.

Discussion

Many of the water quality parameters measured on both DFFs were a reflection of the water flowing into the DFF from neighbouring properties and generally improved by the time they left the bottom monitoring

Table 2 Catchment area-specific loads (all units kg/ha/yr except *E. coli*, log_{10} cfu/ha/yr e.g. $1.60^9 = 1.60 \times 10^9$) of nutrient, sediment and *E. coli* at each sampled site.

Parameter	Glenomaru DFF			Waimea DFF			Range for NZ studies[1]
	Top	Bottom	Outlet	Fenced	Partly fenced	Unfenced	
DRP	0.04	0.04	0.03	0.03	0.03	0.04	0.01-0.5
TP	0.23	0.21	0.56	0.61	0.65	0.90	0.1-1.7
SS	40	20	58	92	125	201	22-2000
E. coli	1.07^{10}	6.93^{8}	1.60^{9}	1.32^{9}	1.25^{9}	1.82^{9}	-
NH_4^+-N	0.03	0.14	0.12	0.23	0.32	0.39	0.05-1.1
NO_x-N	0.78	0.75	6	10	22	18	0.5-29
Total N	-[2]	1	7	14	20	27	4-35

[1] Taken from Cooper & Thomsen (1988), McDowell & Stevens (2006), Quinn & Stroud (2002), Wilcock (1986), Wilcock et al. (1999), and Vant (2001).
[2] Not measured at Glenomaru top site.

site. The perception that through behavioural characteristics, such as fence-line pacing and wallowing, deer can exacerbate contaminant (sediment, nutrient and faecal bacteria) concentrations in waterways has prompted action by both DFFs to attempt to and achieve improvements in water quality leaving the catchments.

In a previous study of soil and water quality on an Otago deer farm, McDowell & Paton (2004) and McDowell & Stevens (2006) estimated concentrations and loads for nutrients, sediment and *E. coli* for catchments draining a deer farm in Otago. Concentrations for one catchment with stock access to a stream also drained a deer wallow and as a result no water quality guidelines were met. Some parameters (such as N species) were met in the other catchments while others such as SS and TP concentrations were just in-excess of guidelines and exacerbated by soil disturbance via stock and subsequent erosion. Part of this was attributed to fence-line pacing, whereby compaction, loss of pasture cover, increased activity and mechanical disturbance of fence-line soils enhanced soil loss (McDowell et al. 2004). Preliminary soil sampling of the Glenomaru DFF indicated that while fence-line soils were compacted (pores less than 30 μm < 10%; J. Paton, pers. comm.), compared to soils from the rest of the paddock, most fence-line soils still maintained pasture cover and were probably not the main source of SS and TP; a similar picture was evident at the Waimea DFF.

At the Glenomaru DFF, the greater median SS concentration at the top site compared to others was probably a reflection of steeper slope in the headwaters and occasional bank disturbance by cattle outside the deer farm. This, along with high soil Olsen P concentrations (38 mg/kg) across the catchment, would have also contributed to the high median TP concentration. Furthermore, due to regular aerial applications of superphosphate and contributions from dung the median DRP concentration of the Glenomaru DFF sites was greater compared to the Waimea DFF sites where no P fertilizer had been applied during the previous summer and the mean soil Olsen P concentration was less. Concentrations of NO_x-N at the Glenomaru DFF tended to increase downstream most likely as a result of inputs via subsurface drainage, but varied little compared to sites at the Waimea DFF. This inferred that access by stock and input of N via urine was a major downstream source of NO_x-N at the Waimea DFF. This was supported by increased median NH_4^+-N concentrations in unfenced compared to fenced-off waterways.

Stock access was clearly the cause of the difference between median concentrations of *E. coli* and NH_4^+-N since the primary source of *E. coli* is faeces, which is also a significant source of NH_4^+-N. Similarly, median concentrations increased between the top and middle site at the Glenomaru DFF which encompassed a short length of stream to which deer had access. In contrast, median *E. coli* concentration decreased along with DRP, TP and SS between the middle and bottom site where water had flowed into a pond installed for aesthetic reasons but which acted as a sedimentation pond settling out SS, and with it sorbed P. The large surface area may also have enhanced the bactericidal action of UV on *E. coli* compared to an unmodified channel (Vinten *et al*. 2004).

Measurements taken from the tile drain at the winter grazed forage crop site at the Glenomaru DFF exhibited the highest median concentrations for all parameters and sites except DRP and NO_x-N. These two parameters were probably low due to the redistribution of P rich material within the profile and the flushing of NO_x from the profile before measurements began (measurements began 3 months later than at other sites). McDowell & Monaghan (2002) showed that cultivation diluted the P flowing within established pathways compared to established pasture with intact macropores. However, TP and SS concentrations reflected soil disturbance, while elevated *E. coli* numbers reflected the presence of a self-feeding silage pit in the paddock and the presence of many more stock than normal.

Both loads and concentrations at the Waimea DFF emphasised the restorative effect of the QEII covenant area, which occupied 33% of the total stream length on the deer farm and 18% of the total length. Despite receiving elevated concentrations and loads of different contaminants, the concentration and load of each had decreased by the time it was measured at the outlet of the QEII covenant area. It is possible that water at the outlet was diluted by cleaner water from the half of the catchment that was not in the deer farm. However, a longitudinal survey conducted in January 2006 of all streams leading into the main stem revealed that the concentrations and instantaneous loads were similar to that of the unfenced stream. Although, this represents just one snapshot in time and is therefore not conclusive proof of water quality improvement by the QEII covenant area, two earlier samplings of streams leading into the main stem and the unfenced tributary have exhibited similar concentrations.

In terms of future best management practices for both DFFs a number of possibilities exist. Fencing off waterways to exclude stock would continue to improve water quality. Although the pond at the Glenomaru DFF does appear to mitigate some of the water quality contaminants (*E. coli* and P) it is probably less effective for other contaminants. For example, an elevated median NO_x-N concentration could be a reflection of high rainfall combined with winter forage crops leading to loss of NO_x in subsurface drainage. Similarly, elevated Olsen P concentrations cause increased P loss. Changes in fertiliser policy, such as the use of nitrification inhibitors and less superphosphate, could yield less N and P loss and also save money. At the Waimea DFF, further fencing of waterways would help improve water quality, as shown by the results through the QEII covenant. An approach combining in-paddock BMPs such as nutrient budgeting, planting and good grazing management to alleviate fence-line pacing, and provision of shade and shelter and a reticulated water supply, with in-stream BMPs such as riparian plantings, sedimentation ponds and wetlands would be the most effective at mitigating contamination of waterways. However, the price of fencing and poor current returns faced by many in the deer industry may preclude fencing off waterways and other BMPs. A need to wallow may be a main driver for red deer congregating around waterways. A simple engineering approach such as the creation of artificial wallows that are not connected to the waterway may encourage them away from the stream bank.

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REFERENCES

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

APHA. 1998. Standard methods for the examination of water and wastewater. 20th edition. American Public Health Association, American Water Works Association, Water Environment Federation. Washington D.C.

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.

Eyles, R.; Niyogi, D.; Weinstein, P.; Townsend, T.; Brooks, H.; Trott, A.; 2002. Ecosystem change and Campylobacter in freshwaters: a New Zealand perspective. *In*: Society for Applied Microbiology Summer Conference: Pathogens in the Environment and Changing Ecosystems. University of Nottingham, UK. Accessed: July 2004, (http://telperion.otago.ac.nz/erg/freshwater/documents/REylesPosterA4.pdf).

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

McDowell, R. W.; Monaghan, R. M. 2002. The potential for phosphorus loss in relation to nitrogen fertilizer application and cultivation. *New Zealand Journal of Agricultural Research 45*: 245-253.

McDowell, R W.; Paton, R. J. 2004. Water and soil quality in an Otago deer farm. *Proceedings of the New Zealand Grassland Association 66*: 187-194.

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.

MfE. 2003. Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment, Wellington, 159pp.

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.

Roberts, A. H. C.; Morton, J. D. 1999. Fertiliser use of New Zealand dairy farms. *New Zealand Fertiliser Manufacturers' Association, Auckland, New Zealand*. 37 pp.

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.

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.

Vinten, A. J.; Douglas, J. T.; Lewis, D. R.; Aitken, M. N.; Fenlon, D. R. 2004. Relative risk of surface water pollution by *E. coli* derived from faeces of grazing animals compared to slurry application. *Soil Use and Management 20*: 13-22.

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.

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

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 Marin and Freshwater Research 33*: 683-696.