Client Report

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Effects of trees on fence-line pacing of deer and associated impacts on water and soil quality

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1. Executive Summary

Soil and water quality can be impaired by fence-line pacing. Our hypothesis was that well designed shelter could alleviate fence-line pacing. To test this we took intact soil samples (1 m long by 0.2 m wide by 0.1 m deep) from near the fence-line and away from the fence line in paddocks that had no, one or two shelter belts in them. The soils were all the same and taken from a finishing farm in Northern Southland. Samples were then put under a rainfall simulator and overland flow produced. Contaminants in flow (phosphorus and nitrogen fractions, suspended sediment, and the faecal indicator bacteria, *E. coli*) were tested and results show that more were present in flow from the fence-line paced soils than the samples from the rest of the paddock, but only *E. coli* was decreased in fence-line soils in the paddocks with shelter. Additional samples showed more soil compaction in fence-line paced soils, but no improvement with shelter. Although only *E. coli* concentrations were improved by the inclusion of shelter, benefits for improved production and animal welfare weigh heavily in favour of installing and maintaining shelter on deer farms. Furthermore, the benefit of shelter for soil and water quality should be tested in other farms where factors such as slope, soil, climate, and farm management may increase the contrast with no shelter.

2. Abstract

Sustainable land use for deer farming requires the maintenance of good soil and water quality, which can be adversely effected by fence-line pacing. This study tested the hypothesis that the absence or presence of shelter belts (one or two) in paddocks decreases fence-line pacing and associated soil and water quality impacts. Soils near the fence-line and in the rest of the paddock, in paddocks containing no, one or two shelter belts, were sampled for bulk density, macroporosity. Large intact samples (1 m long by 0.2 m wide by 0.1 m deep) were used to generate overland flow via rainfall simulation. The flow was tested for nutrients (phosphorus [P] and nitrogen [N] fractions), suspended sediment (SS), and the faecal indicator bacteria, *E. coli*. Results showed that bulk density, void volume, SS, particulate P and total P were affected by location (fence-line or rest of paddock) but, along with all other measurements except *E. coli*, not affected by the number of shelter belts. Thus, the inclusion of shelter had no effect on the concentration of contaminant lost in overland flow or any soil physical parameter, but decreased the runoff of *E. coli*. The lack of contrast between the location of soils can be partly attributed to the soil type (Brown, NZ soil classification), which compared to past studies was less erosive and lost less P into solution. Other factors may have been good management or the lesser impact of weaners compared to older hinds and stags on soil

properties. Although only *E. coli* concentrations were decreased by the inclusion of shelter, factors such as improved production and animal welfare weigh heavily in favour of installing and maintaining shelter on deer farms. However, the environmental benefit of shelter should be tested in other farms where factors such as slope, soil, climate, and farm management may increase the contrast with no shelter.

Keywords: Red deer, fence-line pacing; shelter belt; phosphorus; *E. coli*; eutrophication; hydrology

3. Introduction

As of 2003, numbers of red deer (*Cervus elaphus*) and their hybrids with wapiti (*Cervus elaphus* spp.) farmed in New Zealand are estimated at 2.5 million (Loza 2003). This figure has been revised to a current estimate of 1.78M (MAF Statistics 2005) which agrees with recalculated estimates of numbers following a Deer Industry New Zealand survey of producers in October 2004. (Deer Industry New Zealand *pers. comm*.) Most (65%) of these are farmed either in the provinces of Canterbury, Otago or Southland in the South Island where water quality is generally very good. However, deer farming is a recent land use and there are concerns that environmental quality may deteriorate, prejudicing sustainability (Moyes 2002; Loza 2003). Sustainability can encompass many aspects of farming. For example, internationally, and in New Zealand, deer are known to negatively impact on species richness or biodiversity of plant species due to foraging. Lyon & Sharpe (1995) showed that excluding deer from clearcut areas in a Pennsylvanian forest aided in the recovery and woody species diversity. However, the major concern surrounds soil erosion, and the transfer of sediment, nutrients and faecal bacteria to waterways. Thorrold & Trolove (1996) estimated that erosion losses from 3 deer paddocks with Pumice soils in the Bay of Plenty region were at least 2.1, 2.2 and 22 t ha^{-1} yr^{-1}. In contrast, McDowell & Paton (2004) estimated a mean erosion rate of 1.1 t ha^{-1} yr^{-1} for a Pallic soil in Otago. Overall, Rodda *et al.* (2001) have modelled catchment sediment losses from land under deer farming to be up to 4.5 times greater than from land under other livestock farming or forestry. In terms of nutrients in waterways, McDowell & Paton (2004) found that mean values for two sites that drained 100% deer farmed land in Otago exceeded current lowland surface water quality limits for dissolved reactive P (DRP, 0.01 mg P L^{-1}), total P (TP, 0.033 mg P L^{-1}) and ammonical-N (0.021 mg L^{-1}): limits for nitrate-N (0.444 mg L^{-1}), and *E. coli* (127 *E. coli* $100mL^{-1}$), as the faecal indicator bacteria of choice, were also exceeded in another site draining a wallowing area.

Behavioural characteristics of deer in farmed conditions are associated with these problems. For example, fence-line pacing decreases pasture cover, increasing the risk of erosion (Evans 1996). Fence-line pacing occurs in most paddocks but is exacerbated by stress such as when feed is low, during calving, or when deer can see others in an adjacent paddock through the fence (Moore *et al.* 1985). Fence line pacing may also be increased in frequency as a direct consequence of too intensive subdivision and holding deer at relatively high stocking rates per hectare even though feed may be in abundance. Obviously, when more time per unit area of ground is spent by deer fence-line pacing than in remaining pasture, this decreases animal productivity and increases dung and urine deposition and soil disturbance by treading. Consequently, increased treading of fence-line soils increases soil compaction, decreases pore space, infiltration and pasture growth leading to increased potential for overland flow and with it the likelihood of contaminant (nutrients and faecal bacteria) loss (McDowell *et al.* 2004).

To alleviate fence-line pacing, the New Zealand Deer Farmers' Landcare Manual (NZ Deer Farmers' Association, 2004), a collation of deer farmer experiences and recommendations, promotes the use of shelter belts. Apart from being aesthetically pleasing, trees can form up to 70-80% of the diet of wild deer and are a good source of timber. It is thought that by grazing deer in paddocks with shelter belts, stress will be decreased by restricting the view of deer in adjacent paddocks and by protection from sun, wind and rain. While we know fence-line pacing has detrimental effects, to date it is not known the effect or arrangement of shelter belts would have on mitigating these. Consequently, our objective was to test the potential for losses of P, sediment, N species (NH_4^+-N and NO_3^--N) and *E. coli* in saturation excess overland flow from, and soil compaction (as an indicator of soil quality) in, soils near the fence-line and soils from the rest of the paddock in paddocks with either 0, 1 or 2 shelter belts.

4. Materials and Methods

4.1 Site

A deer finishing farm (venison production) was selected near Mossburn, Northern Southland, New Zealand. The farm carried 8000 weaner deer on an effective area of 759 ha split into 148 paddocks each with a variety of shelter to protect against the prevailing north-westerly winds. The shelter consisted of either none (i.e. fences only), a shelter belt along one side of the paddock (either on the northern or western edge) or 2 shelter belts along the north and west edges of the paddock. Trees in the shelter were commonly > 50 y old macrocarpa (*Cupressus macrocarpa* sp.), < 5 y old poplars (*Populus* spp.) or as along one side of the farm, scrub dominated by gorse (*Ulex* *europaeus*). The soil on the farm was a Honeywood stoney silt loam classified as a mottled-cemented firm Brown soil (NZ classification, Hewitt 1998: USDA Taxonomy: Typic Fragiudalf). This soil has soil moisture deficits in summer and, due to severely impeded drainage in the B horizon (20-40 cm depth, saturated hydraulic conductivity < 1 mm h^{-1}, J. Paton, pers. comm.) and almost fragipan characteristics below that, surpluses in winter months causing saturation-excess conditions and overland flow.

Each year 160 kg ha^{-1} of urea was applied in two applications of 80 kg ha^{-1} in spring and autumn, while 250 kg ha^{-1} of superphosphate was applied in late spring. Additional applications of fertiliser or lime were made when, during the farmers' soil sampling, a paddock was found to be deficient in N or P or of low pH. In August (before N or P application) the site was sampled by sourcing paddocks within the farm that had either no shelter, one shelter belt or two shelter belts and not been grazed for 6 d. This represented the most common lag period at the time before one of two herds of 400 weaners were rotated back into the paddock to graze. Of these paddocks, 2 had no shelter, 5 had one shelter belt, and the remaining 3 had two shelter belts. Within each paddock 4 plots (2 × 2 m) were marked out within 2 m of each fence-line, while another 4 plots were randomly sited > 2 m of the fence-line in the rest of the paddock. The visually determined percentage (Milne *et al.* 1995) of bare ground was determined on each plot. The treatments are referred to as no, 1 or 2 shelter and by location (fence-line or rest of paddock).

4.2 Soil sampling

Intact fence-line and rest of paddock soils were sampled manually from each plot using a metal cutting blade (1 m long × 20 cm wide and 10 cm deep) and placed in boxes, 1 m long by 20 cm wide by 12.5 cm deep. Boxes were moved to an indoor rainfall simulation facility and rain applied as described below. At the same time as sampling intact soils, core samples were taken for determination of macroporosity (% of pores > 30 μm), and bulk density from the 0-5 cm depth (Drewry *et al.* 2000). At the end of the trial, samples (0-7.5 cm) were also taken for Olsen P.

4.3 Overland Flow

Overland flow was generated by applying artificial rainfall (tap water, P less than detection limit of 0.005 mg P L^{-1}) at 20 mm h^{-1} to each boxed soil, inclined at 5% slope. The rainfall simulator uses one TeeJet 1/4HH-SS30WSQ nozzle (Spraying Systems

Co., Wheaton, IL) approximately 250 cm above the soil surface to gain terminal velocity. The nozzle, in-line filter and pressure gauge were fitted onto a 305 cm high by 305 cm wide by 305 cm deep aluminium frame with tarpaulins on each side to provide a windscreen. The drop-size, velocity, and impact energies approximated natural rainfall (Shelton *et al.* 1985). The 20 mm h^{-1} rainfall-intensity has a return frequency of approximately twice a year for a 15 minute event. During simulation, 1 L of overland flow was collected per box, per event. Time to initiation of flow and the time required to collect a 1 L sample were noted. The volume within each occupied by water (termed here void space) was determined by difference of weight before and after raining while the soil was saturated. The rainfall simulation and soil boxes used in this study were not designed to quantify field scale losses *per se*.

4.4 Soil, water and statistical analyses

Soils were air-dried, crushed, sieved (< 2 mm) and analysed for bicarbonate extractable P (Olsen P). Overland flow samples were filtered (< 0.45 μm) immediately and analysed for DRP within 24 h, and total dissolved P (TDP) after persulphate digestion within 48 h. An unfiltered sample was also digested and 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^{o}C) residue left after filtration through a GF/A glass fibre filter paper. Samples were analysed for NH_4^+-N and NO_3^--N concentrations using standard auto-analyser procedures.

Numbers of Escherichia coli were measured as the preferred faecal indicator bacteria for freshwater in New Zealand (MfE 2003). Overland flow samples from fence-line soils were diluted 1:20 w/w with sterile distilled water (otherwise undiluted). For each sample, diluted or not, a volume of 100 ml was enumerated using the Colilert® media and the Quanti-Tray® system (IDEXX Laboratories, Maine, USA).

Preparation for macroporosity measurements involved first trimming the base of each core then peeling away the upper surface to give an unsmeared surface. Earthworms were removed with formaldehyde, before saturating the cores and equilibrating them at -10 kPa matric potential on tension tables to determine macroporosity. Dry bulk densities were calculated from oven dry weights.

Data was analysed using the REML procedure in GenStat version 7 (GenStat Committee 2003). The number of shelter belts (0, 1 or 2), the location of the sample in the paddock (Fence-line or rest of paddock), and their interaction were modelled as categorical fixed effects. The random component herd/paddock/location (location within paddock within herd) was included in the model allow for herd, paddock and location effects. Values for *E. coli* were $\log_{10}$-transformed, and the NH_4^+-N and SS data were natural log-transformed prior to analysis. Predicted means and standard errors of the difference were calculated for the six shelter belt by location treatments. The importance of the fixed effects was examined using the Wald test by sequentially adding the terms location, shelter and their interaction to the fixed model.

5. Results

Values for soil hydrological and physical measurements are given in Table 1. The influence of fence-line pacing was most evident in the comparison of sampling location: fence-line paced soils had a greater bulk density and lesser void volume than those from the rest of the paddock. This also reflected the longer time taken by the soils from the rest of the paddock to start flowing compared to fence-line soils.

Despite obvious differences between soils taken at different locations within the paddock no significant treatment effects were noted for the number of shelter belts in the paddock or for the interaction between location and the number of shelter belts.

The dominant fraction of TP lost in overland flow was PP (about 70%, while the remainder was evenly split between DRP and DOP (Table 1). More PP was lost from the fence-line soils than soils from the rest of the paddock, which was mirrored by SS concentrations. However, neither SS nor any of the P fractions showed any response to the number of shelter belts. Interestingly, although the concentration of *E. coli* in overland flow from soils with 1 or 2 shelter belts was significantly less than that from soils with no shelter belts, the concentration between locations was not.

For N species concentrations of NH_4^+-N and NO_3^--N were not significantly different from fence-line soils than soils from the rest of the paddock: neither were differences between the number of shelter belts nor for the interaction of location and shelter. No significant differences were noted between soil Olsen P concentrations.

6. Discussion

6.1 Soil hydrology and physical condition

Previous studies of soil physical properties on deer farms with Pallic soils have shown macroporosity, void volume and time to flow were decreased and bulk density increase in fence-line paced soils compared to soils from the rest of the paddock (Pollard & Drewry 2002; McDowell *et al*. 2004). Similarly, our data indicated that both void volume and bulk density were different between locations, but macroporosity was not, implying that significant differences were due to pores < 30 µm. McDowell *et al*. (2003a) found that a good relationship existed between macroporosity and the time to flow in pasture and cultivated soils that had been trodden by cattle. Consequently, deer had done some damage at the soil surface but not enough to alter the drainage characteristics of this Brown soil at any location or zero, one or two shelter belts.

While previous work has shown that soil can be compacted by deer farming, other work has shown the capacity of soil to become compacted and recover depends on soil type, management and climatic conditions. For instance Drewry *et al*. (2000) showed that in sheep pastures, subsoiling a Pallic soil resulted in an increase in macroporosity of up to 27%, whereas the same treatment applied to a mottled firm Brown soil, similar to that tested in this study, resulted in increases of up to 39% (Drewry & Paton 2000). Drewry *et al*. (2004) showed that in cattle grazed pastures macroporosity was least in spring but recovered during summer and autumn. Values of macroporosity < 10% v/v indicate that soil is compact and likely to impair pasture growth (Drewry *et al*. 2000). All mean values of macroporosity in our study were above this value (Table 1), and sampled in spring when soils should have exhibited the greatest degree of compaction. However, while macroporosity for Pallic soils grazed by cattle can be decreased at soil depths of below 5cm, this has yet to be seen for deer farmed soils (Drewry *et al*. 2004; McDowell *et al*. 2004). Furthermore the soils sampled in this study were Brown soils, which have better resistance to compaction than Pallic soils (e.g., McDowell & Paton 2004), and the site was also a finishing farm supporting weaners, which are light compared to many other stock types.

6.2 Contaminant loss

For SS, the range of mean concentrations among treatments was 0.191 g L^{-1} in the fence-line paced soil with 1 shelter belt to 0.058 g L^{-1} for soil in the rest of the paddock with 2 shelter belts. Using the same rainfall rate, McDowell *et al*. (2004) found SS concentrations of about 2.2 g L^{-1} in fence-line paced soils and 1.4 g L^{-1} for soils from the rest of the paddock. McDowell & Paton (2004) estimated that annually fence-line pacing accounted for about half of visible erosion from sampled paddocks (0.5-1.0 Mg ha^{-1}), the remainder due to wallowing. However, the soil studied was a Pallic soil, which is more prone to erosion than the Brown soil studied here. In contrast, sediment losses as a result of deer farming on Pumice soils in the Bay of Plenty region of New Zealand were estimated at 2.1-22 Mg ha^{-1} yr^{-1}; comparative losses under sheep farming were an order of magnitude less. (Rodda *et al*. 2001; Thorrold & Trolove 1996).

Erosion in deer farms is exacerbated adjacent to fence-lines by a combination of compaction and disturbance by the animals. In addition to the work of McDowell *et al*. (2004), Evans (1996) noted that 26% of land adjacent to a 26-km fence-line in Norway was severely or very severely damaged during summer grazing by reindeer. Thorrold & Trolove (1996) noted that more erosion occurred on boundary than internal fences. Furthermore they noted that erosion was greater along fence-lines protected by shade and shelter. Our study indicated that SS loss was greater from fence-line paced soils than soils from the rest of the paddock (P = 0.08, Table 1); however, the influence shelter was not significant (Table 1). Thorrold & Trolove (1996) hypothesized that camping of animals at fence-lines adjacent to shelter may exacerbate erosion. The corollary is that increasing shelter may decrease fence-line pacing and erosion and dilute camping alongside fence-lines. While our data indicated that SS loss was not decreased by the number of shelter belts, it was not increased.

Phosphorus is strongly bound to soil and, as such, PP was the major component of TP in overland flow (Table 1). Similar to SS, PP and TP were greater in fence-line paced soils than soils from the rest of the paddock; however, again shelter did not affect the loss of any P fraction. It is interesting to note that despite soils at both locations being enriched with P (Olsen P ≥ 50 mg kg^{-1}), overall TP concentration was less than a quarter of the TP lost in overland flow from a deer farmed Pallic soil of similar Olsen P concentration (53 mg kg^{-1}) studied by McDowell *et al*. (2004). This is a reflection of the greater sediment load from, and poor P sorption strength of, many Pallic soils compared to Brown soils (McDowell *et al*. 2003b).

Similar to P, NH_4^+-N is associated with sediment. However, neither location nor the number of shelter belts had a significant effect on losses: NO_3^--N was also unaffected. Relative to New Zealand guidelines, NH_4^+-N, NO_3^--N, DRP, TP, and *E. coli* concentrations in overland flow were in excess of their trigger values for adverse effects in lowland streams or bathing water quality (DRP = 0.01 mg P L^{-1}, TP = 0.033 mg P L^{-1}, NO_x-N = 0.444 mg N L^{-1}; NH_4^+-N = 0.021 mg N L^{-1}; *E. coli* = 127 cfu $100mL^{-1}$: ANZECC 2000; MfE 2003). While these concentrations would be of concern if overland flow was directly linked to the stream, several factors impact to decrease concentrations en route.

These include sorption of P species and NH_4^+-N, uptake by biota, dilution and die-off. In addition, soils with adjacent shelter belts will tend to be drier due to water uptake by tree roots. Carroll *et al*. (2004) found water infiltration rates were up to 60 times greater in areas with young trees than adjacent pasture, but did not consider the likely effects of compaction due to fence-line pacing. Consequently, the effect of fence-line pacing on overland flow will vary according to the degree of soil compaction and soil type. The concentrations presented in this paper should only be considered as potentials and only used for comparative purposes.

Contrary to all other contaminants and properties tested, *E. coli* in overland flow was affected by the number of shelter belts: soils with no shelter had significantly greater *E. coli* losses in overland flow than soils with 1 or 2 shelter belts. A similar concentration of *E. coli* losses (2.2 – 3.5 $\log_{10}$ cfu 100 mL^{-1}) were found by McDowell *et al*. (2004) for a paddock without shelter to the mean for paddocks without shelter studied here (Table 1). However, while losses from fence-line paced soils were slightly greater than soils from the rest of the paddock this was not significant. One reason for the effect of shelter on *E. coli* losses could be the increased camping of animals next to shelter belts. This increased the proportion of bare land in the paddock and its sampling. Compared to areas of good pasture cover, conditions on bare land would have promoted bacterial die-off due to higher temperatures and solar radiation, and decreased moisture (Crane & Moore 1986).

6.3 Management

The results (Table 1) show a lack of interaction between the location (fence line and the rest of the paddock) and shelter belts. This indicates that the use of these types of single row shelterbelts, either on one or two fences of a paddock, offers little respite from fence pacing. Both the old macrocarpa and young poplar shelter belts were open at the base. This type of shelter may decrease wind speed by as little as 12% (Yeates 1948) and hence provide little reprieve from the weather conditions. Well designed shelter belts may decrease wind velocities by greater than 50% for distances of 10 times the height of the shelter (Sturrock 1972), while low porosity shelter belts may decrease wind speeds by up to 80% for short distances (Gregory 1995). Hence, the type of shelter may be important.

Production impacts that are often attributed to shelter include a decrease in the maintenance requirement of deer (Fennessy *et al.* 1981), improved calf survival (Pollard 2003) and decreased fence pacing (NZ Deer Farmers' Association, 2004) along with associated decrease in energy required for locomotion (Pollard & Stevens 2002). The benefits of shade have also been investigated though have impact only in the severest of conditions.

The production system of finishing weaners represented in this study is one of several currently practices by New Zealand deer farmers. Others include breeding hinds and velveting stags. Each system is unique in its requirements for both shade and shelter, and has a unique set of conditions that may contribute to fence-line pacing. Therefore the design and success of shelter in mitigating such behaviours as fence pacing are likely to be different for each system. The impacts of shelter systems on each of these enterprises need to be identified. Extrapolation of these results beyond the production system, shelter type and soil type should be avoided.

7. Conclusions

Our results showed that bulk density, void volume, SS, PP and TP were affected by location but, along with all other measurements except *E. coli,* were not affected by the number of shelter belts. Thus, the inclusion of shelter had no effect on the concentration of contaminant lost in overland flow or any soil physical parameter, but decreased the runoff of *E. coli*. The lack of contrast between the location of soils near the fence-line and the rest of the paddock can be partly attributed to the soil type (Brown, NZ soil classification), which compared to past studies was less erosive and lost less P into solution. Other factors may have been due to good management or the lesser impact of weaners compared to older hinds and stags on soil properties. Although only *E. coli* concentrations were decreased by the inclusion of shelter, factors such as improved production and animal welfare weigh heavily in favour of installing and maintaining shelter on deer farms. However, the environmental benefit of shelter should be tested in other farms where factors such as slope, soil, climate, and farm management may increase the contrast with no shelter.

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Table 1. Predicted means of soil physical parameters and contaminants in overland flow for each location (fence-line or rest of paddock, ROP) by number of shelter belts treatment, and the maximum standard error of the difference. The Chi-square probability for the Wald test, from sequentially adding the terms location, shelter and their interaction to the fixed model, is also presented.

		Number of Shelter-Belts			Max.	*Chi-Square Probability*		
Variable	Location	0	1	2	SED	Location	Shelter	Location × Shelter
Bulk density	Fence-line	0.91	0.96	1.01	0.058	<0.001	0.45	0.34
(t m^{-3})	ROP	0.85	0.86	0.85				
Macroporosity	Fence-line	14.6	15.3	13.6	2.15	0.25	0.76	0.80
(% v/v)	ROP	15.4	16.1	16.2				
Void volume	Fence-line	11.5	12.3	10.8	1.25	0.01	0.37	1.00
(%)[a]	ROP	14.5	14.4	14.6				
Time to flow	Fence-line	15.6	15.3	14.9	1.93	0.20	0.91	0.83
(min)	ROP	16.1	17.3	16.5				
Ln SS	Fence-line	-1.14	-0.72	-1.06	0.553	0.08	0.69	0.86
(g L^{-1})	ROP	-1.51	-1.14	-1.23				
NH_4^+-N	Fence-line	-0.23	-1.74	-1.94	1.060	0.15	0.22	0.21
(Ln mg L^{-1})	ROP	-1.14	-2.60	-1.49				
NO_3^--N	Fence-line	5.18	4.40	4.32	1.206	0.11	0.42	0.83
(mg L^{-1})	ROP	4.61	3.10	3.63				

E. coli	Fence-line	2.96	2.23	2.31	0.315	0.18	0.03	0.25
(log_{10} cfu 100 mL^{-1})	ROP	2.51	1.75	1.89				
DRP	Fence-line	0.060	0.064	0.053	0.0166	0.20	0.99	0.41
(mg L^{-1})	ROP	0.066	0.063	0.077				
DOP	Fence-line	0.047	0.058	0.045	0.0122	0.34	0.96	0.31
(mg L^{-1})	ROP	0.057	0.050	0.057				
PP	Fence-line	0.276	0.241	0.333	0.1097	0.02	0.77	0.85
(mg L^{-1})	ROP	0.163	0.178	0.210				
TP	Fence-line	0.383	0.360	0.432	0.1024	0.04	0.72	0.97
(mg L^{-1})	ROP	0.287	0.289	0.346				
Olsen P	Fence-line	55	59	50	7.4	0.62	0.48	0.40
(mg kg^{-1})	ROP	50	50	51				

[a] % volume occupied by water under saturated conditions in turves after flow had stopped.