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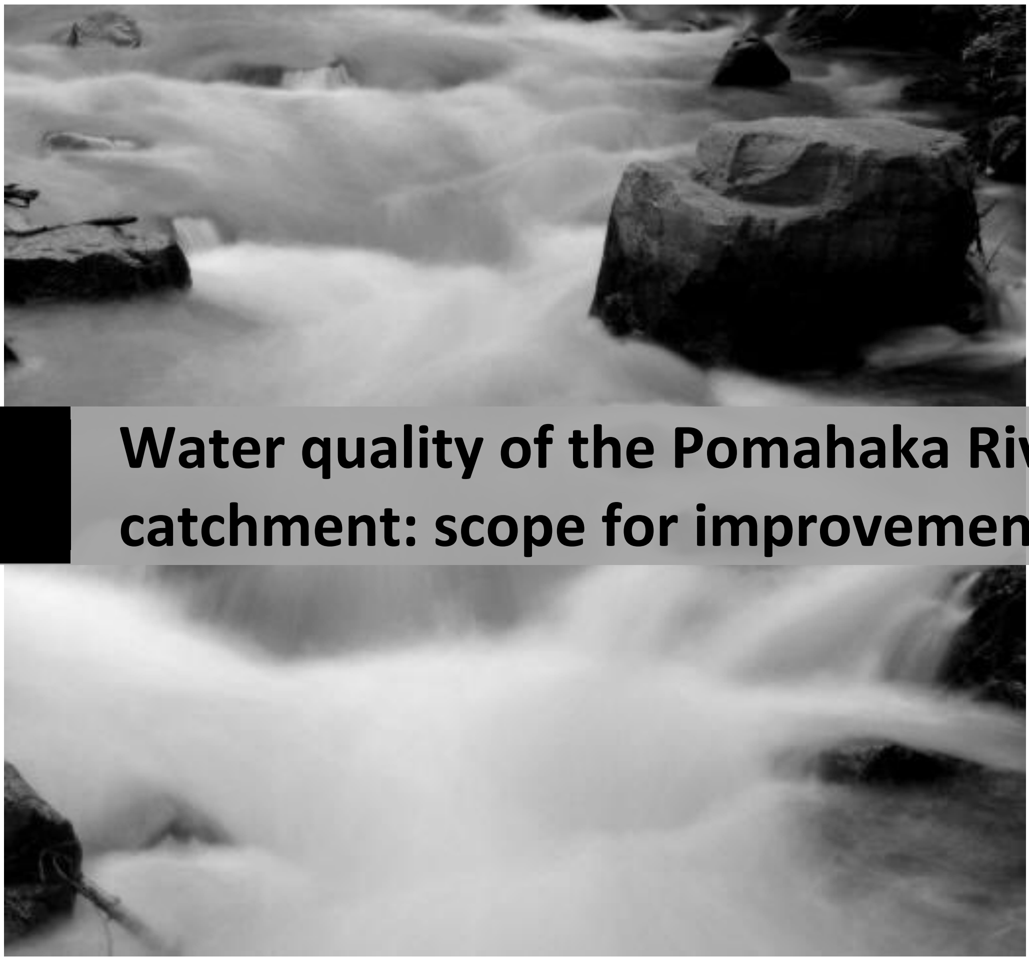

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Water quality of the Pomahaka River catchment: scope for improvement

Report for Otago Regional Council | R.W. McDowell, R.M. Monaghan, R.W. Muirhead

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R.W. McDowell, R. Monaghan, R.W. Muirhead and N. Cox

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Summary

Land use change and the expansion of dairying are perceived as the cause of poor water quality in the Pomahaka catchment. This report outlines the long-term trend at four sites, and current state in 13 sub-catchments, of water quality. Drains in dairy-farmed 2 sub-catchments were also sampled to determine their potential as a source of stream contamination. Data highlighted an overall increase in the concentration of phosphorus (P) fractions at long-term sites. Loads of contaminants (nitrogen (N) and P fractions, sediment and *E. coli*) were greatest in those sub-catchments with the most dairying, or as in the case of the Upper Waipahi River, the drainage of a wetland. Baseline (without human influence) contaminant concentrations suggested that there was considerable scope for decreasing losses. At most sites, baseline concentrations were <20% of current median concentrations.

Contaminant losses via drainage were recorded despite there being no rainfall that day and attributed to factors like applying too much effluent onto wet soil. A statistical test to detect “contaminated” drainage was developed from historical data. If this test had been applied to remove contaminated drainage from samples of the two dairy-farmed sub-catchments, median contaminant concentrations and loads would have decreased by up to 58% (greater decreases were found for *E. coli*, ammoniacal-N and total P than other contaminants).

Additional work looking at the cost and effectiveness of different contaminant loss mitigation strategies for a model sheep and dairy farm indicated that there was no “silver bullet” available that can substantially decrease <u>all</u> farm scale losses, alone. However, there were a range of options available that, if implemented collectively, could make significant decreases in contaminant losses. In the case of the model Dairy farm, most of the measures (including better effluent management) had relatively little impact on farm profit. Unfortunately, for the model sheep farm, all of the mitigation strategies evaluated were likely to impair farm profit. Given that many of the strategies, such as deferred irrigation (and low rate application), to decrease contaminant losses from effluent are not commonly practiced in the catchment, there appears considerable opportunity to decrease losses from dairy-farmed land (without much cost) and improve water quality within the Pomahaka River.

1. Introduction

The Pomahaka is a large catchment (1881 km^2) in Otago, New Zealand that contains a nationally significant recreational fishery. However, water quality as measured by the concentration of nutrients, sediment and faecal indicator bacteria in parts of the Pomahaka River and its tributaries is poor (Otago Regional Council, 2007). The state of the river has been attributed to land use change (Harding et al. 1999), especially an increase in the number of dairy farms from 38 in 1999 to 105 in 2010 (Otago Regional Council, 2010a).

During land use change to dairying, paddocks may be modified either by resizing and adjusting fencing, or ploughed and new grasses sown together with a large application of fertiliser (especially phosphorus, P). This can result in a sudden increase in sediment and nutrient loss that decreases with time (Withers et al., 2007), but when aggregated can cause significant contamination on a catchment scale. Others have also highlighted areas like loafing pads and barnyards that can be a significant source of contaminant loss (Edwards et al., 2008; Withers et al., 2009).

Grazed pastoral farming in the Pomahaka catchment is characterised by the widespread use of artificial drainage. These drains respond quickly via macropores or artificial mole channels and preferential flow to remove excess water, but also act as a direct conduit for contaminants to enter streams. Common practice on dairy farms in the catchment is to apply dairy shed effluent to land, often on a daily basis during the milking season. The application of effluent on artificially-drained land can, via macropores or ancillary drains connected to main drains, result in effluent reaching the stream (Monaghan and Smith, 2004; Houlbrooke et al., 2008). This loss can occur when drains would not typically be flowing in summer or autumn when ecosystem effects and recreational use are greatest (Jarvie et al., 2006). While past work has indicated that effluent application combined with artificial drainage can act as a source of contaminant loss, isolating this on a farm-by-farm or catchment scale is problematic, especially if natural background losses are high.

In 2010 the Otago Regional Council proposed to implement an effect-based policy that related catchment values to water quality indicators (e.g. contaminant concentrations, Otago Regional Council, 2010b). As part of this strategy, advice was sought on a potential approach. The aims of this report are to:

1) Present summary statistics for current surface water quality in the Pomahaka catchment and for tile drain discharge concentrations of dissolved reactive P (DRP), nitrate-N (NO_3-N), ammoniacal-N (NH_4-N), suspended sediment (SS) and *Escherichia coli* (*E. coli*) for the Apr-Oct period and annually (including long-term drainage data from Kelso in the Pomahaka River catchment and Tussock Creek, near Invercargill, Southland).

2) Present and comment upon the published guidelines and/or standards for different community values according to Table 1.
3) Discuss potential limits relative to known concentrations of contaminants in effluent and suggest technically defensible limits based on probability distribution or quartiles presented in point 2 and relative to a natural baseline (i.e. without human influence).
4) Model sheep and dairy farms (1 each) and assess loads and concentrations via models like Overseer® and the potential cost and effectiveness of some mitigation strategies for contaminant losses.

Table 1. Receiving water standards to meet various values

	Protection of aquatic ecosystems							Food gathering	Primary contact recreation	Human drinking water	Animal drinking water	Abstraction (irrigation, industrial supply)*
	High conservation value systems (99% protection)	Slightly to moderately disturbed systems (95% protection)	Highly disturbed systems (80 to 90% protection)	Trout Spawning	Trout Fishery	Eel fishery	Shellfish					
Nitrate-nitrogen												
Dissolved reactive phosphorous												
Suspended solids												
E coli												

*Excluding domestic and animal drinking use

2. Material and methods

2.1 Catchment description and sampling

The Pomahaka River drains a catchment of 1881 km^2 and supports a wide variety of land use typified by either red tussock, native forest, plantation forestry (largely *Pinus radiata*) or extensive rangeland farmed with drystock (red deer, sheep and beef) in uplands, while lowlands are dominated by a mixture of drystock and increasingly, dairying. Some tributaries, such as the upper Waipahi River, have also seen the conversion and drainage of large wetland areas in the last 10 years.

Rainfall varies from *c*. 1250 mm in the headwaters draining altitudes of up to 1440 metres above sea level (msl) to *c*. 650 mm near the catchment outlet at about 60 msl. Slopes tend to be steep ($> 20^o$) in the headwaters and often $<2^o$ in the lowlands. Soils within the catchment are dominated by Pallic soils (NZ soil classification [Hewitt, 1998]; encompassing Fragiudalfs and Haplustalfs in USDA taxonomy) of moderate natural fertility, but characterised by summer dry and winter wet soil moisture conditions, a high soil bulk density (> 1.3 g cm^{-3}) and imperfectly to poorly drained. In low lying areas, profile drainage is facilitated by a network of mole channels (about 40-50 cm deep) that feed into tile or pipe drains at about 70-100 cm below the soil surface (collectively termed artificial drainage).

Since April 1997, water quality and continuous flow have been measured bi-monthly at 4 long-term “State of the Environment” sites on the Pomahaka and Waipahi Rivers as part of regular assessments made by the Otago Regional Council. For 14 months, beginning in October, 2008 this was supplemented by fortnightly sampling (n = 30) and continuous flow measurements (gauged fortnightly) of the long-term sites and 11 other “short-term” sites on the Pomahaka and its tributaries. On the same day as sampling short-term sites, an additional 20 short-term drainage sites (14 draining dairy-farmed land and 6 draining sheep-farmed land) were also sampled and flow gauged (Fig. 1).

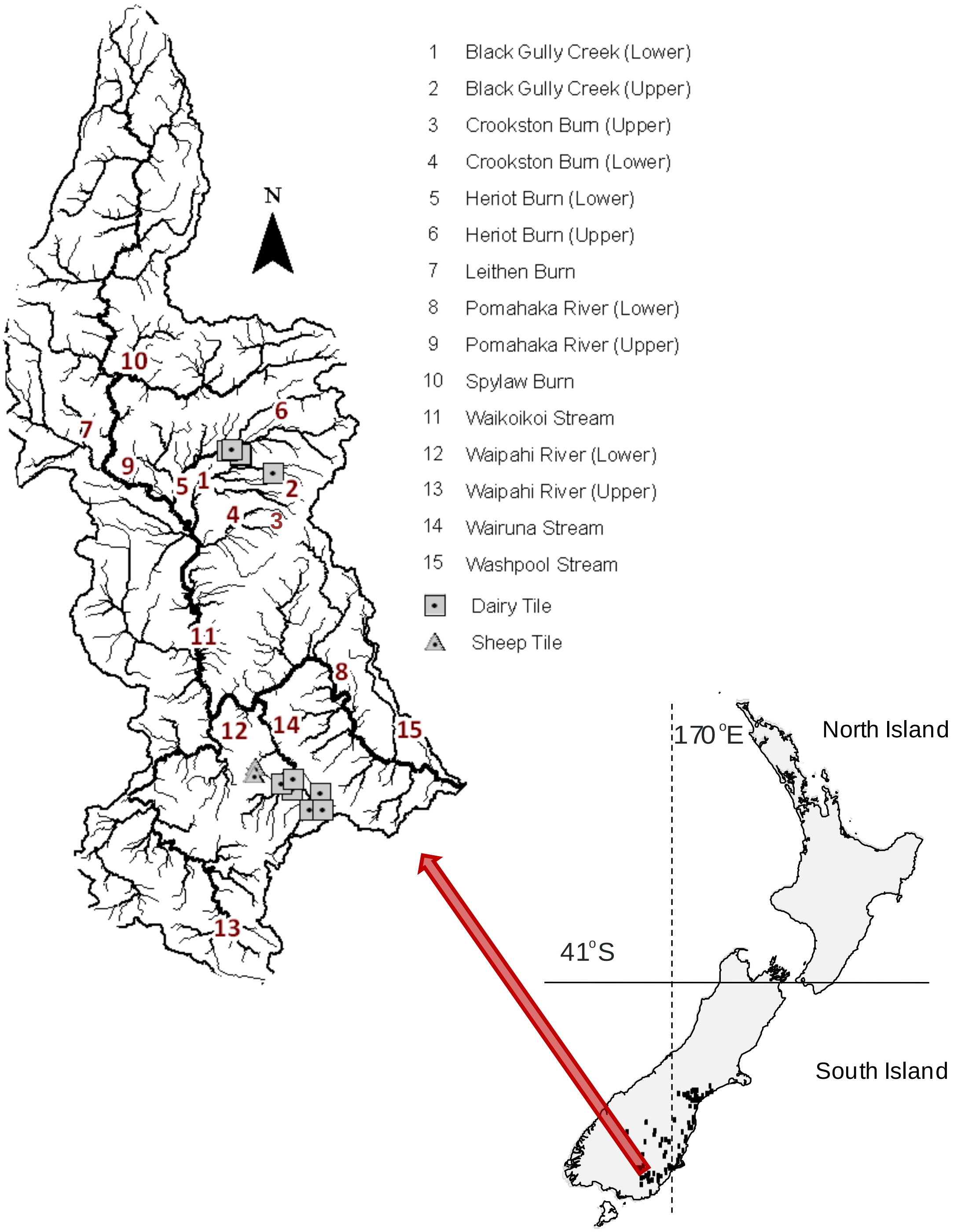

Fig. 1. Map showing the location of long-term, short-term and artificially (tile) drained sites in the Pomahaka River catchment.

2.2 Long term drainage sites

Two sites were used to supplement tile drainage data taken by the Otago Regional Council, Kelso and Tussock Creek. The Kelso site was located 10 km north-west of Tapanui (within the Pomahaka River catchment), West Otago. In October 1999, two plots (27m wide by 35m long) were hydrologically isolated from one another and tile drains installed at a depth of 75cm. In November, mole drains were pulled in each plot at a depth of 45cm to connect with the tile line. Prior to installation, the site had been in pasture for at least 12 years. The soil is a Waikoikoi silt loam (NZ Classification: Mottled Fragic Pallic soil). Beginning with the first drainage event in May 2001, drainage water volumes have been continuously recorded using 3 L tipping buckets connected to a Campbell Scientific CR10 datalogger. Samples of drainage water from each event were collected on a flow-proportional basis for analysis of DRP, TP, NO_3-N, NH_4-N, SS and *E. coli* using the methods outlined for stream samples. Plots were denoted as either effluent or non-effluent irrigated, with effluent from a nearby milking shed being regularly applied to the effluent plot during the trial via a rotating twin-gun travelling irrigator up to winter 2006 and via a low rate (K-line) system until the end of the experiment in Nov 2008. Applications of P fertiliser in early summer were adjusted to take into account the quantity of total P applied in the effluent. With the exception of winter months (June–July), regular rotational grazing (every 20-30 days) of both plots occurred simultaneously during the trial at an annual stocking rate equivalent to 3.0 cows ha^{-1}

2.3 Sample analyses

In the laboratory, stream and drainage samples (2 L) were filtered (< 0.45 μm) in the field and analysed for DRP within 24 h, and an unfiltered sample digested with persulphate and TP measured within 7 days. The P analyses were made using the colorimetric method of Watanabe and Olsen (1965). Suspended sediment was determined by weighing the oven dry (105°C) residue left after filtration through a GF/A glass fibre filter paper. Filtered samples were also analysed for NH_4^+-N (this includes NH_3 and NH_4^+, but referred to here as NH_4-N), (NO_2^-+NO_3^-)-N = NNN (or just NO_3-N for drainage from Kelso and Tussock Creek), and TN (after persulphate digestion) concentrations using standard auto-analyser procedures (APHA 1998). *Escherichia 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).

Annual stream loads on a kg ha^{-1} basis of N and P fractions and SS were calculated via interpolation of fortnightly samples (see method 5; Jones, 2007). While it should be noted that this method may underestimate loads for contaminants such as SS which are dominated by stormflow (Johnes, 2007), the recommended weekly sampling could not be achieved due to cost. However, as stormflow wasn't specifically targeted, but is known to carry > 90% of annual *E. coli* loads (Davies-Colley et al. 2008), loads for this contaminant are not presented. Summary statistics (mean, median, standard deviation and range) for each site and trend analysis for the long-term sites was conducted with Time Trends v3.0 (Jowett, 2010). For trend analyses individual parameters were subject to Seasonal Kendall tests on raw and flow-adjusted data. The Sen Slope Estimator (SSE) was used to represent the magnitude and direction of trends (median concentrations) in data. Flow adjustment was carried out using LOWESS smoothing (30% span; Hirsch and Slack, 1984).

3. Results and discussion

3.1 Summary of water quality state and trends in the Pomahaka River catchment

3.1.1 Long term SOE sites

Summary statistics, including mean, median, standard deviation and range, for each of the 4 long-term sites within the Pomahaka River catchment are given in Table 2. Guidelines for good surface water quality in lowland streams in New Zealand are set at 0.009, 0.033, 0.444, 0.9, 0.614, and 8.2 mg L^{-1} for DRP, TP, NNN, NH_4-N, TN and SS (assuming a 2:1 ratio of SS to turbidity), respectively (ANZECC, 2000), and 126 cfu $100mL^{-1}$ (*E. coli*) for contact recreation (MfE, 2003). The median concentrations of DRP, TP, NNN and TN exceeded their guideline at all but the upper Pomahaka River site, while the median concentration of *E. coli* exceeded its guideline at all but the lower Pomahaka River site. Ammoniacal-N and SS met guideline concentrations at all sites. However, work in the catchment by the ORC has identified sediment as having an impact on physiological habitat and ecological values, which should not be allowed to decline (ORC, 2011).

Trend analysis of contaminant concentrations from 1997 to 2010 indicated a significant increase in DRP and TP at all sites, whereas ammoniacal-N increased at the lower Waipahi River site, but decreased at both Pomahaka River sites (Table 2). Total N and NNN also increased at the lower Waipahi River site, while an increase in TN was noted for the upper Waipahi River site. Visual inspection of DRP and TP data showed that concentrations tended to be least in 2003 (Fig. 2). Focusing on those contaminants that exhibited a trend from 1997 to 2010, and splitting the data either side of June 30th, 2003, showed that there was often a decreasing trend in DRP or TP concentration before June 30th, 2003 and a much stronger increasing trend after June 30th, 2003 (Table 3). Median concentrations of DRP, in particular, were about double after than before June 30th, 2003. This split in the data coincided with many of the dairy conversions in the catchment.

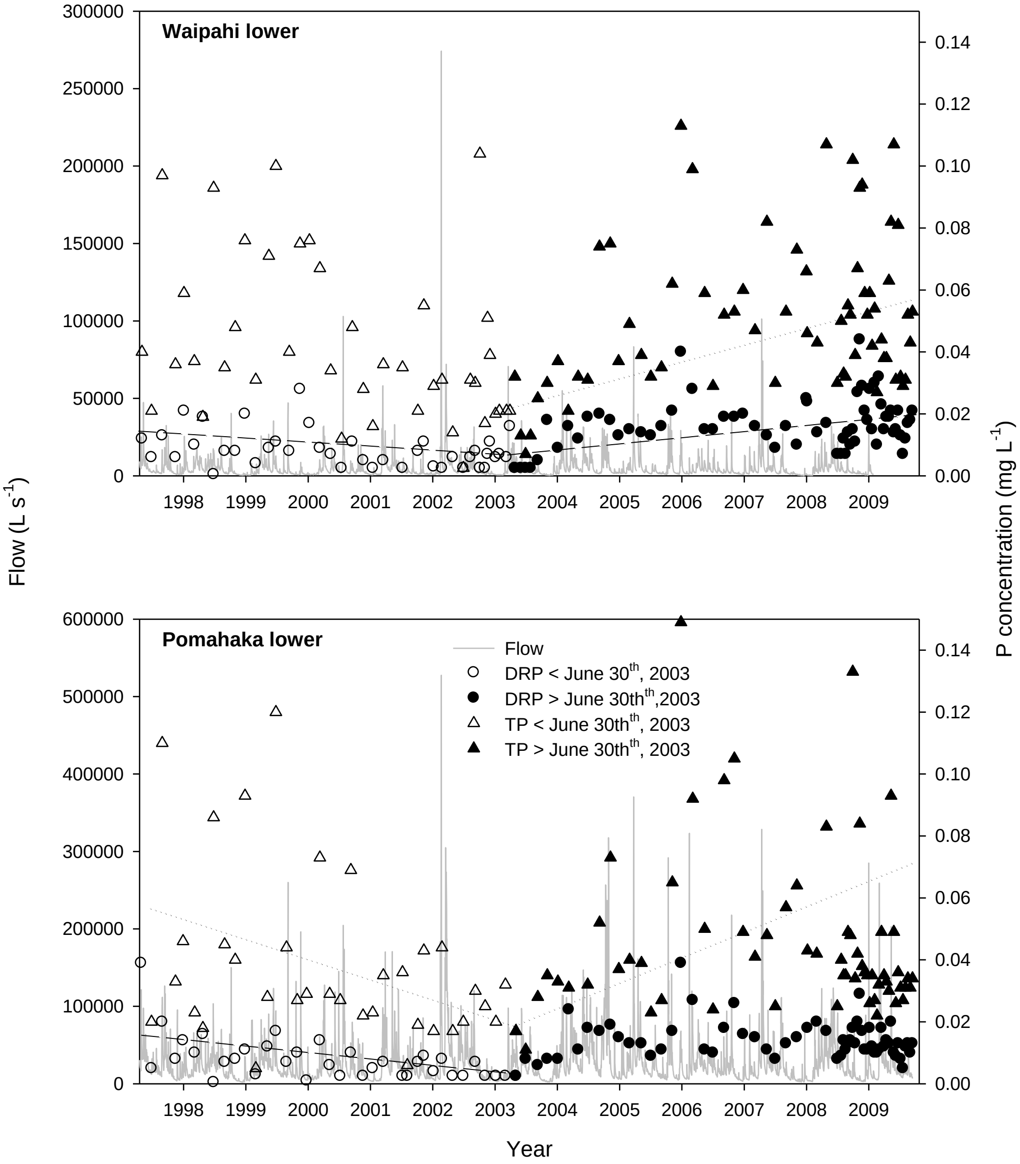

Fig. 2. Variation in flow and the concentration of dissolved reactive P (DRP) and total P (TP) in the lower Waipahi and low Pomahaka rivers < and > June 30th, 2003. Lines represent a significant fit (*P*<0.05 or better) of the data as assessed by the seasonal Kendall test pre and post June 30th, 2003.

Table 2. Summary statistics and seasonal Kendall test for constituents (all mg L^{-1} except for *E. coli* which is measured as coliform forming units 100 mL^{-1}) measured from 1997 to 2010 at long-term sites in the Pomahaka catchment.

Site / constituent	Mean	Standard deviation	Range	Median	Sen slope trend (change in median)	Significance[a]
Waipahi upper						
DRP	0.017	0.009	0.003-0.050	0.018	0.003	***
TP	0.072	0.064	0.012-0.394	0.057	0.006	***
NH_4^+-N	0.019	0.013	0.005-0.070	0.020	<0.001	ns
NNN	0.719	0.402	0.020-1.870	0.616	-0.004	ns
TN	1.121	0.493	0.440-3.700	0.980	0.036	*
E. coli	1343	4657	10-37000	250	-7	ns
SS	16.8	28.8	7.0-206.0	7.0	0.2	ns
Waipahi lower						
DRP	0.013	0.008	0.001-0.044	0.013	0.001	***
TP	0.049	0.027	0.001-0.155	0.040	0.002	**
NH_4^+-N	0.019	0.015	0.003-0.070	0.020	0.006	***
NNN	0.964	0.706	0.002-2.920	0.939	0.020[b]	**
TN	1.334	0.731	0.170-3.460	1.340	0.022[b]	**
E. coli	555	1447	1-10800	130	-6	ns
SS	9.1	13.0	0.5-72.0	4.0	<0.1	ns
Pomahaka upper						
DRP	0.008	0.005	0.001-0.027	0.008	<0.001	***
TP	0.025	0.020	0.002-0.113	0.019	<0.001	*
NH_4^+-N	0.010	0.008	0.005-0.040	0.005	<-0.001	*
NNN	0.090	0.152	0.001-1.090	0.036	-0.001	ns
TN	0.268	0.197	0.025-1.050	0.210	<-0.001	ns
E. coli	442	874	18-4800	140	-5	ns
SS	5.7	9.4	0.5-53.0	2.0	<0.1	ns
Pomahaka lower						
DRP	0.012	0.007	0.001-0.039	0.011	0.006	***
TP	0.048	0.053	0.005-0.500	0.035	0.008[b]	*
NH_4^+-N	0.020	0.024	0.005-0.220	0.020	-0.001	***
NNN	0.594	0.483	0.003-2.870	0.471	0.003	ns
TN	0.953	0.053	0.090-4.000	0.740	-0.007	ns
E. coli	700	1911	1-12000	99	-5	ns
SS	11.8	27.6	0.5-260.0	5.0	-0.1	ns

[a] *, **, and *** represent significance for the annual change in median concentration (seasonal Kendall test) with time at the $P<0.05$, 0.01 and 0.001 level, respectively. ns = not significant.

[b] Sen slope estimator presented for flow adjusted data where model accounts for > 50% of the variance.

Table 3. Pre and post June 30th, 2003 median concentration and seasonal Kendall test results for constituents exhibiting significant trend with time (1997-2010) at long-term sites in the Pomahaka catchment.

Site / constituent	-------------------- < June 30th, 2003 --------------------			-------------------- >June 30th, 2003 --------------------		
	Median	Sen slope trend (change in median)	Significance[a]	Median	Sen slope trend (change in median)	Significance[a]
Waipahi upper						
DRP	0.004	<0.001	ns	0.018	0.002	***
TP	0.027	<0.001	ns	0.057	0.007	*
Waipahi lower						
DRP	0.008	-0.001	*	0.016	0.001	*
TP	0.036	-0.002	*	0.050	0.004	*
NH_4^+-N	0.020	-0.002	ns	0.019	<-0.001	ns
NNN	1.050	-0.027	ns	1.005	0.055	ns
TN	1.400	-0.046	ns	1.315	0.077	*
Pomahaka upper						
DRP	0.004	-0.001	ns	0.009	<0.001	ns
TP	0.017	-0.001	ns	0.020	0.002	*
NH_4^+-N	0.013	-0.001	ns	0.010	<-0.001	*
Pomahaka lower						
DRP	0.007	-0.002	**	0.013	<0.001	ns
TP	0.029	-0.004	*	0.040	0.001	*
NH_4^+-N	0.020	<0.001	ns	0.018	<0.001	ns

[a] *, **, and *** represent significance for the annual change in median concentration (seasonal Kendall test) with time at the $P<0.05$, 0.01 and 0.001 level, respectively. ns = not significant.

3.1.2 Short term sites

More intensive sampling of all sites occurred for 14 months from October, 2008. Summary box plots for contaminants measured from all stream and river sites are shown in Figure 3. Sites were chosen to reflect and capture most land use and potential contaminant sources within the wider Pomahaka River catchment. Similar to the long-term sites, which were included in the wider dataset (Fig. 3), median concentrations of the DRP, TP, and at times NNN or *E. coli*, exceeded guidelines (see dashed lines in Fig. 3). Using an interpolation procedure, area specific loads were also calculated for each contaminant, and listed alongside land use, for each site in Table 4.

Notable discussion points in contaminant concentrations at each site include: the enriched contaminant concentrations in the Washpool and Wairuna streams, both of which drain a much larger proportion of dairy-farmed land than other sites; enriched losses of all contaminants except *E. coli* from the Waipahi River sites, including the upper site which contains forest/native tussock, but has recently seen a wetland within the catchment drained for grazing (not captured by landuse data in Table 4); enriched concentrations of NNN and TN from the Crookston Burn and Flodden Creek; and the very low concentrations of contaminants lost from the Black Gully Creek Upper site, despite draining 100% forested land.

Loads of contaminants on a per ha basis ranged from a low in the upper Black Gully creek to a high in either the upper Waipahi River or Wairuna stream (Table 4). As a comparison, McDowell and Wilcock (2008) established mean loads (kg ha^{-1}) in New Zealand pastoral catchments of TN, TP and SS at 11, 1.3 and 1,156, respectively for sheep and beef farmed land; 27, 1.9 and 299, respectively for dairy farmed land; and 2, 0.2 and 174, respectively for forest or native bush. Among sites, those that had at least 25% dairying in the catchment (e.g. lower Black Gully creek, Crookston Burn, Flodden Creek, and the Wairuna and Washpool streams) had similar loads to means loads for dairy-farmed catchments in New Zealand. The exception was the large TN and TP load from the forested upper Waipahi river site, ascribed as mentioned before, to the drainage of a large wetland.

Seasonal changes in contaminant loads are demonstrated by mean monthly *E. coli* concentrations at each site in Figure 4. Changes in *E. coli* concentration over time were consistent with flow rates (i.e. diluting concentrations in winter months of June to August when no enriched source like effluent was being applied). However, evident at many of the sites was a sudden increase in concentrations in May, and enriched concentrations in spring for those sites with at least 25% dairying (e.g. Wairuna and Washpool). The increase in May could be due to a flushing effect as sediment, and entrained NH_4-N, P fractions and *E. coli*, are re-suspended in the water column as flow rates increase (Muirhead et al., 2004). However, the May samplings occurred before any significant rainfall. Furthermore, *E. coli*, TP and NH_4-N concentrations in tile drainage (see section 3.1.3), sampled before rainfall, were also enriched suggesting the source as effluent-derived. The seasonal pattern for NH_4-N, SS, DRP and TP at the short-term sites was similar to *E. coli*, whereas NNN and TN (NNN generally comprised >60% of TN) were greatest in May to July as NNN was flushed from the soil upon the onset of autumn/winter drainage and uptake by plants and periphyton was less due to shorter day length and lower light intensity and temperature.

An effect of enriched P loss to the Pomahaka River and its tributaries will be periphyton growth. If flows are stable during November to April, i.e. when day length is long and temperatures warm enough to promote growth (Young and Huryn, 1996), periphyton utilise dissolved N and P to grow until one of the nutrients becomes limiting. We calculated a dissolved N (NH_4-N + NNN) to P (DRP) ratio for each site and used the ratios published by Guildford and Hecky (2000) of <7:1 and >15:1 N:P to indicate N- and P-limitation, respectively (mass basis). These ratios are analogous to those used by the MfE (2007) and White (1983). Ratios indicative of P-limitation, during November to April, were evident at Lower Black Gully Creek, Upper, the Crookston Burn, Flodden Creek, both Heriot Burn sites, the Upper Pomahaka, both Waipahi sites, and the Wairuna Stream, all others were N-limited. Apart from the upper Pomahaka site, all other sites had a significant proportion of dairying in the catchment. In addition, the mean N:P ratio for artificial drainage was > 100. Withers et al. (2009) also found discharges from drainage of farmyards and hard-standing areas was P-limited, but noted that due to the greatly enriched concentrations of both N and P, P-limitation would only occur when biomass was already high. The prevalence of P-limitation in the streams, and P-rich discharge from tiles, suggests that tile drainage could have a large effect on periphyton growth.

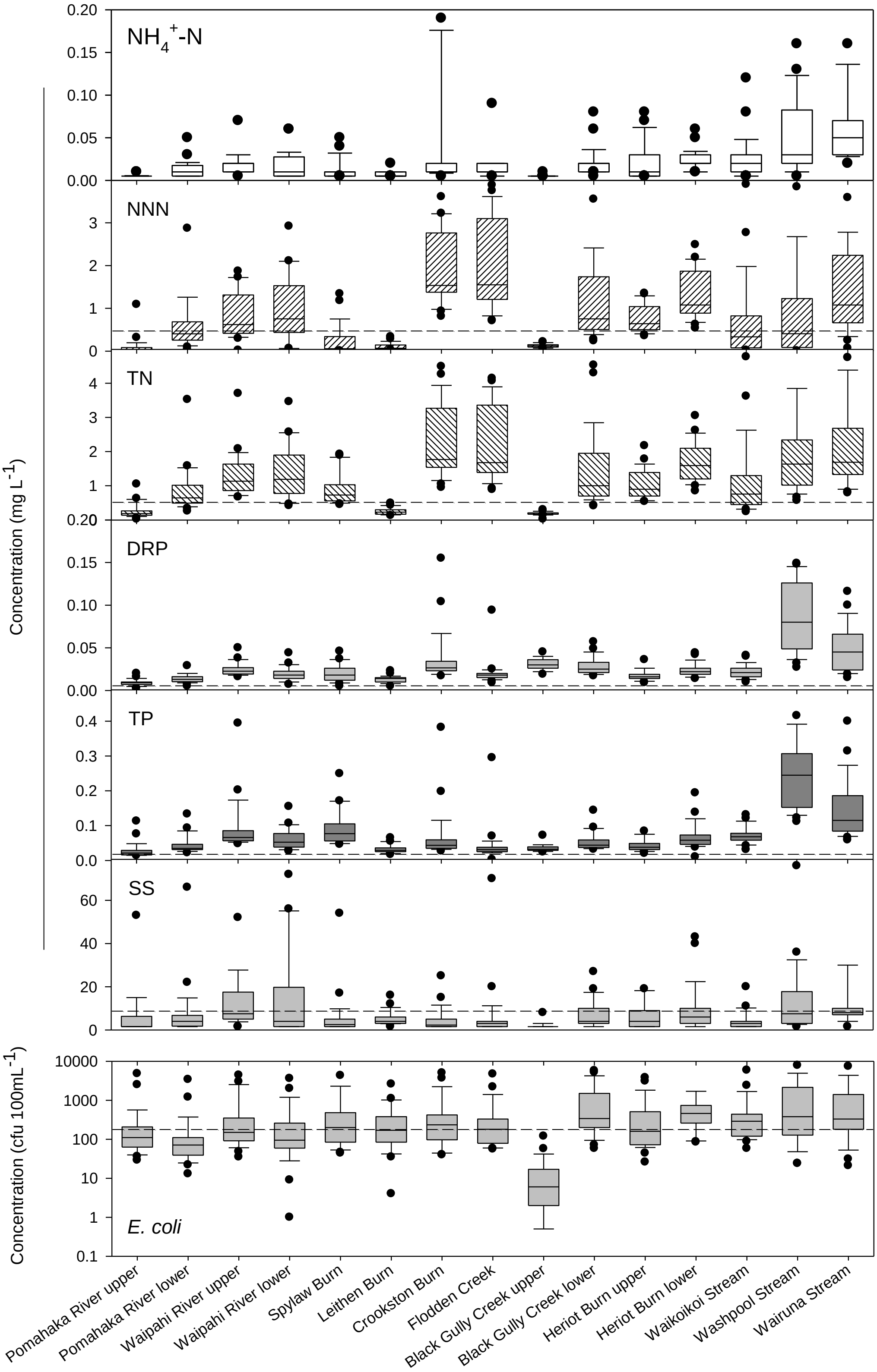

Fig. 3. Box (25th and 75th percentile and median) and whisker (5 and 95th percentile, outliers shown as filled circles) plots indicating the relative concentration of contaminants during 2009 at each site. The ANZECC (2000) guidelines for the concentration of each contaminant and amber limit for *E. coli* (Ministry for the Environment, 2003) are indicated by the dashed lines.

Table 4. Land use (km^2) and loads of contaminants (all kg ha^{-1}) estimated for each site for 2009.

Site	------------- Land use -------------				--- Loads ---					
	Total	Dairy	Sheep & beef	Other[a]	NH_4^+-N	NNN	TN	DRP	TP	SS
Black Gully Creek lower	25	9	6	10	0.09	5.1	6.0	0.08	0.15	26
Black Gully Creek upper	6	0[b]	0	6	0.03	0.6	1.0	0.15	0.17	11
Crookston Burn	32	14	8	10	0.31	11.2	13.5	0.17	0.35	32
Flodden Creek	43	11	19	13	0.05	7.6	8.6	0.07	0.16	29
Heriot Burn lower	142	22	17	103	0.05	3.4	4.2	0.04	0.13	25
Heriot Burn upper	25	3	6	16	0.05	2.9	4.0	0.05	0.31	252
Leithen Burn	72	0	29	43	0.03	0.7	1.4	0.06	0.15	30
Pomahaka River lower	1881	141	245	1495	0.07	4.8	6.9	0.05	0.34	60
Pomahaka River upper	714	2	40	672	0.02	0.8	1.6	0.04	0.15	38
Spylaw Burn	167	2	0	165	0.01	0.7	1.3	0.02	0.07	6
Waikoikoi Stream	116	23	0	93	0.06	1.7	2.6	0.04	0.14	11
Waipahi River lower	299	4	8	287	0.11	8.0	10.2	0.09	0.33	104
Waipahi River upper[c]	15	0	0	15	0.09	25.4	38.2	0.12	2.61	528
Wairuna Stream	39	20	0	19	0.57	12.4	17.7	0.24	1.01	292
Washpool Stream	35	28	0	8	0.11	3.6	5.2	0.10	0.32	51

[a] predominantly forest with some native bush or tussock.

[b] percentages < 1 rounded to zero.

[c] land use in the Upper Waipahi catchment has seen recent change to sheep and beef and dairy at the expense of a wetland. This was not capture in the land use data available.

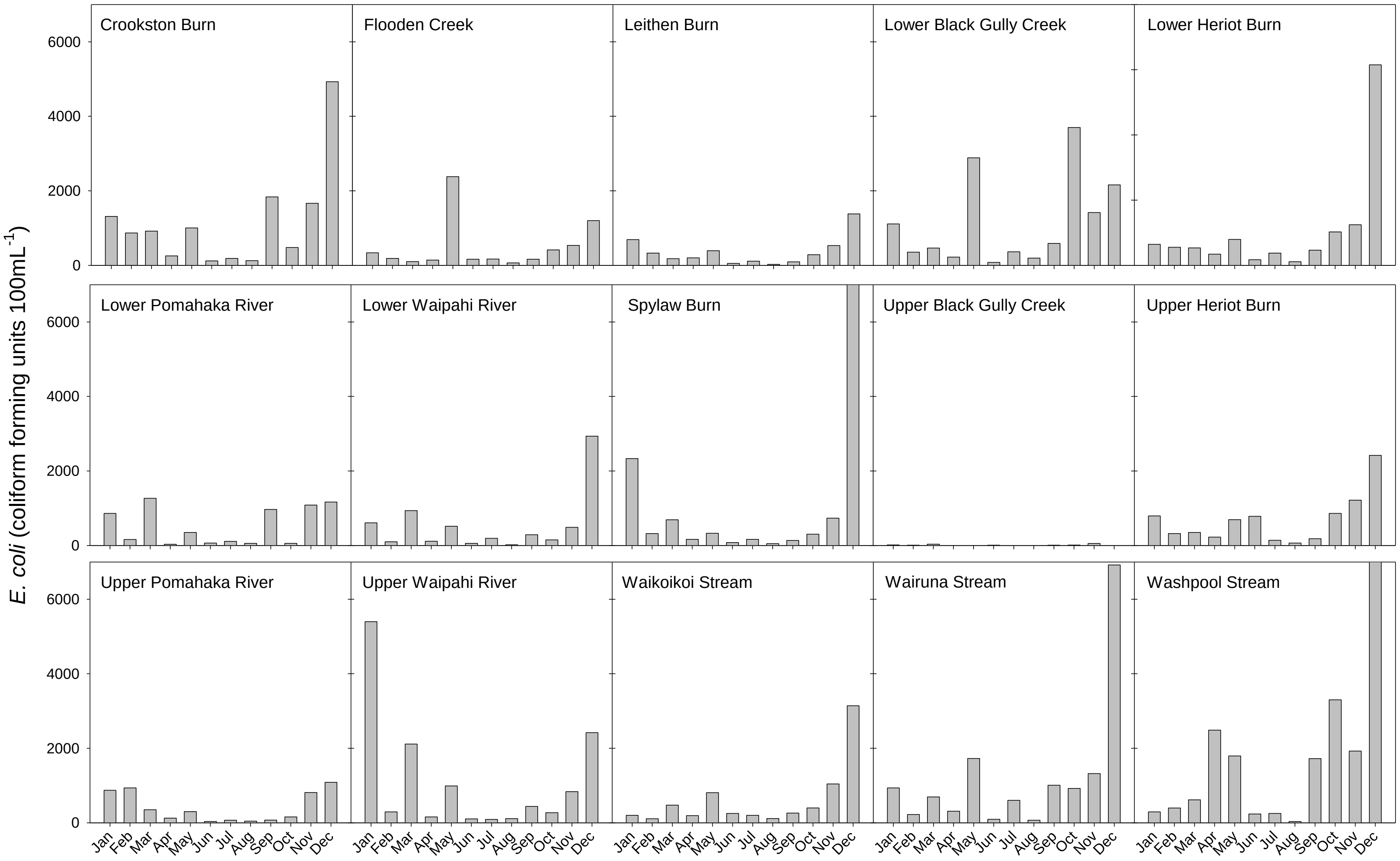

Fig. 4. Mean monthly concentration of *E. coli* in samples from short and long-term sites.

3.1.3 Artificial drainage

Contaminant concentrations are presented as box and whisker plots in Figure 5 draining from dairy and sheep farmed land and for the receiving waterways, the Heriot Burn and Wairuna stream. Generally, a greater range of contaminant concentrations existed in drainage than the receiving waterways, while median concentrations also tended to be greater. As it was not possible to establish the area being drained by each drain (only the dominant land use), loads were not calculated. However, there is much evidence within the catchment and on similar soil types and climates to show that the enrichment of dairy-farmed drains may partly be due to the application of effluent to artificially drained land, which can result in direct loss via preferential flow to surface waterways (e.g. Monaghan and Smith, 2004; McDowell et al., 2005). Losses are exacerbated when too much is applied and/or effluent is applied to wet soils. Such a scenario is common in spring, especially in the Pomahaka catchment, when soils are wet and the few effluent ponds that exist tend to be small and full (Houlbrooke et al., 2008). In addition to the example highlighted for *E. coli* in section 3.1.2, data for TP indicated that while enhanced loads were evident in drainage, when the soil was wet, loads were also enriched despite there being no rainfall (Fig. 6), indicative of contamination by effluent: P loss via flow from springs (also independent of rainfall) is also low.

Incorporating data from Tussock Creek and Kelso brought the total number of tile drainage samples to 1006 of which *c*. 200 occurred from October to April (Fig. 5). Visual inspection of the data suggests that there is potential to distinguish two sets of data for three of the contaminants: NH_4-N, *E. coli* and TP. One set (Eff. drain) was much greater than the other and was associated with drainage soon after the application of effluent. This represents bad practice and resulted in “contaminated” drainage within 24 hrs of application. All other data is pooled together to form the “control” population and represents normal drainage concentrations. We present a technique to detect a real difference between the two populations in section 3.4.

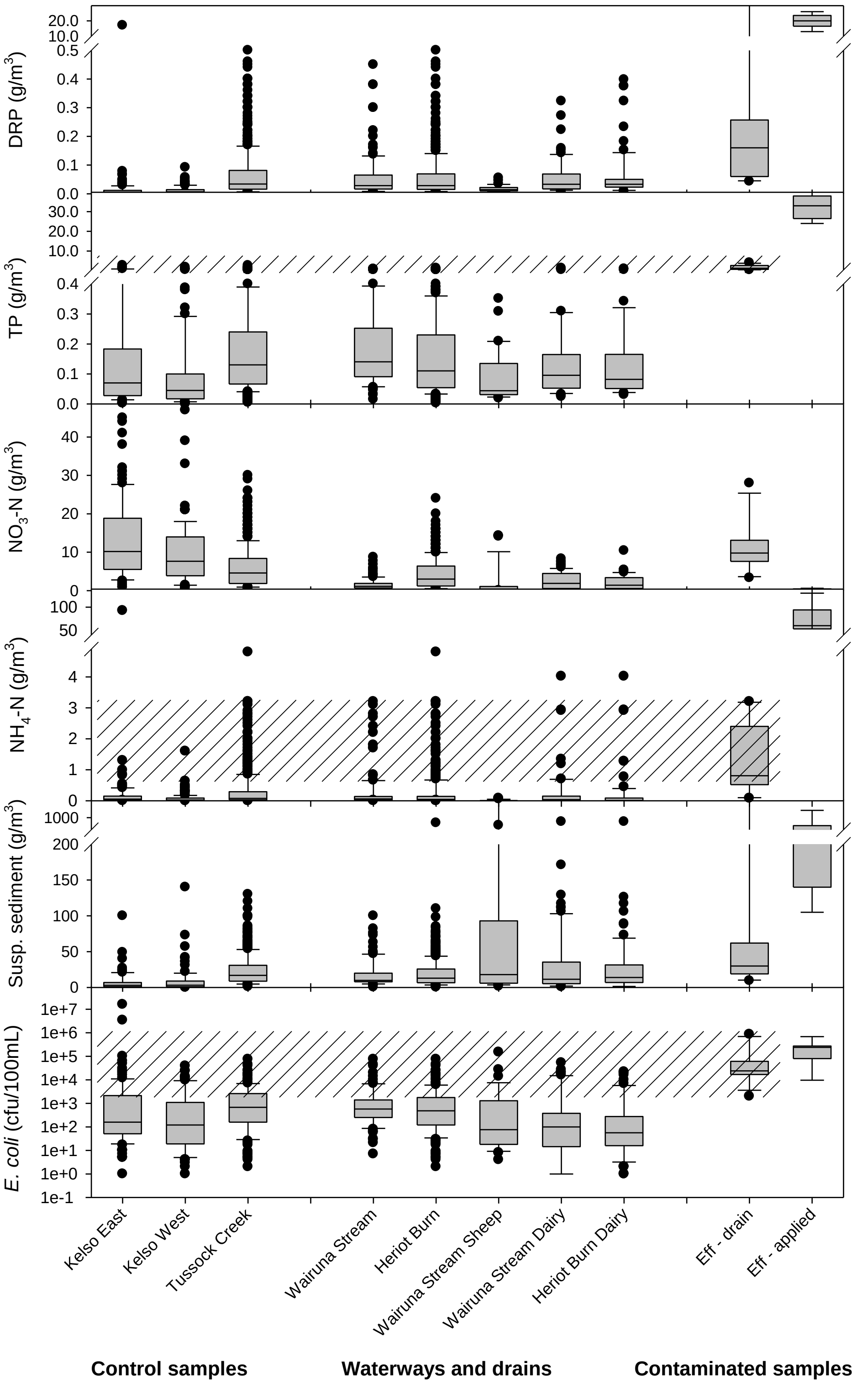

Fig. 5. Box (25th and 75th percentile and median) and whisker (5 and 95th percentile, outliers shown as filled circles) plots indicating the concentration of contaminants in control samples and samples of effluent and drainage within 24 hrs of effluent application (Eff. Drain) that denote contaminated samples from Kelso and Tussock Creek, and Heriot Burn and Wairuna Stream and dairy or sheep drainage samples. Cross-hatching denotes the range of samples from the Eff. drain dataset relative to all other samples for those contaminants that may show a difference between populations.

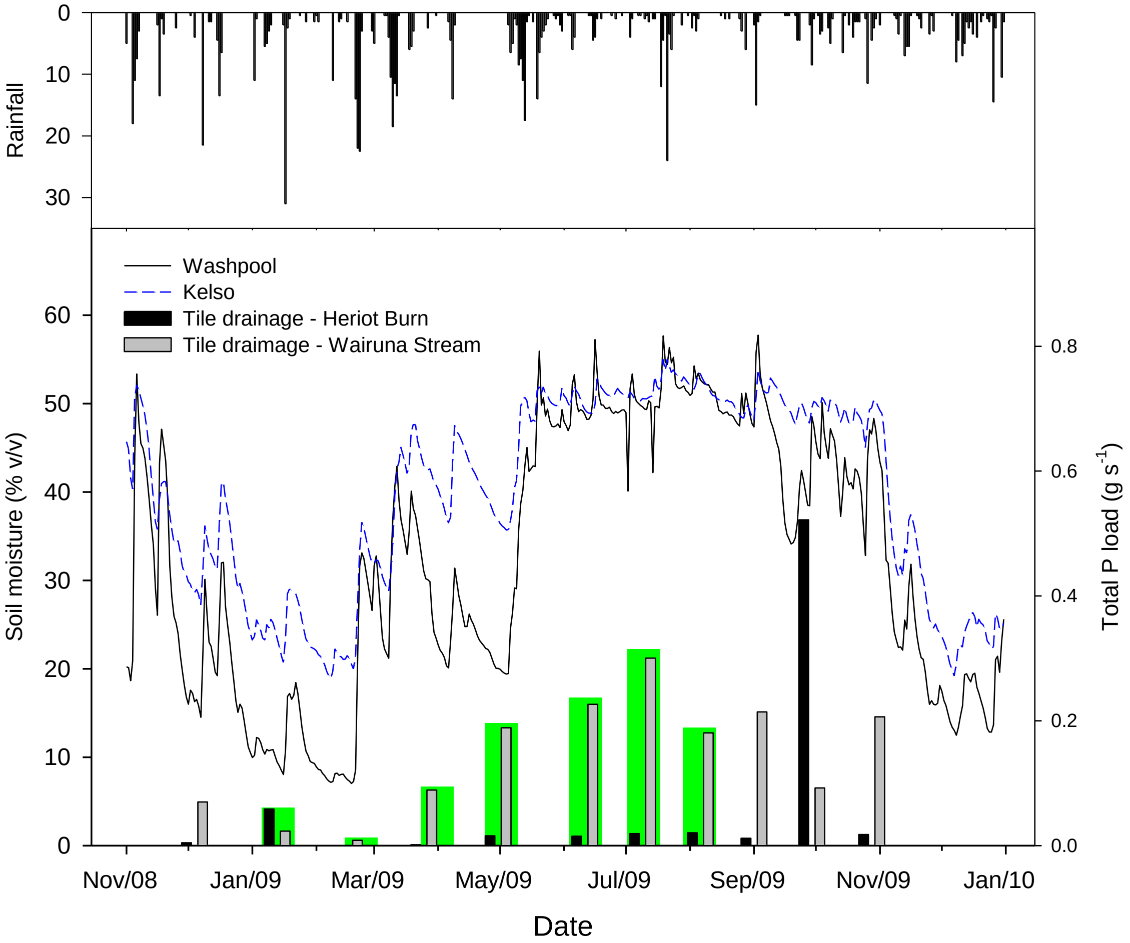

Fig. 6. Mean rainfall and soil moisture at two sites in the Pomahaka catchment (within the Washpool and adjacent to the Wairuna Stream catchment and at Kelso, adjacent to the Heriot Burn catchment; Otago Regional Council, 2011) and the mean load of total P in drainage from dairy-farmed sites in the Heriot Burn and Wairuna Stream catchments. Bars with light green background refer to drainage on a day when no rainfall occurred.

3.2 Published surface water quality guidelines and targets

3.2.1 Populating "Table 1: Receiving water standards to meet various values"

The proposed "Table 1" provided by ORC has been populated and expanded in Table 5. The significant change has been expansion of the number of contaminants from four to 15. This is necessary as it would be impossible to maintain the required values in streams using only four contaminants. Table 5 is a summary of all of the contaminants, further details regarding the interpretation and measurement of these contaminants is discussed further in the following tables.

Table 5: Receiving water standards to meet various values

Contaminant	Protection of aquatic ecosystems							Food gathering	Primary contact recreation	Human drinking water	Animal drinking water	Abstraction
	High conservation value systems	Slightly to moderately disturbed systems	Highly disturbed systems	Trout Spawning	Trout Fishery	Eel Fishery	Shellfish					
Total P	26 ug P L^{-1}	33 ug P L^{-1}										
FRP	9 ug P L^{-1}	10 ug P L^{-1}		26 ug P L^{-1}	26 ug P L^{-1}							
Total N	295 ug N L^{-1}	614 ug N L^{-1}										
NO_x-N	167 ug N L^{-1}	444 ug N L^{-1}		295 ug N L^{-1}	295 ug N L^{-1}							
NO_3-N										11.3 mg N L^{-1}	339 mg N L^{-1}	
NO_2-N										61 ug N L^{-1}	9 mg N L^{-1}	
NH_3-N	900 ug N L^{-1}	900 ug N L^{-1}		21 ug N L^{-1}	21 ug N L^{-1}							
E. coli					260 cfu 100 mL^{-1}				260 cfu 100 mL^{-1}	<1 cfu 100mL^{-1}		
Faecal coliforms							14 cfu 100mL^{-1} and 43 cfu 100mL^{-1}				100 cfu 100mL^{-1} and 400 cfu 100mL^{-1}	Varies depending on water use
Pathogenic protozoa										<1 (oo)cyst 100 L^{-1}		
DO	99-103 %	98-105 %		>80 % saturation	>80 % saturation							
pH	7.3-8.0	7.2-7.8		7.2-8.0	7.2-8.0							
Temperature				< 11 °C	< 19 °C	<28 °C						
Turbidity				0.7 NTU	0.7 NTU							
Clarity									1.2 m			

3.2.2 Guidelines for upland and lowland rivers.

The concentrations in Table 6 are based on the ANZECC (2000) guidelines for upland and lowland river systems with high conservation value and moderately disturbed, respectively. These are trigger concentrations that are used to instigate investigation of the catchment to see if there are any factors that maybe influencing the water quality. If issues are identified they should be managed to limit their effect on water quality. Commensurate with this "meet" or "exceed" analysis, trend analysis should be conducted. If there are no deteriorating trends, and water quality is within guidelines, then the catchment is being effectively managed.

There are no published standards for highly disturbed systems. The simplest approach in this situation is to set targets based on historical water quality data for the catchment of interest. People in the catchments often understand that they cannot go back to a pristine catchment but can often remember a time when the water quality was acceptable, although other groups can find this approach unacceptable. The other key advantage of using historical data is that it also takes into account the geology of the region rather than trying to apply data collected in another region to local issues (see section 3.3).

Table 6. Guidelines for upland and lowland rivers

Contaminant / river system	Value	Measurement	Reference
Upland			
Total P	26 ug P L^{-1}	Single Sample	ANZEEC (2000)
FRP	9 ug P L^{-1}	Single Sample	ANZEEC (2000)
Total N	295 ug N L^{-1}	Single Sample	ANZEEC (2000)
NNN	167 ug N L^{-1}	Single Sample	ANZEEC (2000)
Ammoniacal-N	900 ug N L^{-1}	Single Sample	ANZEEC (2000)
Dissolved Oxygen	99-103 %	Range	ANZEEC (2000)
pH	7.3-8.0	Range	ANZEEC (2000)
Lowland			
Total P	33 ug P L-1	Single Sample	ANZEEC (2000)
FRP	10 ug P L-1	Single Sample	ANZEEC (2000)
Total N	614 ug N L-1	Single Sample	ANZEEC (2000)
NNN	444 ug N L-1	Single Sample	ANZEEC (2000)
Ammoniacal-N	900 ug N L-1	Single Sample	ANZEEC (2000)
Dissolved Oxygen	98-105 %	Range	ANZEEC (2000)
pH	7.2-7.8	Range	ANZEEC (2000)

3.2.3 Trout habitat and spawning

These guidelines are taken from Hay et al. (2006) and will provide conditions suitable for maintaining trout fisheries. These guidelines are targeted at high quality fishing catchments, such as the Pomahaka, that provide a valued recreational resource and bring in economic benefits associated with paying/visiting fishermen. The main challenge appears to be mitigating the impact of sediment and nutrients on trout food supply, turbidity on a trout's ability to hunt food and the impact of sediment on spawning habitat. It should be noted that new evidence is starting to indicate that Trout eggs may be highly sensitive to nitrate in excess of 2 mg nitrate-N L^{-1} and therefore, the required nitrate standards may be revised to lower concentrations in the next version of the ANZECC guidelines (R Young, *pers. comm.*) To maintain a healthy trout population in an agricultural catchment will require a high quality headwater reach and tributaries for trout spawning, juvenile rearing areas and adult feeding habitat. To improve and/or maintain a trout fishery will require a focus on sediment and nutrient loads. We have made an assumption than in the Otago region water temperatures will naturally be acceptable.

To maintain an outstanding fishing habitat guidelines are the same as those for Trout spawning values in Table 7 except that turbidity should be <0.5 NTU, temperature should be <19°C and *E. coli* <260 cfu 100 mL^{-1}. For a significant fishing habitat the only difference to those guidelines listed for an outstanding fishing habitat is that turbidity should be <0.7 NTU.

Table 7. Guideline concentrations, beyond which Trout spawning will be impaired

Contaminant	Value	Measurement	Reference
FRP	26 ug P L^{-1}	Single Sample	Hay et al. (2006)
NNN	295 ug N L^{-1}	Single Sample	Hay et al. (2006)
Turbidity	0.7 NTU	Single Sample	Hay et al. (2006)
Temperature	< 11 °C	Daily Max	Hay et al. (2006)
Ammoniacal-N	21 ug N L^{-1}	Single Sample	Hay et al. (2006)
Dissolved Oxygen	>80 % saturation	Single Sample	Hay et al. (2006)
pH	7.2-8.0	Range	Hay et al. (2006)

3.2.4 Eels fishery and food gathering in freshwater

Published guidelines for maintaining eel fishery habitat indicate that eels are most sensitive to temperature (Richardson et al., 1994; Dean and Richardson, 1999). A water temperature <28°C appears to be sufficient for survival for all life stages of native eels (Richardson et al., 1994).

There are no published guidelines for maintaining water quality in food gathering areas. There are guidelines for the number of *E. coli* in the harvested food, but not for the water the food is grown in (other than for shellfish). There are only weak relationships between *E. coli* concentrations in watercress and in the stream the watercress was collected from Donnison et al. (2009).

3.2.5 Contact Recreation

For contact recreation, the *E. coli* guideline of 260 cfu $100mL^{-1}$ is based on the 95th percentile of a set of reference samples (MfE, 2003), while the clarity guideline of 1.6m via black disc comes from ANZECC (2000). Hay et al. (2006) say that clarity measurement can be related to turbidity (NTU) measurements, but this should be conducted on each individual river.

Contact recreation is also a requirement for fishing values as this sport requires contact with the river. The *E. coli* guidelines required to achieve the contact recreation values will be very hard to achieve in agricultural catchments due to the high levels lost from tile drains even under low-intensity sheep pastures. For contact recreation good water clarity is required to see submerged obstacles and hazards in the stream.

3.2.6 Human and animal drinking water

Table 8. Guidelines for human and animal drinking water

Contaminant / user	Value	Measurement	Reference
Human			
E. coli	<1 cfu $100mL^{-1}$	Single Sample	MoH (2005)
Total Pathogenic Protozoa	<1 (oo)cyst 100 L^{-1}	Single Sample	MoH (2005)
Nitrate-N	11.3 mg N L^{-1}	Single Sample	ANZEEC (2000)
Nitrite-N	61 ug N L^{-1}	Median	ANZEEC (2000)
Animal			
Faecal coliforms	100 cfu 100mL-1	Median	ANZEEC (2000)
Faecal coliforms	400 cfu 100mL-1	80th percentile	ANZEEC (2000)
Nitrate-N	339 mg N L-1	Single Sample	ANZEEC (2000)
Nitrite-N	9 mg N L-1	Single Sample	ANZEEC (2000)

For humans, the microbial guidelines are a lot more difficult to achieve than the nitrite and nitrate guidelines (Table 8). Drinking water is seldom an option for surface waters as it would always require some treatment before use.

Animal drinking water standards can be separated into two parts. The nitrate-N guidelines would appear to be based on scientific studies of effects on animals. The faecal indicator guidelines appear to be based on expert opinion rather than accepted science methods. Given the limited scientific data behind these specific values we could replace “faecal coliforms” with “*E. coli*” to simplify laboratory analysis (Sinton and Weaver, 2008). It is generally accepted that *E. coli* comprise 80 to 95% of the numbers of organisms in the faecal coliform group. This would result in a slightly relaxed standard that according to a report by Abacus (2004) would have little impact on animals drinking the water.

3.2.7 Abstraction - Irrigation water

Irrigation water standards (Table 9) use only faecal microbes as a contaminant and appear to be based on expert opinion rather than accepted science methods.

Table 9. Guidelines for the use of abstracted water

Contaminant	**Value**	**Measurement**	**Reference**
Faecal coliforms	Varies depending on use of irrigation water, see below	Median	Modification of ANZEEC (2000)

Use of irrigation water	**Value**
Human food consumed raw in direct contact with the irrigation water	10 cfu 100mL^{-1}
Human food consumed raw but not in direct contact with the irrigation water	1000 cfu 100mL^{-1}
Pasture and fodder for dairy animals with no withholding period	100 cfu 100mL^{-1}
Pasture and fodder for dairy animals using a 5 day withholding period	1000 cfu 100mL^{-1}
Pasture and fodder for grazing animals other than dairy cows and pigs	1000 cfu 100mL^{-1}
Non-food crops with restricted public access	10,000 cfu 100mL^{-1}

3.3 A baseline of water quality in the Pomahaka River

A baseline concentration is classified here as the median contaminant concentration for a waterway without any anthropogenic influence. A description of the methodology and data used to set water quality baselines in the Pomahaka River is given in McDowell et al. (2011). Briefly, the analysis (T. Snelder, NIWA, *pers. comm.*) used data from 100 State of the Environment (SoE) reporting sites from South Canterbury and North and South Otago for 1998 to 2007. These sites had similar soils and climate as per the River Environment Classification (Snelder and Biggs, 2002). The SoE sites were further classified into lowland and upland sites.

For sites that had at least 40 sampling occasions, median contaminant concentrations were calculated. A regression was then performed between the percentage of pasture in the sample site's catchment as the independent variable and the median concentration as the dependant variable (Dodds and Oakes, 2004). The Y-intercept of the regression is the estimated baseline median concentration of the water quality variable.

Significant relationships were achieved between the percentage pasture and the median concentration of all contaminants except *E. coli* and TP (Table 10), while a different baseline was differentiated for upland and lowland sites for NH_4^+-N and NNN. Median concentrations were greater (by 10% or more) than the estimated baseline at all sites except for three, two and one site for NH_4^+-N, NNN and SS, respectively. This is presented in Table 11 for each site against the respective natural or background median concentration (Smith et al., 2003; Unwin et al., 2010). These highlight the effect of development in the catchment, but if you consider a median concentration to be a surrogate for load, also the manageable load. The challenge is then, within this manageable portion, to establish a cause (see section 3.4) and the impact different strategies can have on mitigating contaminant loss (see section 3.5).

Table 10. Baseline statistics (median, standard error and significance as P value) for contaminant concentrations at upland and lowland sites (if separation is applicable) determined via the intercept of a regression between median concentrations and percentage pasture at 100 state of the environment monitoring sites. Non-significant baselines are not given.

Contaminant	Elevation	Baseline (median g m^{-3})	Standard error	Significance
DRP	Both	0.003	0.001	<0.001
NH_4^+-N	Upland	0.006	0.001	<0.001
NH_4^+-N	Lowland	0.009	0.002	0.031
NNN	Upland	0.024	0.009	<0.001
NNN	Lowland	0.058	0.027	0.022
SS	Both	1.432	0.275	0.044
TN	Both	0.140	0.025	<0.001

Table 11. Median contaminant concentrations for each site and the percentage of the median concentration manageable (manage.) relative to a baseline in Table 10 (i.e. ((Median – Baseline)/Median) × 100%).

Site	Elevation	NH_4^+-N		DRP		NNN		SS		TN	
		Median	% manage.	Median	% manage.	Median	% manage.	Median	% manage.	Median	% manage.
Black Gully Creek upper	H	0.005	0[a]	0.030	90	0.122	80	1.5	5	0.200	30
Heriot Burn upper	H	0.010	40	0.016	81	0.683	96	4.0	64	0.910	85
Leithen Burn	H	0.005	0	0.014	79	0.068	65	4.0	64	0.230	39
Pomahaka River upper	H	0.020	70	0.011	73	0.480	95	5.0	71	0.745	81
Black Gully Creek lower	L	0.020	55	0.025	88	0.754	92	4.0	64	1.000	86
Crookston Burn lower	L	0.010	10	0.018	83	1.550	96	3.0	52	1.680	92
Crookston Burn upper	L	0.010	10	0.027	89	1.535	96	2.3	36	1.770	92
Heriot Burn lower	L	0.020	55	0.022	86	1.080	95	6.0	76	1.590	91
Pomahaka River lower	L	0.008	0	0.008	63	0.037	0	2.0	28	0.210	33
Spylaw Burn	L	0.010	10	0.018	83	0.056	0	2.5	43	0.730	81
Waikoikoi Stream	L	0.020	55	0.021	86	0.335	83	3.0	52	0.760	82
Waipahi River lower	L	0.020	55	0.013	77	0.939	94	4.0	64	1.340	90
Waipahi River upper	L	0.020	55	0.018	83	0.616	91	7.0	80	0.980	86
Wairuna Stream	L	0.055	84	0.030	90	1.000	94	8.0	82	1.660	92
Washpool Stream	L	0.030	70	0.080	96	0.406	86	7.5	81	1.635	91

[a] highlighted percentage refers to a site not significantly different (baseline + standard error) from reference conditions.

3.4 Test to detect the contamination of surface waters by drainage associated with the application of effluent to land under bad practice.

A non-parametric Kruskal-Wallis comparison of median concentrations for each contaminant indicated that there was no significant difference between Kelso or Tussock Creek sites (or between the analysis of annual data and those generated from October to April. Hence, data for all sites, irrespective of time of year, was pooled. However, for three contaminants (*E. coli*, NH_4-N and TP) two populations existed (means different at $P<0.05$). These were classified as contaminated, i.e. those known to occur within 24 hrs of effluent being applied, and control – representing all other data. Although some of the control data may have been influenced by “contaminated” drainage, our classification was based on the isolation of bad practice – here defined as drainage within 24 hrs of effluent applications when the soil moisture deficit was low.

Data was log-normally distributed. Following a log transformation a discriminant analysis was conducted to determine if there was a combination of the three variables that separated the control and contaminated datasets better than a single variable. The resulting equation to calculate the combination variable was:

$$\text{Combination} = 0.13 * \ln(\textit{E. coli} + 1) + 0.14 * \ln(NH_4\text{-N} + 0.005) + 0.57 * \ln(TP + 0.0025)$$

where *E. coli* is measured in cfu $100mL^{-1}$ and NH_4-N and TP in g m^{-3}. The values 1, 0.005 and 0.0025 refer to the detection limit for each contaminant and are necessary to avoid taking the log of zero. The mean of the contaminated data for total P (1.305 mg L^{-1}) was greater than 99.0% of the control concentrations (Table 12). 95.4% of the control population P concentrations are less than 1 standard deviation below the contaminated mean (i.e. the lower 16% of contaminated values – see Fig 7) and 85% of the control population P concentrations are less than 2 standard deviations below the contaminated mean (i.e. the lower 2.5% of contaminated values). Due to a greater overlap between control and contaminated data, the percentiles for NH_4-N and *E. coli* concentrations were less at 56.6% and 76.6% for the mean of contaminated data minus two standard deviations (Table 12). However, using the combination variable, 93.7% of the control concentrations are below a value of 0.44 while only 2.5% of the contaminated population are below this value (Table 12). This is given graphically in Figure 7.

Table 12. log-transformed (and in parentheses the untransformed) mean concentrations of contaminants in the contaminated (contam.) dataset minus one and two standard deviations (SD) and the respective percentile of the control dataset.

Statistic	-------------------------------- Contaminant --------------------------------			
	E. coli	NH_4-N	Total P	Combination
Control mean	5.39	-2.64	-2.28	-1.10
	(220)	(0.071)	(0.102)	(0.332)
Contam. mean	10.13	-0.22	0.27	1.41
	(25010)	(0.805)	(1.305)	(4.078)
% of control dataset less than	*97.0*	*94.7*	*99.0*	*99.4*
Contam. mean – 1 SD	8.67	-1.30	-0.44	0.92
	(5852)	(0.271)	(0.646)	(2.517)
% of control dataset less than	*90.4*	*81.4*	*95.4*	*97.8*
Contam. mean – 2 SD	7.22	-2.39	-1.14	0.44
	(1369)	(0.091)	(0.319)	(1.554)
% of control dataset less than	*76.6*	*56.6*	*85.0*	*93.7*

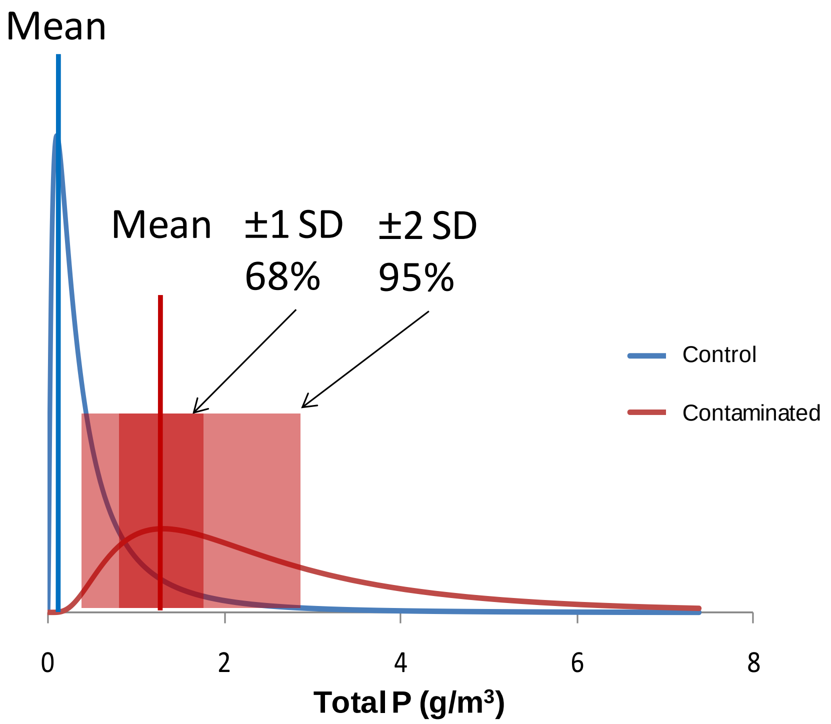

Figure 7. An example distribution of control and contaminated data for total P showing the position and potential overlap of the mean contaminated concentration ± one and two standard deviations. Percentages refer to the proportion of the population that fit within one or two standard deviations of the contaminated mean.

A limit in contaminant concentration, relative to a percentile in the control dataset, could be established. However, the caveat is that our dataset is based on event data and the flow-weighted mean concentration of each contaminant. Taking one sample from an event is therefore subject to change depending on flow rate and when the sample was taken. An event could be, for example, 30 minutes or 2 days long, but the concentration of contaminants like TP, *E. coli* and sediment increases with flow to a maximum before the hydrograph peak, and then decrease rapidly for the remainder of the event. This variation with flow may be acceptable if the objective is to determine contamination as a snapshot in time (i.e. a single sample with a combined variable value > 1.554 still represents poor water quality relative to the control dataset). However, in order to make a definitive statement about sustained contamination either across an area or from one area, over a number of events, then repeated samples are required to statistically link the two datasets.

A power analysis was then conducted to determine an appropriate sample size to detect a difference between a number of contaminated samples and the control population. This analysis determined that, if 4 samples are taken from a contaminated site (with contamination levels like those seen in the samples collected in this study), then there is an 84% probability that the difference will be proven by a statistical test using the combination variable (i.e. significant at the 5% level of significance). If 3 samples are taken the power or chance of seeing a difference at the 5% level decreases to 60%. In simpler words, a sample size of 4 is required to yield a good chance of detecting a real difference between the control combination concentration of 1.554 and the mean concentration of the contaminated samples. Using our analogy above, this translates to either 4 samples taken from randomly selected tile drains over an area that can be linked to a practise or 4 events from the one drain that are separated in time.

Using a combination value of 1.554 as a limit, we identified those samples of dairy drainage samples taken in the Wairuna Stream and Heriot Burn catchments that were found to be "contaminated" (section 3.1.3). Nine percent of dairy drainage samples were found to be "contaminated". Removing the contribution of contaminated samples from the dairy drainage dataset improves water quality from the drains. The resulting median concentration and load decreases by an estimated 3-58% (Table 13). Unsurprisingly, the greatest decreases were evident for those contaminants used to denote a "contaminated" drainage sample (e.g. NH_4-N, *E. coli* and TP), than those, like NNN, that were not.

Table 13. Median concentrations (all g m^{-3}, except *E. coli* which is cfu $100mL^{-1}$) and loads (all g s^{-1} except *E. coli* which is cfu s^{-1}) for samples of tile drainage of dairy-farmed land in the Wairuna Stream and Heriot Burn catchments in existing condition and with "contamination" due to bad effluent practice removed. The percentage decrease for median concentrations and loads is also given.

Parameter	------------- Condition -------------		Percent decrease
	Existing	Without contamination	
Median concentration			
NH_4-N	0.030	0.020	33
DRP	0.038	0.033	13
E. coli	56	39	30
NNN	1.97	1.97	0
SS	14	12	14
Total N	2.985	2.390	20
Total P	0.099	0.090	9
Loads			
NH_4-N	9	5	42
DRP	4	3	17
E. coli	1150376	487994	58
NNN	354	344	3
SS	1890	1456	23

Total N	438	413	6
Total P	11	9	22

Although this statistical test has used tile drainage data, as an indicator of effluent, use of the combination variable does not preclude detection of contamination in open drains.

3.5 Potential to decrease contaminant losses

While this test may identify a “contaminated” sample, a range of strategies are still required to decrease the loss of contaminants either associated with the application of dairy effluent to artificially drained land or other sources such as direct access to streams by stock. Furthermore, these strategies need to be fully-costed. This ensures uptake is based on sound science and economic considerations are incorporated.

3.5.1 Assessments of contaminant losses from typical dairy and sheep farms in the catchment

Soil type, slope and farm management practices have an important influence on the quantities of contaminants lost from farms to water. Models such as the Overseer Nutrient Budgeting model®, hereafter termed Overseer, attempt to account for these effects and provide estimates of losses under contrasting catchment, climatic and management conditions. Here we apply the model to “typical” dairy and sheep farms within the catchment to give an indication of likely contaminant losses for each of these farming systems. Estimates of sediment losses are also provided. These are based upon literature values and unpublished data for similar soils and management systems (e.g. Monaghan et al. 2007). Both model farms are assumed to be located on mole-pipe-drained Pallic soils within the catchment with rainfall inputs of 850 mm per annum. Attributes of these farms are shown in Table 14 along with estimates of annual N, P and sediment losses. Sediment losses from the model sheep farm are assumed to be greater than from the dairy farm due to the combined effects of greater slope and greater livestock access to streams (leading to more treading damage of stream banks and margins).

Table 14. Attributes of, and contaminant losses from, "typical" dairy and sheep farms in the Pomahaka catchment.

Farm attributes	Dairy	Sheep
Area (total hectares)	267	720
Cows or SU per total ha	2.0	9
N fertiliser input (kg N ha^{-1} yr^{-1})	90	10
Soil Olsen P (mg L^{-1})	30	20
Stream lengths remaining un-fenced	5%	60%
Assumed stream density (m ha^{-1})	31	31
Effluent storage	2 weeks	
Contaminant losses to water:		
N loss: kg ha^{-1} yr^{-1}	21	10
g N m^{-3}	10	5
P loss: kg ha^{-1} yr^{-1}	1.0	0.6
g P m^{-3}	0.5	0.3
Sediment loss: kg ha^{-1} yr^{-1}	114	268
g m^{-3}	57	134

3.5.2 The cost and effectiveness of mitigation strategies for decreasing contaminant losses from dairy and sheep farms

Research shows that there is a wide range of Good Environmental Practices (GEPs) that can decrease contaminant losses from pastoral farms to waterways. Some of these are listed in Table 15. Also provided are some rankings according to the relative cost-effectiveness of each GEP. This metric provides an assessment of where we are likely to get the "biggest bang for buck". In other words, a high cost-effectiveness implies that relatively large decreases in contaminant losses can be achieved per $ of mitigation expenditure. Estimates of the annualised net cost of implementing each mitigation measure have been used to calculate a range of cost-effectiveness values based upon information within the BMPToolbox (Monaghan, 2009). For simplicity, this assumes a number of default costs, such as the opportunity cost of capital (8%), depreciation, maintenance, additional labour and feed, and revenue foregone as a result of land lost to production. Any financial benefits expected from implementing measures are deducted from the net overall annualised cost. These benefits can be particularly important where a measure increases productivity (e.g. extra pasture growth from the use of nitrification inhibitors) or decreases farm operational costs such as avoiding off-farm cow wintering fees if the animals are wintered under a Herd Shelter on the home farm. Strictly speaking, any assessment of mitigation costs and effectiveness should be conducted on a farm-specific basis due to the variable nature of farm management systems and landscape features. However, on a regional basis, such an exercise would be impossible to do for every permutation of land use, soil type and management system. Hence, the information in Table 14 provides an indicative assessment of the relative cost-effectiveness of a range of GEPs relevant to "typical" Otago farms.

For simplicity we have grouped the GEPs in Table 15 into categories of high, medium or low cost-effectiveness. These broadly correspond to values of <$25, $25-100 or >$100 net cost per kg of N or P conserved, respectively. The Tier 1 GEPs are also those that are well-proven and do not add great complexity to the farm business. These collective attributes of Tier 1 measures thus allow them to be considered as the "low hanging fruit" of on-farm actions than can be taken to improve the quality of water discharging from pastoral farms.

Some of the GEPs in Table 15 are effective in decreasing multiple contaminants (e.g. the improved effluent management practices) while others target a specific contaminant (e.g. nitrification inhibitors). Nutrient budgeting and stock exclusion are GEPs common to all pastoral land uses and known to be highly cost-effective. Improved effluent management practices are another set of measures that are highly cost-effective mitigation measures for dairy farms. The next tier of GEPs that can be described as being of "medium" cost effectiveness include "facilitated" wetlands and nitrification inhibitors (all pastoral land uses) and off-paddock dairy grazing systems such as wintering shelters and/or restricted autumn grazing practices. The bottom tier of mitigation measures that are relatively cost-ineffective include grass buffer strips, incorporation of low N feeds into the diet and the use of constructed wetlands. It should be noted that our assessment of the cost-effectiveness of constructed wetlands does not fully capture the ancillary benefits of these structures such as habitat, biodiversity and aesthetic values and removal of sediment from stream flows.

The draining and conversion of existing wetlands to productive farmland is of concern for contaminant-stressed catchments. Much national and international research shows that wetlands play an important role in attenuating pollutants in stream flow and groundwater seepage. Their removal and conversion to productive land removes this "filtration" effect. Because drained wetlands typically occupy wet and highly-connected parts of the landscape, it also results in these parts of the landscape becoming important source areas of contaminant loss from farms in their own right. This is particularly evident in places where stock treading damage of these naturally wet areas results in large transfers of dung and sediment via artificial subsurface drainage or overland flow pathways. We suggest that the maintenance of existing wetlands should be a matter of high priority.

Table 15. Suggested good environmental practices (GEPs) that can decrease contaminant losses from farms.

Land use	GEP	Cost-effectiveness	Suggested Tier
Dairy	Nutrient management plans	High	1
	Stock exclusion from streams	High	1
	Effluent storage[a]	High	1
	Low rate effluent application[a]	High	1
	Facilitated wetlands[c]	Medium	1
	Nitrification inhibitors	Medium	2
	Off-paddock wintering[b]	Medium	2
	Restricted autumn grazing	Medium	2
	Elimination of stock stream crossings	Varies according to bridging costs	1
	Constructed wetlands	Medium-low	2
	Grass buffer strips	Low	2
	Incorporating low N feeds into diets	Low	2
	Tracks and lanes sited away from streams & lane runoff diverted to land	Medium-high	2
	Limiting N fertiliser use	Low	2
Sheep	Nutrient budgeting	High	1
	Stock exclusion from streams	High	1 or 2[d]
	Facilitated wetlands	Medium	1
	Nitrification inhibitors	Medium	2
	Elimination of stock stream crossings	Varies according to bridging costs	2
	Constructed wetlands	Medium-low	2
	Grass buffer strips	Low	2

[a] refer to Houlbrooke and Monaghan (2009) for more detailed assessments of soil-topographical categories where these improved effluent management systems are required; [b] assuming cows are wintered in/on structures where full effluent containment is achieved; [c] wetlands targeted at naturally poorly drained and relatively un-productive parts of the landscape such as seeps and bogs (McKergow et al., 2008); [d] dependent on land use intensity e.g. Tier 1 if in a winter forage crop paddock, otherwise a Tier 2 measure.

As further guidance on the cost implications associated with implementing some of the above farm mitigation measures, Table 16 provides an indication of the cost and effectiveness of the most cost-effective measures documented in Table 15. These were assumed to be applied individually to the Dairy and Sheep model farms described in Table 14. The BMPToolbox (Monaghan, 2009) was again used to derive these estimates for costs and nutrient decreases; literature values or "best-guess" estimates were also used for assessments of sediment loss decreases, and for practices that are currently not considered in the BMPToolbox. It must be noted that these assessments are an indication of some of the options available and possible costs and benefits. Actual values will vary between farms and farm-specific actions should be based on farm-specific assessments. Modelling assessments do not take into account the human component of changes to farming systems - farm management expertise will impact on the effectiveness of any scenario and the modelling approach taken here also assumes that animal and farm production is not limited by the human component of the system. Other mitigation options are also potentially available and may be of relevance to farms in the catchment. Hence, our assessments should not be considered as an exhaustive evaluation of all options potentially available to farms in the catchment. The preparation of farm nutrient management plans will provide a focal point for farmers and extension specialists to discuss the relevance and "fit" of mitigation measures that may be required on-farm.

At the risk of stating the obvious, Table 16 indicates that there is no silver bullet available that can substantially decrease farm scale losses of any of the contaminants considered in this report. However, it is also evident that there is a range of options available that, if implemented collectively, could make significant decreases in contaminant losses. In the case of the model Dairy farm, most of the measures in Table 16 have relatively little impact on farm profit. Unfortunately, this is not the case for the model sheep farm, where each of the 3 measures evaluated are likely to impair farm profit. Stock exclusion and wetlands are the 2 measures most relevant to the model sheep farm in the Pomahaka catchment. Stock exclusion is estimated to deliver significant decreases in whole-farm P, sediment and *E. coli* losses, whilst wetlands are estimated to deliver significant decreases in N, sediment and possibly *E. coli* losses. Guidelines for the establishment of grass filter strips in associated with fencing can be obtained from Collier et al. (1995). Factors affecting their performance include slope and infiltration. As an example, an area that is flat (0-30^o) with moderate infiltration (20-64 mm h^{-1}) and clay content (20-40%) requires 2% of the hillslope length to be set aside as a filter in order to achieve a 90% decrease.

The cost-effectiveness of using a nitrification inhibitor as a tool for decreasing nitrate leaching is a subject that is still vigorously debated within the New Zealand science community. The projected decrease in N leaching of between 25 to 34% when a nitrification inhibitor is used on our model dairy farm (Table 16) is slightly less than measured in a grazing trial on a commercial Southland dairy farm (Monaghan et al. 2009). However, this lower and more conservative range estimate is probably more realistic given the practical challenges of uniformly applying the product to all parts of a farm at the correct application rate and time. Due to the lower pasture responses expected when an inhibitor is used on the model sheep farm, and the farm’s lower per hectare profit, the application of a nitrification inhibitor to our model sheep farm is estimated to considerably decrease farm profitability. However, it must also be noted that there is even less research information available that documents the cost-effectiveness of nitrification inhibitor use on sheep farms.

Improved effluent management practices will be one set of on-farm management practices required by dairy farms to ensure water quality within the Pomahaka is protected. Houlbrooke and Monaghan (2009) document how effluent irrigation hardware and management needs to be matched to landscape risk to cost-effectively minimise effluent runoff from dairy farms. Pond storage, application rate and application depth are key criteria that need to be considered within this context of landscape and management risk. Although it will again vary depending on a farm-by-farm basis, as a guide we would expect that most dairy farms on high risk soils (i.e. with artificial drainage, coarse soil structure, impeded drainage or low infiltration rate) would require approximately 3 months effluent storage. Because greater soil attenuation of effluent contaminants can be achieved when effluent is applied little-and-often (Monaghan et al. 2010), less storage will be required for farms where a low rate effluent applicator is used, although modelling suggests that storage requirements will still be approximately two thirds of that required for farms with a travelling irrigator. The Pond Storage Calculator will be an important tool for determining farm-specific requirements as it can also account for effluent generated from hard surface areas such as feed-pads and corralling areas.

Table 16. Indicative assessments of the costs incurred and the effectiveness of the "high" and "medium" cost-effectiveness measures documented in Table 15. Given their low cost and ease of preparation, it is assumed that all farms have a Nutrient Management Plan prepared.

Good environmental practice	Net cost		Effectiveness		
	$/ha/year	Decrease in profit[a]	N decrease, %	P decrease, %	Other decreases
Dairy					
Stock exclusion from streams	2 – 4	<1%	4 – 15	6 – 21	Large decreases in sediment and *E. coli* losses likely.
Improved effluent management	5 – 10	<1%	5 – 10	5 – 30	Large decreases in *E. coli* losses likely.
Facilitated wetlands	20 – 40	2 – 3%	20 – 30	nil	Large decreases in sediment loss likely; possibly also *E. coli.*
Nitrification inhibitors	60 – 90	5 – 8%	25 – 34	nil	None.
Off-paddock wintering	nil[b]?	-	25 – 35	10 – 20	Sediment decreases likely.
Tracks and lanes sited away from streams & lane runoff diverted to land	<5	<1%	1 – 2	5 – 10	5 – 10% decreases in sediment and *E. coli* also estimated.
Sheep					
Stock exclusion from streams	10 – 30 [c]	6 – 18	1 – 6	0 – 20	Decreases in sediment and *E. coli* losses likely.
Facilitated wetlands	10 – 30[c]	6 – 18	20 – 30	Nil	Large decreases in sediment loss likely; possibly also *E. coli.*
Nitrification inhibitors	70 – 110	40 – 60	20 – 30	Nil	None.

[a] assumed dairy and sheep profits of $1,200 and $175 per ha per year, respectively; [b] conflicting evidence and views, partly reflecting the range of systems and management options available. Beukes et al. (2010) and Monaghan et al. (2008) suggest a slight increase in profit where Herd Shelter (i.e. off-paddock) systems are used over winter; [c] actual cost very dependent on length of wetland fencing and additional water reticulation required.

4. Conclusions and recommendations

Monitoring of water quality indicators (P and N fractions, SS and *E. coli*) at four sites since 1997 in the Pomahaka catchment has indicated a strong increase in the concentration of P fractions. A more detailed investigation during 2008 and 2009 established that large (per ha) contaminant loads originated from those sub-catchments of the Pomahaka with a significant area of dairying. Seasonally, contaminant concentrations were greatest in late autumn and spring. Baseline contaminant concentrations suggested that for most sites there was considerable scope for management to improve water quality (e.g. baseline concentrations were commonly <20% of current concentrations).

Sampling of sheep and dairy drainage found that contaminant losses were occurring despite there being no rainfall. This was attributed to poor practice such as applying effluent to wet (near saturated) soil. Using control and contaminated samples from historical data, a three-factor variable, and limit, for “contaminated” drainage was defined statistically. The limit was applied to define “contaminated” samples of dairy-farmed tile drainage taken within the Heriot Burn and Wairuna Stream. If the limit had been applied and the contaminated drainage removed from the dataset, median concentrations and loads of contaminants decreased by up to 58%; greater decreases were found for *E. coli*, NH_4-N and total P, but little for other contaminants.

Additional work looking at the cost and effectiveness of different strategies to mitigate contaminant losses from a model sheep and dairy farm indicated that there was no “silver bullet” available that can substantially decrease all farm scale losses, alone. However, there were a range of options available that, if implemented collectively, could make significant decreases in contaminant losses. In the case of the model Dairy farm, most of the measures (including better effluent management and wintering practice) had relatively little impact on farm profit. Unfortunately, for the model sheep farm, all of the mitigation strategies evaluated were likely to impair farm profit. Given that many of the strategies, such as deferred irrigation (and low rate application), to decrease contaminant losses from effluent are not commonly practiced in the catchment, there appears considerable opportunity to decrease losses from dairy- and sheep-farmed land and improve water quality and the natural and recreational values associated with the Pomahaka River.

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