

# Managing Water Quality in the Pomahaka Catchment: Science Informing Policy

Matt Hickey<sup>a</sup>, Richard W. McDowell<sup>b</sup>, Justin Kitto<sup>a</sup>,

<sup>a</sup> Otago Regional Council, 70 Stafford Street, Private Bag 1954, Dunedin 9054, New Zealand.

<sup>b</sup> AgResearch, Invermay Agricultural Centre, Private Bag 50034, Mosgiel, New Zealand.

**ABSTRACT** An increasing trend of phosphorus (P) fractions at long-term monitoring sites in the 1881 km<sup>2</sup> Pomahaka catchment in Otago, New Zealand is attributed to the expansion of dairying. This study determined the water quality, physical habitat, and ecological values of the Pomahaka River and 13 sub-catchments. Tile drains under dairy and sheep farming were also sampled to compare nutrient losses from the two land uses. Results show that loads of contaminants (Nitrogen (N) and P fractions, sediment and *E. coli*) were greatest in those sub-catchments with the most dairying. Stream surveys showed sediment as having significant impacts on physical habitat. A statistical test that identifies ‘contaminated drainage’ from dairy effluent has been developed. Results indicate that if ‘contaminated’ samples were removed from samples of the two dairy-farmed sub-catchments *E.coli* and P loads could have been reduced by 58% and 22% respectively. Discharge limits on tile drains that target inappropriate effluent management, along with sediment management are key to improving water quality in the Pomahaka catchment. This suggests the proposed effects based permitted activity rules in Otago’s Regional Plan: Water should target sediment management combined with stringent discharge limits that target inappropriate effluent management.

**Keywords:** phosphorus; point source; watershed

## Introduction

In 2007 the Otago Regional Council (ORC) produced a State of the Environment (SoE) report on water quality; it showed that generally water quality in Otago was good, with the exception of South Otago, particularly the Pomahaka catchment. Water quality in the lower Pomahaka catchment has been deteriorating for a number of years as land use has rapidly intensified, mainly due to dairy conversions. A ranking of water quality at the 77 SoE sites across Otago placed four of the eight sites from the Pomahaka catchment in the worst ten sites in Otago (Otago Regional Council, 2007).

The Regional Plan: Water for Otago (2004) lists many natural values for the Pomahaka River that the community has identified, including high fish and macroinvertebrate diversity, rare macroinvertebrates, salmon and trout spawning and rearing habitat, the significant presence of eels, and the significant presence of game birds. The catchment is also listed as having a regionally significant brown trout fishery. An estimated 4,140 fishing days were undertaken in the Pomahaka during 2007/2008 (Unwin, 2009).

Farming in the Pomahaka catchment relies on artificial drainage predominantly in the form of tile drains. Subsurface drainage has been identified as a significant source of contaminants from grazed pastures to waterways (Wilcock et al. 1999, Monaghan et al. 2002a, Monaghan et al. 2002b). If inappropriately managed, these tile and mole drains accelerate water and associated contaminant flows of nitrogen (N), phosphorous (P) and *Escherichia coli* (*E. coli*) to local watercourses and the tile drains also allow riparian zones to be bypassed (Nguyen et al. 2002).

Further intensification is placing additional pressure on Otago's water quality (ORC 2007). In response to this continued degradation, the ORC developed a Rural Water Quality Strategy which is an effects based approach to water quality management (ORC 2010). The strategy is concerned with managing the effects of land use on discharge quality, rather than controlling farm activities. This approach will rely on the community identifying the streams water quality values and ORC setting discharge limits that will maintain or enhance these values. The approach allows farmer flexibility and encourages them to take innovative actions to manage water discharges. The regulatory framework of the strategy is aimed at using permitted activity rules, preventing the need for resource consents to farm as long as the farming practice is having no effect on the receiving stream.

To inform the development of ORC's effects based regulatory approach the Pomahaka catchment was chosen for an intensive investigation into water quality and ecological health. This study also provides the basis for setting tile drain discharge standards that are targeted at poor management practice and a route for the improvement of water quality in the Pomahaka River relative to established community values.

## **Methods**

### *Site description*

The Pomahaka River drains a catchment of 1881 km<sup>2</sup> and supports a wide variety of land use typified by plantation forestry 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 impact of wetland drainage since 2006.

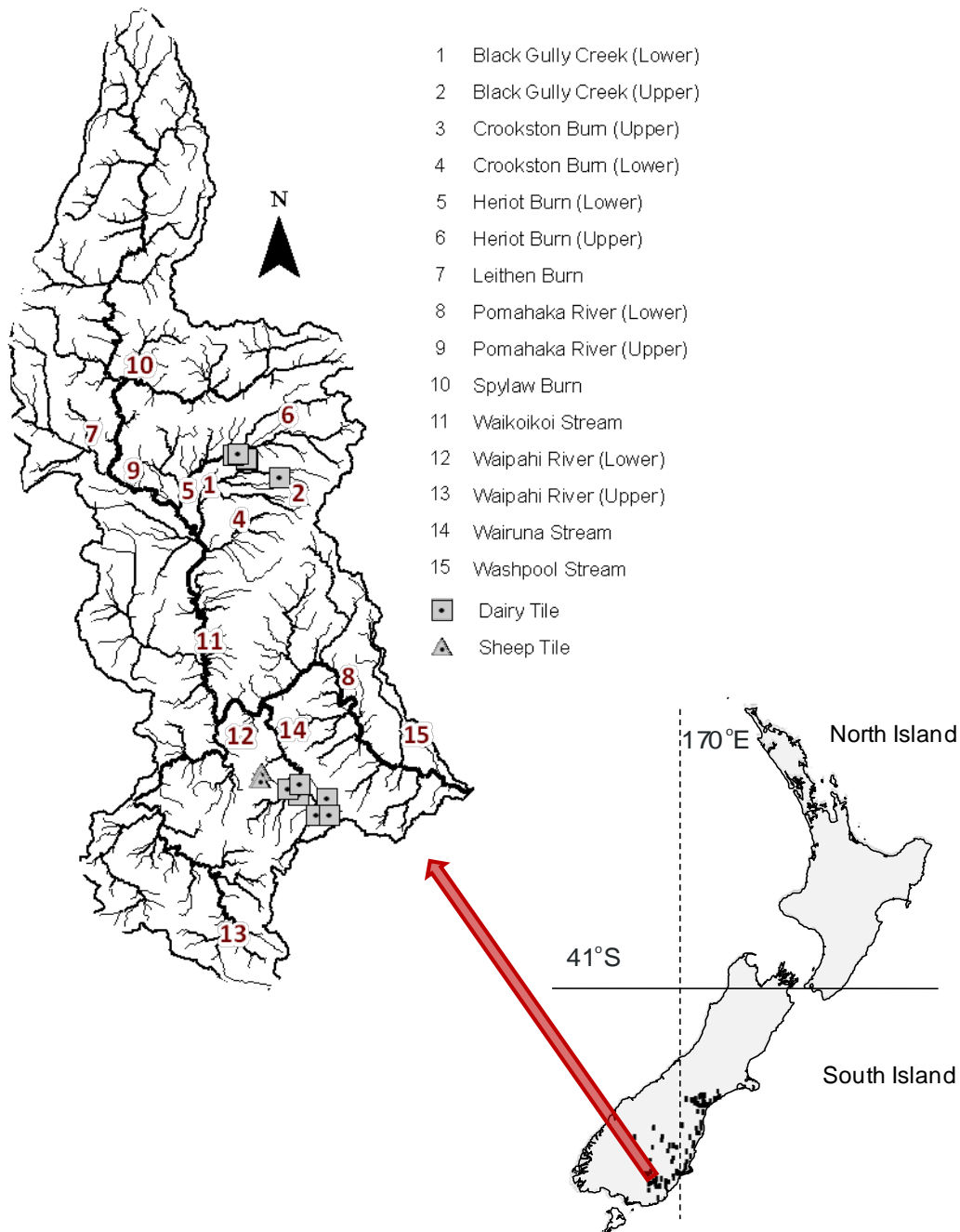
Rainfall varies from *c.* 1250 mm in the headwaters draining altitudes of up to 1440 metres above sea level (msl) to *c.* 650 mm near the catchment outlet at about 60 msl. Soils within the catchment are dominated by Pallic soils. In low lying areas, drainage is facilitated by a network of mole and tile drains at about 70-100 cm below the soil surface (collectively termed artificial drainage).

### *Sampling*

Since April 1997, continuous flow and water quality have been measured bi-monthly at four long-term SoE sites in the Pomahaka Catchment as part of regular assessments made by the ORC. For 14 months, beginning in October, 2008 this was supplemented by fortnightly water quality sampling (n = 30) and continuous flow measurements of

the four 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 tile drains (14 draining dairy and six draining sheep-farmed land) were also sampled and flow gauged (Figure 1). All stream and drainage sites were sampled for Ammoniacal Nitrogen ( $\text{NH}_4^{+-}\text{N}$ ) Nitrite-Nitrate Nitrogen (NNN), Total Nitrogen (TN), Dissolved Reactive Phosphorus (DRP), Phosphorus (TP), *Escherichia coli* (*E.coli*) and Suspended Sediment (SS). Sample analysis was carried out as described in McDowell et al. (2011).



**Figure 1.** Map of New Zealand showing the location of the Long-term SoE sites (sites 6,8,9 and 12), short term stream sites and artificially (tile) drained sites monitored in the Pomahaka River catchment.

Stream sites were graded based on their median values for measured water quality parameters for “non event flows” (flows below the measured median flow) against the effects focused guidelines considered relevant for the Pomahaka River in Table 1.

**Table 1.** Physico-chemical and microbiological analytes and guideline values used for this study.

Analyte	Guideline value	Guideline Source
NH <sub>4</sub>	<0.9 mg L <sup>-1</sup>	ANZECC (2000)
TN	<0.614 mg L <sup>-1</sup>	ANZECC (2000)
NNN	<0.295 mg L <sup>-1</sup>	Biggs (2000)
TP	<0.033 mg L <sup>-1</sup>	ANZECC (2000)
DRP	<0.026 mg L <sup>-1</sup>	Biggs (2000)
<i>E.coli</i>	<260 cfu/100 mg L <sup>-1</sup>	MfE (2003)
SS	<7.2 mg L <sup>-1</sup>	based on the 5 NTU guideline by Young and Hayes (1999) and the relationship with SS data for the Pomahaka River

Grades were as follows:

- Excellent = six variables met guideline values
- Good = four or five variables met guideline values
- Fair = two or three variables met guideline values
- Poor = one or no variables met guideline values
- NH<sub>4</sub>-N was excluded as all sites comfortably passed this guideline.

To assess N or P limitation of periphyton growth a dissolved N (NH<sub>4</sub>-N + NNN) to P (DRP) ratio for each site was calculated and applied following ratios published by Guildford and Hecky (2000).

#### *Stream Habitat Assessment*

Physical habitat was assessed at all sites in February 2010. Protocol 3c from Harding et al. (2009) was used as was the shuffle index proposed in a working draft by Clapcott et al. (2011). Streams were then ranked as either having excellent, good, fair or poor physical habitat condition. This was achieved by ranking sites from 1 (best) to 15 (worst) for each parameter, then summing the totals and breaking this result into quartiles.

#### *Fisheries Assessments*

All sites were electro-fished as in Hickey and Closs (2006) for trout density and condition. Rather than surveying 30m reaches an area of 100m<sup>2</sup> was sampled in this investigation. Trout from each pass were kept separate, counted, weighed and

measured for length and released after the third electric fishing pass. At each site, trout condition (and ranking) was calculated following the formulae (and categories) provided by Barnham and Baxter (1998) (Table 2).

**Table 2.** K-value of fish condition (Barnham and Baxter 1998).

K value	Comments
1.6	<b>Excellent</b> condition
1.4	<b>Good</b> , well-proportioned fish
1.2	<b>Fair</b> fish, acceptable to many anglers
1	<b>Poor</b> fish, long and thin
0.8	<b>Extremely poor</b> , big head and narrow, thin body

To get a comparison of the trout population between the Pomahaka catchment and the remainder of the Clutha catchment (Pomahaka is a tributary of the Clutha River), the New Zealand Freshwater Fish Database (NZFFD) was interrogated to obtain fish density data for sites in the Clutha catchment (based on three pass electric fishing over a known area). To get a categorical ranking of trout health, the trout condition value was then divided by trout density (ranked from highest to lowest) and divided into quartiles and assigned as excellent, good, fair or poor.

#### *Macroinvertebrate Assessment*

Macroinvertebrate communities were sampled at all sites in November 2009. At each site, one extensive kick-net sample was collected, following Protocol c2 by Stark et al. (2001). The condition of each macroinvertebrate community was categorised following Stark et al. (2001) (Table 3).

**Table 3.** Criteria for aquatic macroinvertebrate health, according to different macroinvertebrate indices.

Macroinvertebrate Index	Poor	Fair	Good	Excellent
Total species	<10	15-20	20-30	>30
Total EPT species	<5	5-15	15-20	>20
MCI	<80	80-99	100-119	>120
SQMCI	<4	4-5	5-6	>6

## **Results**

### *Current state and trend analysis of surface water quality contaminants at 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 4. 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* was

exceeded at all but the lower Pomahaka River site.  $\text{NH}_4^+\text{-N}$  and SS met guideline concentrations at all sites.

Trend analysis of chemical concentrations for the four long-term sites within the Pomahaka River catchment from 1997 - 2010 indicated a significant increase in both DRP and TP at all sites, whereas  $\text{NH}_4^+\text{-N}$  increased at the lower Waipahi River site, but decreased at both Pomahaka River sites (Table 4). 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, probably due to the wetland drainage undertaken in 2006. Increasing trends in nutrients coincided with a period of rapid expansion and conversions to dairying, such that the number of dairy farms in the Pomahaka catchment tripled from 38 in 1999 to 105 by 2008 (ORC 2011).

**Table 4.** 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 <sup>a</sup>
<i>Waipahi upper</i>						
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 <sub>4</sub> <sup>+</sup> -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	*
<i>E. coli</i>	1343	4657	10-37000	250	-7	ns
SS	16.8	28.8	7.0-206.0	7.0	0.2	ns
<i>Waipahi lower</i>						
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 <sub>4</sub> <sup>+</sup> -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 <sup>b</sup>	**
TN	1.334	0.731	0.170-3.460	1.340	0.022 <sup>b</sup>	**
<i>E. coli</i>	555	1447	1-10800	130	-6	ns
SS	9.1	13.0	0.5-72.0	4.0	<0.1	ns
<i>Pomahaka upper</i>						
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 <sub>4</sub> <sup>+</sup> -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
<i>E. coli</i>	442	874	18-4800	140	-5	ns
SS	5.7	9.4	0.5-53.0	2.0	<0.1	ns
<i>Pomahaka lower</i>						
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 <sup>2</sup>	*
NH <sub>4</sub> <sup>+</sup> -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
<i>E. coli</i>	700	1911	1-12000	99	-5	ns
SS	11.8	27.6	0.5-260.0	5.0	-0.1	ns

<sup>a</sup> \*, \*\*, 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.

<sup>b</sup> Sen slope estimator presented for flow adjusted data where model accounts for > 50% of the variance.

*Stream water quality results during the 14 month study period*

Median values for measured water quality parameters over the 14 month study period for “non event flows” were assessed against water quality guidelines in Table 1 and ranked (Table 5). “Non event flows” were used as most contact recreation and periphyton growth occurs at lower flows. Flows above median flow generally occur after significant rainfall and common sense suggests meeting the guideline values in Table 1 during high flows in an agricultural catchment is impractical.

**Table 5.** Median water quality results for “non event flows” relative to specific guidelines shown in Table 1 and resulting grades for each site (all mg L-1 except for *E. coli* which is measured as coliform forming units 100 mL-1).

Parameter	DRP	NNN	<i>E.coli</i>	SS	TP	TN	Grade	N- or P-limitation
<b>Guideline value</b>	<b>0.026</b>	<b>0.295</b>	<b>260</b>	<b>7.2</b>	<b>0.033</b>	<b>0.295</b>		
Leithen Burn	0.013	0.072	240	4	0.030	0.190	Exc.	N
Pomahaka River (Upper)	0.009	0.033	336	3	0.025	0.185	Good	N
Black Gully Creek (Upper)	0.032	0.132	19	2	0.037	0.197	Good	N
Flodden Creek	0.018	1.598	251	3	0.030	1.750	Good	P
Pomahaka River (Lower)	0.013	0.354	169	4	0.038	0.606	Fair	P
Spylaw Burn	0.017	0.027	383	2	0.079	0.589	Fair	N
Waikoikoi Stream	0.024	0.212	395	3	0.072	0.566	Fair	N
Waipahi (Lower)	0.018	0.683	189	6	0.051	1.034	Fair	P
Heriot Burn (Upper)	0.018	0.602	307	4	0.038	0.810	Fair	P
Heriot Burn (Lower)	0.024	0.995	648	6	0.061	1.333	Fair	P
Waipahi River (Upper)	0.025	0.849	444	24	0.090	1.314	Poor	P
Black Gully Creek (Lower)	0.030	1.661	387	2	0.048	1.882	Poor	P
Crookston Burn	0.028	0.768	1116	5	0.048	0.972	Poor	P
Wairuna Stream	0.053	1.620	736	7	0.149	2.179	Poor	P
Washpool Stream	0.095	0.165	1447	10	0.271	1.252	Poor	N

### Ecological survey results

Table 6 below summarises the results of the ecological, physical habitat and chemical work based on the categories described in the methods section. Where physical habitat and water quality was good ecological values were also good. Alternatively where both physical habitat and water quality is poor ecological values were compromised (Table 6). All catchments with excess of 30% dairy had poor water quality. The Waipahi Upper site was rated as poor for both water quality and physical habitat though no dairy was present, this was linked to significant wetland drainage in 2006 (ORC 2011).

**Table 6.** Summary of categories for chemical, physical habitat, MCI and trout condition related-density for each stream.

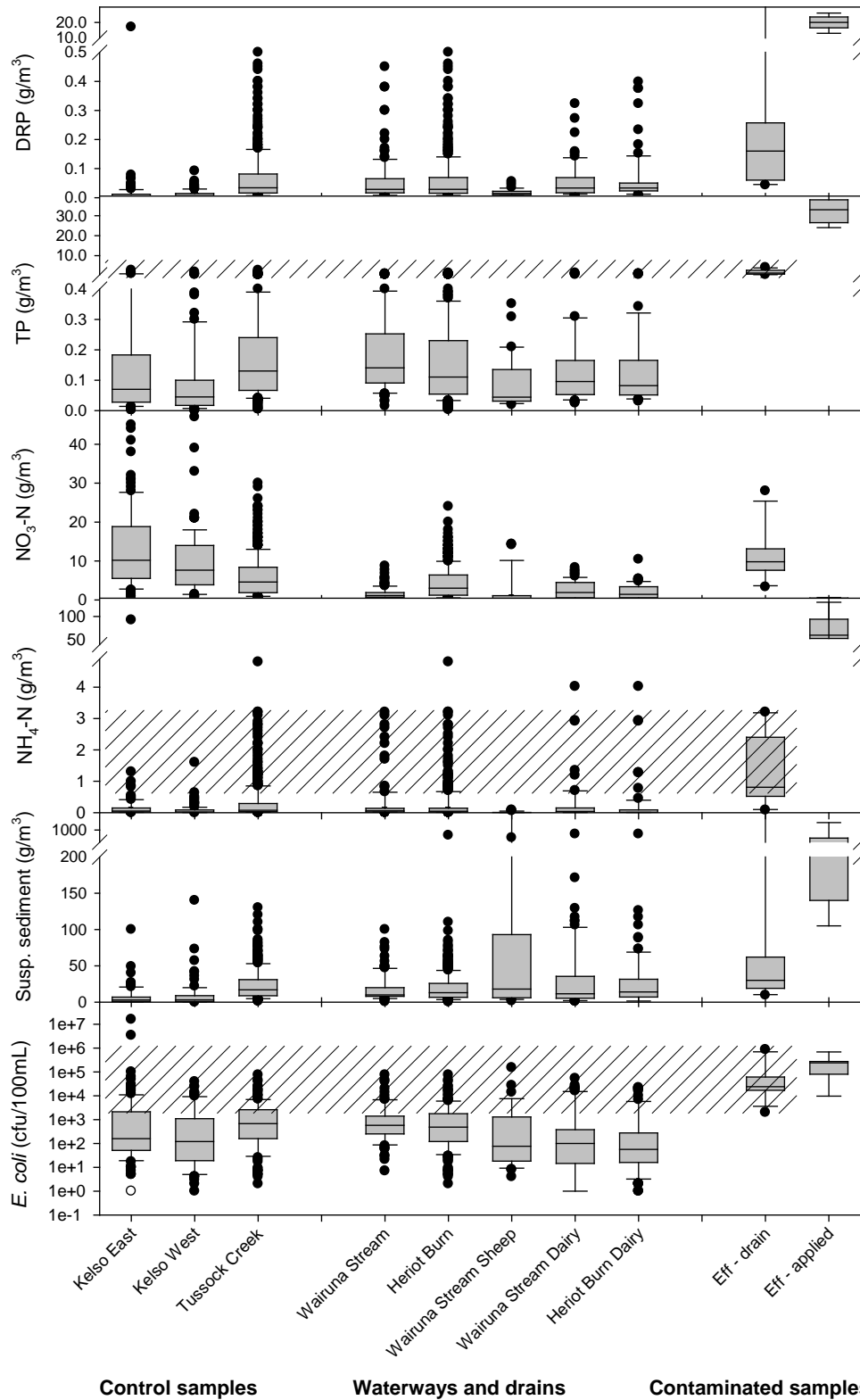
Site	% catchment in dairy	Chemical	Physical habitat	MCI	Trout density/condition
Leithen Burn	0	Excellent	Excellent	Excellent	Excellent
Pomahaka River Upper	0	Good	Excellent	Excellent	n/a*
Black Gully Upper	0	Good	Excellent	Excellent	Good
Spylaw Burn	1	Fair	Good	Fair	Excellent
Pomahaka River Lower	7	Fair	Good	Good	n/a*
Flodden Creek	26	Good	Good	Good	Good
Crookston Burn	44	Poor	Good	Good	Good
Heriot Burn Upper	12	Fair	Poor	Good	Good
Waikoikoi Stream	20	Fair	Good	Fair	Fair
Waipahi Lower	1	Fair	Good	Fair	n/a*
Heriot Burn Lower	15	Fair	Good	Fair	Fair
Waipahi Upper	0	Poor	Poor	Good	Fair
Black Gully Lower	36	Poor	Poor	Good	Fair
Washpool Stream	79	Poor	Poor	Fair	Poor
Wairuna Stream	51	Poor	Poor	Poor	Poor

n/a means density data could not be collected, as the river was too wide to net effectively.

### Artificial drainage - contaminant inputs

Contaminant concentrations from the sheep and dairy land use tile drains are presented as box and whisker plots in Figure 2 along with the receiving waterways, the Heriot Burn and Wairuna Stream.

Contaminant inputs via sub surface drainage can be considerable; a test was carried out to determine whether or not this is due to bad practice or is simply a reflection of increased rainfall and flow. To supplement the tile data collected in our study a total of 1100 drainage events from two AgResearch study farms (Kelso and Tussock Creek, in Otago and Southland, respectively) were used to create a uncontaminated (control) population, and a contaminated sample which derived from drainage that occurred during or within 24 hours of dairy shed effluent being applied to land. From inspection of the data (Figure 2), *E. coli*, NH<sub>4</sub>-N and TP concentrations were used to generate the two populations (control and contaminated).



**Figure 2.** Box (25th and 75th percentile and median) and whisker (5th 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. The cross-hatched boxes denote the range of samples from the Eff. drain dataset relative to all other samples.

The mean P concentration for the contaminated population was greater than 99.0% of the control population (Table 7). In addition, 95% of the control population P concentrations were less than 1 standard deviation below the contaminated mean (i.e. the lower 16% of contaminated samples), and 85% of the control population P concentrations were less than 2 standard deviations below the contaminated mean (i.e. the lower 2.5% of contaminated samples). Due to a greater overlap between control and contaminated data, the percentiles for NH<sub>4</sub>-N and *E. coli* concentrations were less at 56.6% and 76.6% for the mean of contaminated data minus two standard deviations (Table 7). However, a discriminant analysis was able to show that a combination of the three variables separated the control and contaminated populations better than a single variable:

$$\text{Combination} = 0.13 \times \ln(E. \text{ Coli} + 1) + 0.14 \times \ln(\text{NH}_4\text{-N} + 0.005) + 0.57 \times \ln(\text{TP} + 0.0025)$$

Using this combination variable, 93.7% of the control concentrations were below a value of 1.554 (or 0.44 when using the above calculation that incorporates a log transformation), while only 2.5% of the contaminated population were below this value (Table 7). Using a combination value of 1.554 as a limit, 9% of dairy drainage samples taken in the Wairuna Stream and Heriot Burn catchments were found to be “contaminated”.

**Table 7.** Log-transformed (and in parentheses the untransformed) mean concentrations all mg L-1 except for *E. coli* which is cfu 100mL-1) of contaminants in the contaminated (contam.) dataset minus one and two standard deviations (SD) and the respective percentile of the control dataset.

Statistic	----- Contaminant -----			
	<i>E. coli</i>	NH <sub>4</sub> -N	Total P	Combination
Control mean	5.39 (220)	-2.64 (0.071)	-2.28 (0.102)	-1.10 (0.332)
Contam. mean	10.13 (25010)	-0.22 (0.805)	0.27 (1.305)	1.41 (4.078)
% of control dataset	97.0	94.7	99.0	99.4
Contam. Mean – 1 SD	8.67 (5852)	-1.30 (0.271)	-0.44 (0.646)	0.92 (2.517)
% of control dataset	90.4	81.4	95.4	97.8
Contam. Mean – 2 SD	7.22 (1369)	-2.39 (0.091)	-1.14 (0.319)	0.44 <b>(1.554)</b>
% of control dataset	76.6	56.6	85.0	93.7

The effect on water quality from the drains was clear if the contribution of contaminated samples was removed from the dairy drainage dataset. The resulting median concentration and load decreases by an estimated 3-58% (Table 8). Unsurprisingly, the greater decreases were evident for those contaminants used to denote a “contaminated” drainage sample (e.g. NH<sub>4</sub>-N, *E. coli* and TP), rather than for those, like NNN, that were not.

**Table 8.** Median concentrations (all mg L<sup>-1</sup>, except *E. coli* which is cfu 100mL<sup>-1</sup>) and loads (all mg s<sup>-1</sup> except *E. coli* which is cfu s<sup>-1</sup>) for existing dairy drainage samples from 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	----- Existing	Condition ----- Without contamination	Percent decrease
<i>Median concentration</i>			
NH <sub>4</sub> -N	0.030	0.020	33
DRP	0.038	0.033	13
<i>E. coli</i>	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
<i>Loads</i>			
NH <sub>4</sub> -N	9	5	42
DRP	4	3	17
<i>E. coli</i>	1150376	487994	58
NNN	354	344	3
SS	1890	1456	23
Total N	438	413	6
Total P	11	9	22

## Discussion

The results of this study indicate that farming and in particular the expansion of dairy farming has impacted on water quality significantly in the Pomahaka catchment in the last decade. All catchments with more than 30% of the catchment under dairy farming had poor water quality.

Water quality results indicate that 9 of the 15 streams in the Pomahaka are P limited, while the drainage results showed that poor effluent management contributed significant levels of P to streams. Enriched P loss to the Pomahaka River and its tributaries increases the risk of prolific periphyton growth. Periphyton utilise dissolved N and P to grow until one of the nutrients limits growth, nuisance growths of periphyton can affect aesthetics, biodiversity, particularly invertebrate taxa, native fish spawning and trout feeding (Biggs, 2000). Algal proliferations can also cause large diurnal fluctuation in dissolved oxygen further impacting on ecological values (Biggs, 2000).

The results from this paper show that P loads could be reduced by 22 % in the Wairuna and Heriot Burn catchments by better dairy effluent management. Houlbrooke et al. (2008) compared the loss of N and P from a ‘one-off’ application onto wet artificially drained land with measured annual losses of N and P when using a deferred irrigation strategy over a whole year. N and P losses from the ‘badly-managed’ irrigation (12 kg N/ha and 2 kg P/ha) were 6-10 times greater than losses associated with deferred irrigation (5 events). Such strategies are not yet common place in the Pomahaka catchment, and given the potential

contributions of contaminants to stream loads, would have considerable scope in improving water quality in the Pomahaka if correctly implemented.

Stream habitat assessments indicate that physical habitat degradation through sedimentation is having a significant impact on ecological values (both macroinvertebrates and trout) which is consistent with the findings of Wagenhoff et al. (2011) in other Otago streams. Sediment control is critical as it can smother macroinvertebrate and fisheries habitat (Parkyn and Wilcock, 2004), harbour bacteria (Pachepsky and Shelton, 2011) and bind P (Haygarth et al. 1998). P previously bound to sediment can be released back into the system during the low flow periods, potentially increasing algal growth. The drainage analysis indicates there is potential to reduce SS by 23%.

This study showed that 10 of the 15 stream sites monitored had a median *E.coli* level greater than the Ministry for the Environment's safe level for contact recreation of 260 cfu/100m-L (MfE 2003) during flows when contact recreation was most likely. The drainage data collected showed *E.coli* levels were high in both dairy and sheep tile-drained land after rainfall. However, high *E.coli* concentrations were also recorded from dairy farm tile drains during dry weather, indicating effluent contamination through inappropriate application rates of dairy shed effluent. By managing effluent appropriately this study has shown *E.coli* loads from tile drains could have been reduced by 58% in the Wairuna and Heriot Burn catchments.

The Regional Plan Water for Otago (2004) has listed the natural values identified by the community that must be maintained in the Pomahaka Catchment. The Rural Water Quality Strategy provides a direction for using permitted activity rules that focus on controlling effects rather than farm activity (ORC 2010). This study has shown that effects based rules should focus on sediment control, while a limit using a combination variable for contaminated drainage detection could be used control dairy effluent management. Data suggests an effects focused regulatory approach provides considerable opportunity to improve water quality and maintain the natural values the community identifies with the Pomahaka River.

## **Conclusion**

Water quality monitoring has indicated a strong increasing trend in the concentration of P fractions at long term monitoring sites in the Pomahaka catchment. The increase in P concentrations coincides with an increase in dairy land use.

During sampling of dairy farm drainage, significant concentrations of contaminants, particularly P, *E.coli* and NH<sub>4</sub>-N were detected despite there being no rainfall, indicating the likely input of contaminants due to poor effluent management.

Physical habitat surveys indicate that sedimentation is degrading ecological values, suggesting reducing sediment inputs will have a significant improvement for instream values.

Strategies such as deferred irrigation (and low rate application) have the potential to greatly decrease P losses from effluent to water in the Pomahaka catchment.

This paper has provided a statistical method for setting a drainage limit which targets "contaminated" losses from 'badly-managed' effluent irrigation.

## References

- ANZECC (Australian and New Zealand Environment and Conservation Council), (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council – Agriculture and Resource Management Council of Australia and New Zealand, Department of Sustainability, Environment, Water, Population and Communities, Canberra, Australia.
- Barnham, C., and A. Baxter. (1998) Condition Factor K for Salmonid Fish. In: Fisheries Notes, State of Victoria Department of Primary Industries 2003, Department of Primary Industries, Melbourne, Australia.
- Biggs, B.J.F. (2000). New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. Ministry for the Environment, Wellington, New Zealand.
- Clapcott, J.E., Harding, J.S., Matthaei, C.D., Quinn, J.M. and Young, R.G. (2011). Sediment Assessment Methods: Protocols and Guidelines for Assessing the Effects of Deposited Fine Sediment on Instream Values - DRAFT. P. 112. Cawthron Institute, Nelson, New Zealand.
- Guildford, S. and Hecky, R.E. (2000). Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? *Limnol. Oceanogr.* **45**, 1213-1223.
- Haygarth, P.M., Hepworth, L. and Jarvis, S.C. (1998). Forms of phosphorus transfer in hydrological pathways from soil under grazed grassland. *European Journal of Soil Science.* **49**, 65-72.
- Harding, J.S., Clapcott, J.E., Quinn, J.M., Hayes, J., Joy, M., Storey, R., Greig, H., Jay, J., James, T., Beech, M., Ozzane, R., Meredith, A. and Boothroyd, I. (2009). Stream habitat assessment protocols for wadeable rivers and streams of New Zealand. University of Canterbury, Christchurch, New Zealand.
- Hickey, M.A., and Closs, G.P., (2006). Evaluating the potential of night spotlighting as a method for assessing species composition and brown trout abundance: a comparison with electrofishing in small streams. *Journal of Fish Biology.* **69**, 1513-1523.
- Houlbrooke, D.J., Horne, D.J., Hedley, M.J., Snow, V.O. and Hanly, J.A. (2008). Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. *Aust. J. Soil Res.* **46**, 45-52.
- McDowell R.W., Snelder, T., Littlejohn, R., Hickey, M., Cox, N. and Booker D.J. (2011) State and potential management to improve water quality in an agricultural catchment relative to a natural baseline. *Agriculture, Ecosystems and Environment.* In Press.
- MfE (Ministry for the Environment), (2003). Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment. Wellington, New Zealand (See: [www.mfe.govt.nz/publication/water/microbiological-quality-jun03](http://www.mfe.govt.nz/publication/water/microbiological-quality-jun03)).

Monaghan, R.M., Paton, R.J. and Drewey, J.J. (2002a): Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. NZ Journal of Agricultural Research Vol.45:197-205.

Monaghan, R.M., Horne, D., Hedley, M. and Nguyen, L. (2002b); Subsurface drainage review - Water and contaminant loads from artificial subsurface drainage system in New Zealand. Prepared for Fonterra Research Centre. AgResearch, Invermay Agricultural Centre, Private Bag 50034 Mosgiel, New Zealand.

Nguyen, M.L., Eynon-Richards, N. and Barnett, J. (2002): Nitrogen removal by a seepage wetland intercepting surface and subsurface flows from a dairy catchment in Waikato. In: Dairy farm soil management (Eds L Currie and P Loganathan), Occasional Report No 15. Fertilizer and Lime Research Centre. Massey University. Palmerston North, New Zealand.

Otago Regional Council. (2004). Regional Plan: Water for Otago. Otago Regional Council, Dunedin, New Zealand.

Otago Regional Council, (2007). State of the Environment Report: Surface Water Quality in Otago. Otago Regional Council, Dunedin, New Zealand.

Otago Regional Council, (2010). Rural Water Quality Strategy: A new approach to water pollution from runoff, drains and leaching. Otago Regional Council, Dunedin, New Zealand.

Otago Regional Council, (2011). Effects of land use on water quality in the Pomahaka catchment. Otago Regional Council, Dunedin, New Zealand.

Pachepsky, Y.A. and Shelton, D.R. (2011). *Escherichia Coli* and Fecal Coliforms in Freshwater and Estuarine Sediments. Critical Review in Environmental Science and Technology, 41: 1067-1110.

Parkyn, S. and Wilcock, B. (2004). Impacts of agricultural land use in Harding, J; Mosley, P; Pearson, C; Sorrell, B. (eds) in Freshwaters of New Zealand. New Zealand Society of Limnology, The Caxton Press, Christchurch, New Zealand.

Stark, J.D., Boothroyd, I.K.G., Harding, J.S., Maxted, J.R. and Scarsbrook, M.R. (2001) Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for the Ministry for the Environment. Sustainable Management Fund Project No. 5103, Ministry for Environment, Wellington, New Zealand.

Unwin, M. (2009). Angler usage of lakes and river fisheries managed by Fish and Game New Zealand: Results from the 2007/0 National Angling Survey. NIWA Client Report CHC2009-046, National Institute of Water & Atmospheric Research Ltd, Christchurch, New Zealand. .

Wagenhoff, A., Townsend, C.R., Phillips, N. and Matthaei, C.D. (2011). Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. Freshwater Biology. In Press.

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

Young, R. and Hayes, J. (1999). Trout Energetics and Effects of Agricultural land use on the Pomahaka Trout Fishery. Prepared for Fish and Game Otago. February 1999, Cawthron Institute, Nelson, New Zealand.