Technical Report

Investigations and Monitoring Group

Hurunui River - Influence of the middle reach tributaries on water quality of the lower Hurunui River (2005-2008)

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Environment Canterbury
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Report prepared for Environment Canterbury by

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EXECUTIVE SUMMARY

Concerns were raised in the late 1990s about the quality of the lower Hurunui River. The lower reaches of the river frequently had high nutrient and indicator bacteria concentrations which compromised its suitability for contact recreation. The Culverden basin was identified as potential source of these contaminants via the various hill-fed and groundwater-fed streams flowing across the intensively farmed plains into the Hurunui River. In November 2005 Environment Canterbury started a monitoring programme focussed on the middle and lower reaches of the Hurunui River. This programme aimed at providing background water quality and river flow data for the middle reaches of the Hurunui River and its main tributaries.

The aim of this study was to analyse the water quality data relating to nutrients and indicator bacteria collected by Environment Canterbury between November 2005 and March 2008. The study focussed on the middle Hurunui catchment between SH7 and SH1, and aimed at investigating the following points:

- the state of the Hurunui River and its main tributaries;
- the annual contaminant loads in the Hurunui River;
- the contribution of the different main tributaries to the measured contaminant loads in the catchment.

The Hurunui River has generally acceptable microbiological water quality, but the Culverden Basin tributaries have high numbers of indicator bacteria, and are likely to be unsuitable for contact recreation or as a source for stock drinking water.

Nutrient enrichment and associated excessive periphyton growth appear to be the predominant water quality issue in the middle Hurunui catchment. A significant degradation of the Hurunui River water quality for both DRP and SIN was observed between the upper and lower reaches of the middle Hurunui catchment. Guideline levels are complied with (DRP) or marginally exceeded (SIN) at the upstream (SH7) site, but breached at downstream end of the study area (SH1).

It was estimated that the Hurunui River carries annually 3.5 to 6 tonnes of DRP at the top end of the study area (SH7) and 6 to 10 tonnes at the bottom end (SH1), or an increase of 45- 82 %. Estimated annual SIN loads increase 360 to 580% between SH7 (56-81 Tonnes/year) and SH1 (350-500 Tonnes/year).

Most tributaries of the middle Hurunui catchment reaches have elevated (i.e. above guideline levels) concentrations of both DRP and SIN. The Pahau River, St Leonards Drain and Dry Stream generally have the highest concentrations of both nutrients.

The calculation of the contribution of each sub-catchment to the total measured contaminant inputs to the catchment provides some information on the source of nutrient enrichment in the lower Hurunui River:

- The Pahau River appeared to be the biggest contributor of both DRP (39%) and SIN (51%);
- Put together, the Pahau River, St Leonards Drain and Dry Stream contributed on average 57 % of the total DRP measured inputs to the middle Hurunui River;
- The Pahau River and St Leonards Drain contributed nearly 80% of the total SIN inputs to the middle Hurunui River;
- The lower Pahau, St Leonards Drain and Dry Stream catchments had the highest DRP yields;
- St Leonards Drain catchment had by far the highest SIN yield, followed by the Pahau catchment.

Analysis of water quality data under different river flow conditions and during/outside the main irrigation season indicates that:

- 50 to 85% of the annual DRP load in the Hurunui River occurred during the irrigation season;
- The DRP concentrations in the Pahau River, Dry Stream and St Leonards Drain were significantly higher during the irrigation season than during the rest of the year
- The accumulated relative contribution of the Pahau River, Dry Stream and St Leonards Drain increased during periods of low river flow (i.e. when irrigation is most likely to occur) and during the main irrigation season to approximately 70% of the total measured DRP inputs;
- Irrigation season did not appear to have a major influence on SIN concentrations or loads;
- Similarly to DRP, *E. coli* concentrations in a number of tributaries were significantly higher during the irrigation season.

Diffuse sources of *E. coli* and phosphorus to waterways are generally associated with particles carried in surface runoff. On the other hand, inorganic nitrogen (particularly nitrates) is highly soluble and tends to reach the waterways with subsurface/ groundwater flows. The results support the fact that irrigation practices were a likely causing a significant input of DRP and *E. coli* in the Pahau River, St Leonards Drain and Dry Stream. Soluble inorganic nitrogen, dominated by nitrate in the Hurunui system, probably reaches the surface waterways via subsurface/groundwater paths.

The monitoring record is too short to obtain a robust conclusion on the presence of significant temporal trends using standard statistical tests (such as the seasonal Kendall test). However, significant improvements in DRP and *E. coli* concentrations in the Pahau River between the 2005-06 and the 2007-08 irrigation seasons may be indicating that recently implemented changes in the management of the wipe-off water, including capture in ponds for re-use and/or treatment have been somewhat successful in reducing DRP losses from agricultural land to the Pahau River.

Periphyton growth in the middle and lower Hurunui River is likely to be predominantly phosphorus-limited. The direct management implication is that DRP should be considered as the priority nutrient for management. However, national experts agree that managing only one nutrient is a strategy fraught with risk, and recommend that both nitrogen and phosphorus be managed (whilst placing a higher priority on the limiting nutrient) (Wilcock *et al.* 2007).

The Pahau River and St Leonards drain catchments are the biggest contributors to the DRP loadings in the Hurunui River, and should be the priority targets for management action.

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1. Context

1.1. Introduction

Concerns were raised in the late 1990s about the quality of the lower Hurunui River. The lower reaches of the river frequently had high nutrient and indicator bacteria concentrations which compromised its suitability for contact recreation (Hayward, 2001). Nuisance growth of algae (periphyton) in the Hurunui River are possible every couple of years and have led to complaints in the past (Mosley, 2002).

The Culverden basin was identified as potential source of these contaminants via the various hill-fed and groundwater-fed streams flowing across the intensively farmed plains into the Hurunui River. Water quality sampling has shown high nutrient and bacterial concentrations in the Culverden basin streams. However, little was known of water quality in other main tributaries, such as the Waikari, Waitohi and Kaiwara rivers. Furthermore, relative nutrient and bacterial loadings from tributaries have not been estimated.

In November 2005 Environment Canterbury started a monitoring programme focussed on the middle and lower reaches of the Hurunui River. This programme aimed at providing background water quality and river flow data for the middle reaches of the Hurunui River and its main tributaries.

1.2. Aim and scope of the study

The aim of this study was to analyse the water quality data relating to nutrients and indicator bacteria collected by Environment Canterbury since November 2005. In particular, the study investigated the following points:

- the state of the Hurunui River and its main tributaries;
- the annual contaminant loadings in the Hurunui River;
- the contribution of the different main tributaries to the measured contaminant loads in the catchment.

Temporal trends in contaminant concentration have not been studied in this report, principally due to the shortness of the data record.

This study primarily focuses on providing an analysis of nutrients and indicator bacteria (*E. coli*) concentration and loads in the middle reaches of the Hurunui catchment. Although some comments relating to other contaminants, such as ammonia, turbidity or dissolved organic carbon (DOC), are provided, any in-depth analysis of these contaminants is outside the scope of this study.

2. Methods

2.1. Original dataset

The core dataset for this study comprised of 7 sites, monitored monthly by Environment Canterbury for water quality and flow ("spot gaugings") since November 2005. Two sites were added in June 2006 to provide water quality information on the upper reaches of two tributaries, the Pahau River and St Leonard's Drain. Monitoring at two further sites, on the Waikari and Kaiwara River above their respective confluences with the Hurunui River, was discontinued in June 2006, as it was considered sufficient data had been gathered.

In addition to the sites described above, NIWA monitors water quality at two sites in the Hurunui River: at Mandamus, in the upper reaches of the catchment, and at SH1, in the lower catchment. Table 1 provides a summary of the data used in this study.

2.2. Water quality data preparation

The dataset contained a relatively small proportion of “less than detection limit” results. To conduct statistical analysis, such “censored” data should be replaced by numerical values. The “less than” values represented less than 10% of the total dataset for each parameter and were replaced by half of the detection limit, which is consistent with the recommendations in Scarsbrook and McBride (2007).

Between April 2005 and June 2007, the Hurunui River upstream of the Waikari confluence was sampled immediately downstream of a footbridge (Hurunui River just below footbridge – Nth Bank). To avoid any potential localised contamination caused by birds roosting under the footbridge, the sampling location was moved immediately upstream of the footbridge in July 07. *E. coli* analysis were carried out at both sites on each sampling occasions after July 07, to provide an indication of possible differences in water quality between upstream and downstream of the footbridge. A paired T-test indicated no significant difference between the *E. coli* datasets collected at the two sites. It was assumed that the water quality was not significantly different between the two sites, and the datasets were merged into one site, called “Hurunui at Footbridge” in this report.

2.3. Flow data

Continuous (15 min interval) flow data are available at three sites in the Hurunui catchment: Hurunui River upstream of the Mandamus River confluence (“Hurunui at Mandamus”) (NIWA site), Mandamus River upstream of its confluence with the Hurunui River (Mandamus at Tekoa Road) and Hurunui River at SH1 (Environment Canterbury sites). All flow data used in this report from these sites were based on daily average flow.

A synthetic flow record was created for the Hurunui River downstream of its confluence with the Mandamus River by adding daily average flows for each day of record. After 17th November 2005, flow records are available for the Mandamus River. For the period 1 July 2004 to 16 November 2005, the flow in the Mandamus River was estimated by Environment Canterbury based on a flow correlation with the Hurunui at Mandamus flow recorder. This synthetic flow record was used in the contaminant load calculations for the Hurunui at SH7 site.

River flow at each other sampling site on each sampling date was available either from continuous flow records or from direct flow gauging, except for a few sites, where river flow was estimated from upstream data (refer to Table 1). These river flow data were also used in the contaminant load calculations presented in section 4 of this report.

The Hurunui at SH1 river level recorder was primarily a flood warning site from June 1999 to July 2007 and only rated at high river flows. From July 2007 onwards, rating over the full range of flows has been undertaken. The flow record was used as provided, but caution should be exerted in using the results as some low flow data may have inaccuracies.

Table 1: Summary of the water quality and flow data used in this study on the Hurunui catchment. Phy-Chem: Physico-chemical parameters, including water temperature, pH, conductivity and dissolved oxygen. Nutrients include dissolved reactive phosphorus (DRP) and soluble inorganic nitrogen (SIN). Cover: Periphyton cover

Monitoring site	Water quality data					Flow data	Comments
	Record Period	Parameters					
		Phy-Chem	Nutrients	E. coli	Cover		
Hurunui at Mandamus	Monthly 1989-2006	✓	✓	Ltd	✓	Continuous 1957-2008	NIWA water quality and flow monitoring site
Mandamus at Tekoa Rd	-	-	-	-	-	Continuous 11/05-2008	Environment Canterbury flow monitoring site
Hurunui at SH7	Monthly 04/05 -03/08	✓	✓	✓	✓		Flow estimated as the sum of the flows at Hurunui at Mandamus an Mandamus at Tekoa Rd
Waitohi above Hurunui	Monthly 04/05 -03/08	✓	✓	✓	✓	Gaugings 04/05 -03/08	
Dry Stream above Hurunui	Monthly 04/05 -03/08	✓	✓	✓	✓	Gaugings 04/05 -03/08	
Hurunui above Pahau	Monthly 04/05 -07/07	✓	✓	✓	✓		Water quality sampling ceased in Ceased – concerns about local influence on water quality Flow estimated as Hurunui at SH7 + Waitohi +Dry Stream
Pahau at SH7	Monthly 06/07 -03/08	✓	✓	✓	✓		Added to the programme to obtain information on the upper Pahau River
Pahau at Dazell's Bridge	Monthly 04/05 -03/08	✓	✓	✓	✓	Gaugings 04/05 -03/08	
St Leonards Drain at Lowry Peaks Rd	Monthly 06/07 -03/08	✓	✓	✓	✓	-	Added to the programme to obtain information on the upper St Leonards Drain
St Leonards Drain below bridge	Monthly 04/05 -03/08	✓	✓	✓	✓	Gaugings 04/05 -03/08	
Hurunui at Footbridge	Monthly 04/05 -03/08	✓	✓	✓	✓		Merged data from two close-by sites Flow estimated as Hurunui above Pahau + Pahau at Dazell's Bridge + St Leonards Drain
Waikari above Hurunui	Monthly 04/05 -05/06	✓	✓	✓	✓	Gaugings 04/05 -05/06	Monitoring stopped June 06
Kaiwara at Cat Hill Rd	Monthly 04/05 -05/06	✓	✓	✓	✓	Gaugings 04/05 -05/06	Monitoring stopped June 06
Hurunui at SH1	Monthly 11/05 -03/08	✓	✓	✓	✓	Continuous 07/75-03/08	Environment Canterbury water quality and flow monitoring site

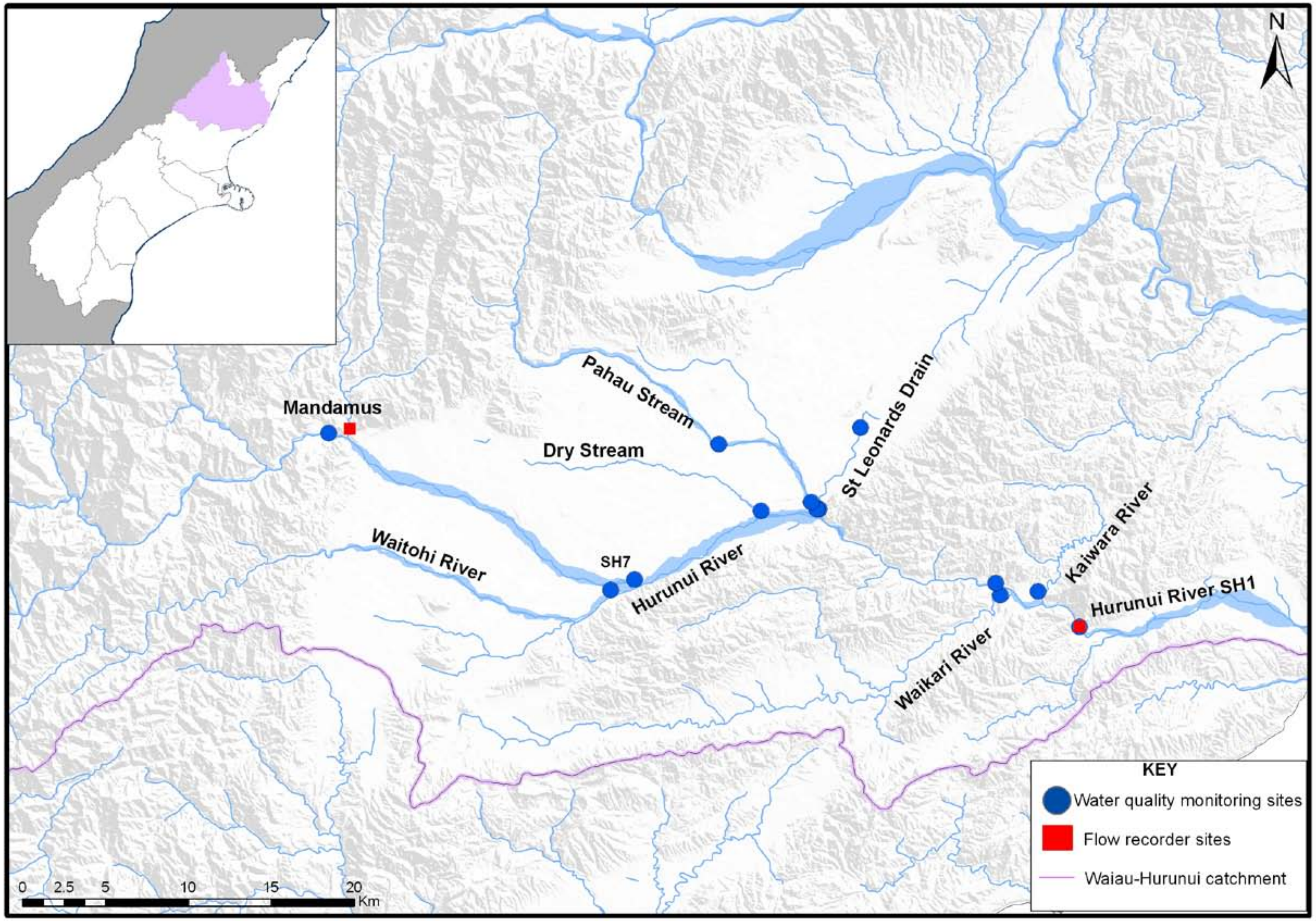

Figure 1: Middle Hurunui catchment and location of water quality monitoring sites

2.4. Data analysis

Descriptive statistics (mean, percentiles, confidence intervals), such as those provided in Appendix A and showed in different tables and figures in this report were calculated with a number of macros developed for Microsoft Excel 2007.

To provide more in-depth analysis, water quality data were generally analysed:

- year-round at all flows (i.e. all data available),
- under 3 times median flow, to remove the potential influence of flood flows;
- under the lower quartile (25th percentile) flow, to reflect low river flow conditions;
- during and outside the main irrigation season (October to April inclusive) to tease out any difference in water quality between these two periods;

T-test or Mann-Whitney tests were used to compare two groups of unpaired data (e.g. winter/summer comparisons). Wilcoxon test or paired T-test were used to compare two groups of paired data (e.g. comparing contaminant concentration at two sites with the same sampling dates).

2.5. Annual Contaminant loads

Contaminant loads are the amount of contaminant carried by the river through one point, or more correctly one transversal section of the river in a given length of time. Calculation methods generally assume that the contaminant concentration is homogenous across the section of river. Annual loads were calculated for water years spanning 1 July-30 June.

When both continuous river flow and contaminant concentration data are available, instantaneous contaminant flux can be calculated at any point in time, and an estimate of the contaminant load during a given period of time can be calculated by simply summing up the instantaneous flux:

$$Load(year_i) = \int_{01/01/year_i}^{31/12/year_i} [Pollut](t) \cdot Flow(t) \cdot dt$$

When contaminant concentrations are known only at regular time intervals (e.g. monthly), the above formula can be approximated using a number of approaches. Two approximations methods were used in this report. Both methods require continuous river flow data, thus load calculations were only undertaken for three sites on the Hurunui River: at Mandamus, Footbridge and SH1.

2.5.1. Averaging approach

This method uses the monthly average river flow and the monthly average contaminant concentration to estimate monthly loads. The annual load is then calculated by summing up the monthly loads. This method is particularly applicable when the contaminant concentration and river flow are independent variables (Richards, 1998).

Monthly load: $$Load(month_i) = [Pollut](month_i) \cdot \int_{01/month_i}^{31/month_i} Flow(t) \cdot dt$$

Annual load: $$Load(year_i) = \sum_i [pollut]_{monthi} \cdot Monthly\_average\_flow_{monthi} \cdot \Delta t$$

2.5.2. Ratio approach: The Beale ratio estimator

Ratio estimators use the year's data to calculate a mean daily load, then use the mean flow from days lacking concentration data to adjust the mean daily load. The annual load is obtained by multiplying the mean daily load by 365 (Richards, 1998). Ratio estimators assume that there is a positive linear relationship between river flow and contaminant load.

The basic assumption of a ratio estimator is that the ratio of contaminant load to river flow for the entire year is the same as on days the contaminant concentration was measured.

$$\frac{Average\_daily\_load_{year}}{Average\_daily\_flow_{year}} = \frac{Average\_daily\_load_{o}}{Average\_daily\_flow_{o}}$$

where the subscript "year" refers to an average for the year, and the subscript "o" refers to an average over the days on which concentration was observed.

However, as daily load and daily flow are correlated variables, this ratio estimator is biased and a bias correction factor must be used.

The Beale Ratio estimator is one way to correct the bias:

$$Average\_daily\_load_{year} = Average\_daily\_load_{o} \cdot \frac{Average\_daily\_flow_{year}}{Average\_daily\_flow_{o}} \left[\frac{1+\left(\frac{1}{n}-\frac{1}{N}\right)\frac{s_{lq}}{l_o q_o}}{1+\left(\frac{1}{n}-\frac{1}{N}\right)\frac{s_{qq}}{q_o^{\,2}}} \right]$$

Where: S_{lq} is the covariance between flow and pollutant flux, s_{qq} is the variance of the flow based on the days on which concentration was measured. N is the expected population size (365), and n is the number of concentration measures (generally 12, as we have one measure for each month). l_o and q_o represent the average daily flux and flow respectively on the days concentrations were measured.

The square root of the mean square error of the daily load (RMSE) provides an estimate of the standard deviation, and is given by:

$$RMSE = \sqrt{\bar{l}_o^2 \left[\left(\frac{1}{n}-\frac{1}{N}\right)\left(\frac{S_{qq}}{\bar{q}_o^2}+\frac{S_{ll}}{\bar{l}_o^2}-2\frac{S_{lq}}{\bar{l}_o\,\bar{q}_o}\right)+\left(\frac{1}{n}-\frac{1}{N}\right)^2\left(2\frac{S_{qq}^2}{\bar{q}_o^4}-4\frac{S_{qq}}{\bar{q}_o^2}\frac{S_{lq}}{\bar{l}_o\,\bar{q}_o}+\frac{S_{lq}^2}{(\bar{l}_o\,\bar{q}_o)^2}+\frac{S_{qq}}{\bar{q}_o^2}\frac{S_{ll}}{\bar{l}_o^2}\right) \right]}$$

3. The Hurunui Catchment

3.1. The Hurunui Catchment

The Hurunui River takes its source in the Southern Alps, out of Lake Sumner (North Branch) and Harper Pass (South Branch). The Hurunui is one of the major braided rivers in the Canterbury region, with a catchment area of 1,070 km^2, and an annual mean flow of 73 m^3/s at SH1, 16 km upstream of the river mouth (Hayward, 2001).

3.1.1. Values

The values of the Hurunui River and its catchment are extensively described in Mosley (2002). The following values were identified as being of particular significance:

- Ecological values associated with the aquatic and riparian ecosystems and significant habitats of indigenous fauna and flora. In particular, the Hurunui River is ranked as of national to international significance for threatened bird species;
- Natural character and outstanding and significant natural features and landscapes;
- Cultural and heritage values;
- Recreational and amenity values, including a nationally significant trout and salmon fishery, and swimming, kayaking and jetboating.

3.1.2. Landcover and landuse

The Culverden Basin is intensively farmed, with a well established border dyke irrigation scheme. Dairying is the dominant land use on the plains area, with sheep and beef grazing dominating the surrounding hills (Figure 2). Border dyke irrigation often results in surface runoff from the irrigated land – known as wipe-off water. The discharge of wipe-off water and increased drainage from the land has resulted in high summer water tables and continuously flowing streams which would have otherwise gone dry in summer.

Wipe-off water typically contains high concentrations of mobile contaminants, particularly phosphorus and bacterial indicators of faecal contamination. Wipe-off water has been identified as a major contributor to poor water quality in rivers and streams of the Culverden Basin (Hayward 2001). Changes in management of the wipe-off water, including capture in ponds for re-use and/or treatment have recently been implemented and appear to be relatively successful in reducing wipe-off losses to the waterways (Houlbrooke, 2007). It remains unclear whether these changes have been successful in improving water quality in the Culverden Basin waterways and the Hurunui River.

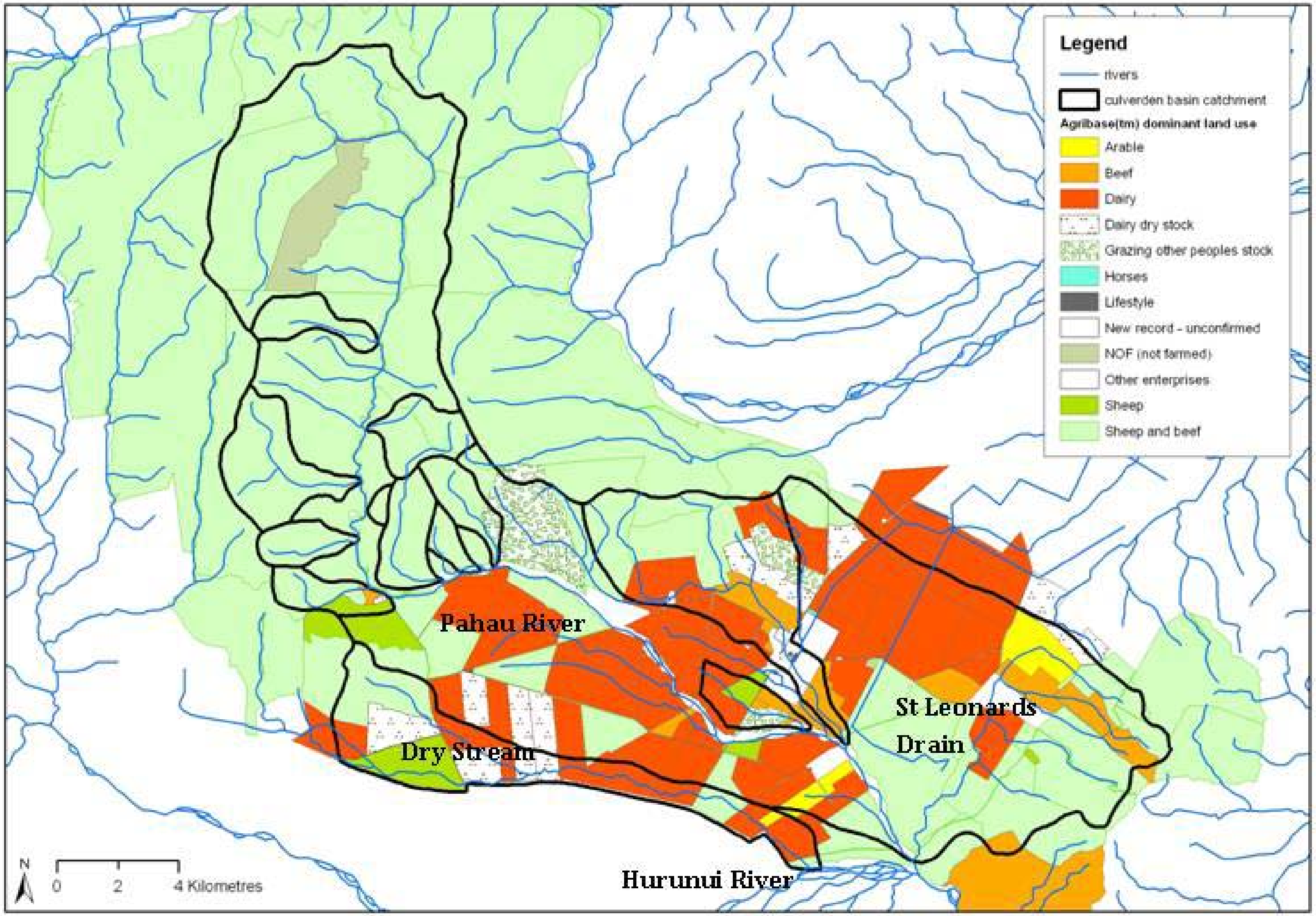

Figure 2: Major land uses in the Dry Stream, Pahau River and St Leonards Drain catchments derived from AgriBase™ (AgriBase™ data are a product of AsureQuality)

Table 2: Summary of water quality state at three monitoring sites on the Hurunui River. The grey-shaded cells are those used to assess compliance with the standards/ guidelines. MAC: Microbiological Assessment category, as per MfE (2000)

Parameter	Monitoring Site	Average	Median	90th percentile	95th percentile	Compliance with standard	Standard/ Guideline
pH	SH7	7.7	7.8	7.5-7.9	7.3-7.9	✓	7.3-8.0 (ANZECC 2000)
	Footbridge	8.0	7.9	7.6-8.7	7.4-8.8	✗	
	SH1	8.1	7.9	7.6-8.7	7.5-8.8	✗	
Dissolved Reactive Phosphorus (DRP (g/m^3)	SH7	0.002	0.002	0.005	0.005	✓	0.003 (Biggs 2000)
	Footbridge	0.004	0.004	0.008	0.009	✗	
	SH1	0.004	0.004	0.008	0.009	✗	
SIN (g/m^3)	SH7	0.041	0.035	0.066	0.085	✗	0.034 (Biggs 2000)
	Footbridge	0.327	0.305	0.519	0.575	✗	
	SH1	0.331	0.290	0.517	0.572	✗	
Ammonia-N (g/m^3)	SH7	0.011	0.011	0.018	0.021	✓	0.400 (ANZECC 2000 at pH 8.5)
	Footbridge	0.012	0.010	0.018	0.023	✓	
	SH1	0.012	0.011	0.019	0.022	✓	
Turbidity Under lower quartile flow	SH7	0.5	0.5	0.7	0.8	✓	4.1 (ANZECC 2000)
	Footbridge	0.8	0.7	1.3	1.6	✓	
	SH1	1.5	0.7	2.9	4.8	✓	
E. coli (/100mL) Under 3 times median	SH7	171	125	402	460	75 % (MAC C)	260 (MfE 2000)
	Footbridge	95	36	206	355	94 % (MAC C)	
	SH1	69	35	187	235	94 % (MAC B)	
E. coli (/100mL) Irrigation season Under 3 times median	SH7	209	190	430	460	65 % (MAC C)	260 (MfE 2000)
	Footbridge	133	48	334	562	88 % (MAC C)	
	SH1	85	43	234	290	88 % (MAC C)	
Periphyton cover Long filaments (%)	SH7	3	0	10	14	100 %	30 (Biggs 2000)
	Footbridge	9	0	33	40	88 %	
	SH1	9	10	19	29	96 %	
Periphyton cover Thick mats (%)	SH7	21	10	61	69	88 %	60 (Biggs 2000)
	Footbridge	27	18	55	71	92 %	
	SH1	25	15	71	79	88 %	

3.2. Water Quality of the Hurunui River

Table 2 provides a summary of the water quality at three monitoring sites in the upper (SH7), middle (Footbridge) and lower (SH1) parts of the Hurunui Catchment's middle reaches.

3.2.1. Nutrients

The NZ periphyton guidelines suggest a maximum annual mean DRP and SIN concentrations of 0.003 and 0.034 g/m^3 respectively (using a 40 days accrual period) to prevent maximum periphyton biomass from exceeding maximum acceptable levels for the protection of the river's aesthetic, recreational and trout habitat/angling values (Biggs, 2000). These thresholds are used in this report.

Annual mean DRP concentration is below the guideline level of 0.003 g/m^3 at the uppermost (SH7) monitoring site. Both the middle (Footbridge) and lower (SH1) sites exceed the guideline. A two-tailed Wilcoxon ranked test shows statistically significant differences between SH7 and each of Footbridge ($p<0.01$) and SH1 ($p<0.05$). The same test does not indicate a significant difference between Footbridge and SH1.

DRP concentrations during and outside the irrigation season are very similar at the upstream (SH7) site. At the two downstream sites, the irrigation season DRP concentrations appear slightly higher than the "winter" concentrations, although the difference was not significant (two-tailed Mann-Whitney test: $p=0.07$ at Footbridge and $p=0.22$ at SH1).

Annual mean SIN concentrations exceed the guideline level at all three sites, although the breach was only marginal at SH7. The SIN concentration rose considerably at both downstream sites, to approximately four times the guideline concentration. The same pattern as for DRP emerges from statistical analysis: SH7 is significantly different from Footbridge and SH1 ($p<0.001$ in both cases), but the two downstream sites exhibited no significant differences.

The SIN/DRP ratio can be a useful indicator of which of SIN or DRP is the likely limiting nutrient for periphyton growth. Both nitrogen and phosphorus are needed for periphyton growth in an average weight ratio of 7:1, as defined in the Redfield equations (Stumm and Morgan, 1996 in Wilcock *et al.*, 2007). A ratio of approximately 7 is the theoretical limit between N-limited (ratio<7) and P-limited (ratio >7) conditions.

Generally, elevated SIN/DRP ratios (above 20) are a strong indication of P-limited conditions, and low ratios (<4) are a strong indication of N-limited conditions. Ratios between 4 and 20 are generally inconclusive or may indicate that the nutrient limitation may "switch" between" the two nutrients at different times of the year/ flows. Plots of SIN/DRP ratios (Figure 3) indicate that:

- SH7 is generally P-limited, although no definite conclusion can be drawn for about half of the datapoints. A similar pattern was observed during the irrigation season (Appendix B);
- N/P ratios at Footbridge and SH1 strongly indicate that, if nutrient concentration is a limiting factor to periphyton growth, then phosphorus is likely to be the limiting nutrient at both sites.

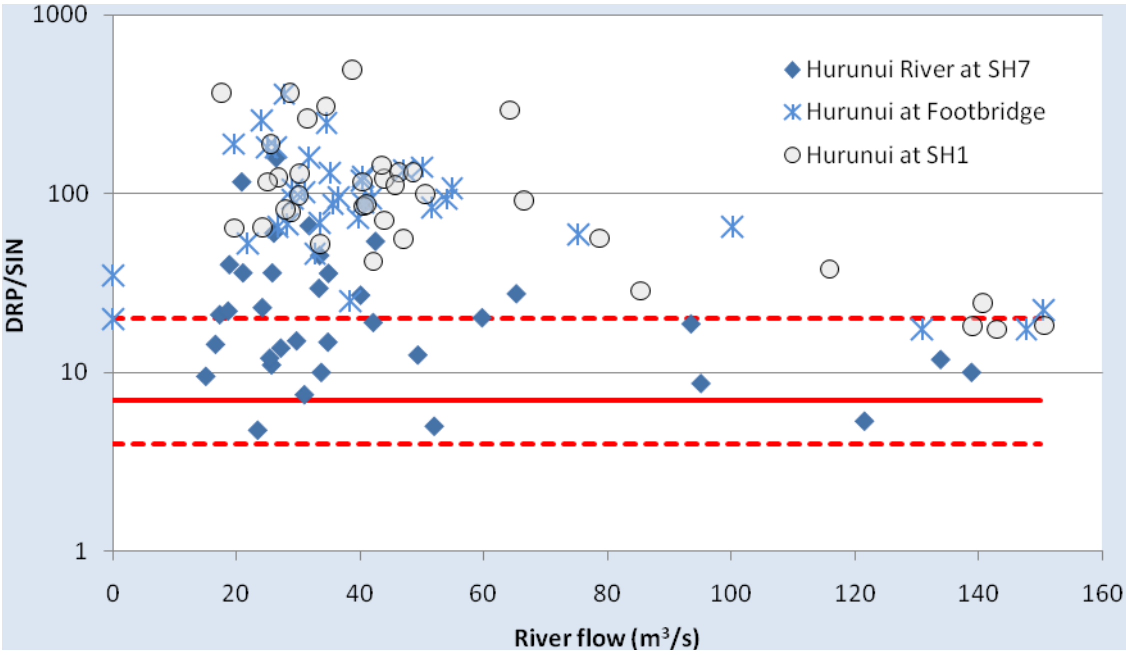

Figure 3: SIN/DRP ratio at three monitoring sites in the upper (SH7), middle (Footbridge) and lower (SH1) parts of the Hurunui Catchment's middle reaches. The solid red bar represents a SIN/DRP ratio of 7, and is the theoretical limit between N-limited and P-limited conditions. Datapoints above the top dotted red line (SIN/DRP=20) indicate P-limited conditions. Datapoints below the bottom dotted red line indicate N-limited conditions. No firm conclusions can be drawn from DRP/SIN ratio for datapoints between the two dotted red lines

3.2.2. Periphyton

The NZ periphyton guidelines define nuisance periphyton growth as a maximum periphyton cover of the visible river bed of 60% by diatom/cyanobacteria mats more than 3mm thick or 30% by filamentous algae more than 2cm long.

No periphyton biomass data were available. The periphyton cover presented in Table 2 was estimated from the riverbank and should be considered as indicative, categorical data, and may not be representative of the whole river width.

Filamentous algae cover at the upstream (SH7) site was below the 30% guideline level on all monitoring occasions. Both downstream sites occasionally breached the 30% threshold (three times at Footbridge, once at SH1).

It should also be added that there is anecdotal evidence of nuisance periphyton growth in the Hurunui River, which has led to complaints in the past (Mosley, 2002).

3.2.3. E. coli

The 2002 microbiological guidelines for recreational waters recommend the use of the indicator bacteria *Escherichia coli* (*E. coli*) as indicator of health risk in freshwaters (MfE, 2000). The Guidelines define a three-mode management system for recreational freshwaters: Acceptable/Green mode (*E. coli*<260/100mL), Alert/Amber mode (*E. coli*<550/100mL) and Action/Red mode (*E. coli>550*/100mL). The green mode indicates a low level of health risk, the Amber mode is indicative of a slightly more elevated, although still acceptable, health risk, and the red mode indicates the health risk to swimmers is unacceptable and the site/ beach is unsuitable for swimming. The 2002 MfE guidelines also define a classification of recreational waters (Microbiological Assessment Category or MAC) based on five year's historical data, from A (highest water quality) to D (poorest water quality).

Recreational use of rivers is generally low during floods, and some activities, such as bathing and trout fishing are generally more common during periods of low river flow. Accordingly, data analysis was performed at river flows below three times the median flow (to remove the flood flows) and at river flows below the 25th percentile (lower quartile) of the flow distribution.

Analysis of data collected year round under 3 times median indicates that all three Hurunui River monitoring sites had acceptable level of compliance (more than 75%) with the 260 *E. coli*/100mL guideline. All three sites have a compliance of at least 95 % with the 550 *E. coli*/100mL guideline. No significant differences were found between the mean or median *E. coli* concentrations observed at the three sites (Two-sided ranked Wilcoxon test).

However, the percentage of compliance with the 260 *E. coli*/100mL level is higher at the two downstream sites (94%) than at the SH7 site (75%). The Microbiological Assessment Category (MAC) is better (B) for the most downstream site (SH1) than for the two upstream sites (C). The reasons why the microbiological water quality was relatively more degraded at the upstream site are unknown and should be investigated.

Median *E. coli* are higher during the irrigation season at all three sites. An ANOVA undertaken on all three sites indicates an effect of the season (irrigation vs. non-irrigation) on *E. coli* concentrations. ($p<0.005$). However, Mann-Whitney tests on individual sites show only marginally significant differences between irrigation and non-irrigation season at SH7 and Footbridge ($p=0.056$ and $p=0.073$ respectively).

3.2.4. Other determinands

Water pH records indicate that both downstream sites have relatively frequent elevated pH (i.e. higher than 8.5). These pH values are within the tolerable range for salmonids (5-9.5) but slightly outside the optimal range of 6.7 to 7.8 (Raleigh *et al.* 1986). As such, the pH values observed in the Hurunui River should not be a significant stressor to aquatic life. Rather, they are likely associated with active algal growth[1], and can be an indicator of important periphyton biomass.

Ammonia and dissolved organic carbon concentrations were below guideline levels, and, based on the data available, not a cause for concern in the Hurunui River.

It is noted that turbidity increases significantly in the lower catchment compared to the upper catchment. However a detailed analysis of turbidity/water clarity data were outside the scope of this study.

[1] During the day, algal production uses CO_2 faster than it can be replaced from the atmosphere, causing the dominant CO_2/HCO_3^- equilibrium to be displaced so that the pH is increased ($HCO_3^- + H^+ \leftrightarrow CO_2 + H_2O$).

3.3. Water quality in the Hurunui River Tributaries

3.3.1. DRP

Annual mean DRP concentrations exceed the guideline level in all tributaries (Figure 4). Dry Stream, St Leonard's Drain, the Pahau River and the Waikari River have particularly elevated mean DRP concentrations (at or above 15 mg/m^3).

The irrigation season DRP concentrations are significantly higher than during the non-irrigation season in Dry Stream, the Pahau River and St Leonard's Drain (Figure 4), suggesting an influence of irrigation practices on DRP concentrations in these waterways.

Seven sites have been monitored monthly since 2005. Over the three irrigation seasons analysed in this study, mean DRP concentrations have significantly reduced in the Pahau River (-52%)[2], indicating that recently implemented changes in irrigation practices management have been efficient in reducing DRP losses from agricultural land to the Pahau River. A moderate, but not statistically significant, mean DRP concentration decrease is also observed in St Leonards Drain (-24%). No significant changes were detected at any other of the seven sites, including the Hurunui River (Figure 5).

3.3.2. SIN

All tributaries largely breach the 0.034g/m^3 annual mean SIN concentration guideline level. St Leonard's Drain and the Pahau River have particularly elevated mean SIN concentrations, in excess of 1g/m^3.

No significant differences were found between irrigation and non-irrigation season (Figure 6).

Over the last three irrigation seasons, a slightly increasing trend is apparent in St Leonards Drain and in the Hurunui River at the two downstream sites (Footbridge and SH1). However, none of these changes are statistically significant (Figure 7).

3.3.3. E. coli

A number of tributaries breach regularly the 550 *E. coli* /100mL guideline alert level, indicating significant health risk to recreational users.

The median *E. coli* counts were significantly higher during the irrigation season in most tributaries, including the Waitohi, Dry Stream, Pahau River and St Leonards Drain (Figure 8).

Over the last three irrigation seasons, a decreasing trend is apparent in the Pahau River and in the Hurunui River at the two downstream sites (Footbridge and SH1). Seasonal Kendall tests do not indicate any significant temporal trend, although this is probably partly due to the very short data record. However, Mann-Whitney tests do indicate significant differences ($p<0.05$) in the median *E. coli* concentrations recorded during the 2005-06 and the 2007-08 irrigation seasons (Figure 9).

[2] A Seasonal Kendall test also shows a marginally significant ($p=0.08$) downward trend (-1% per year).

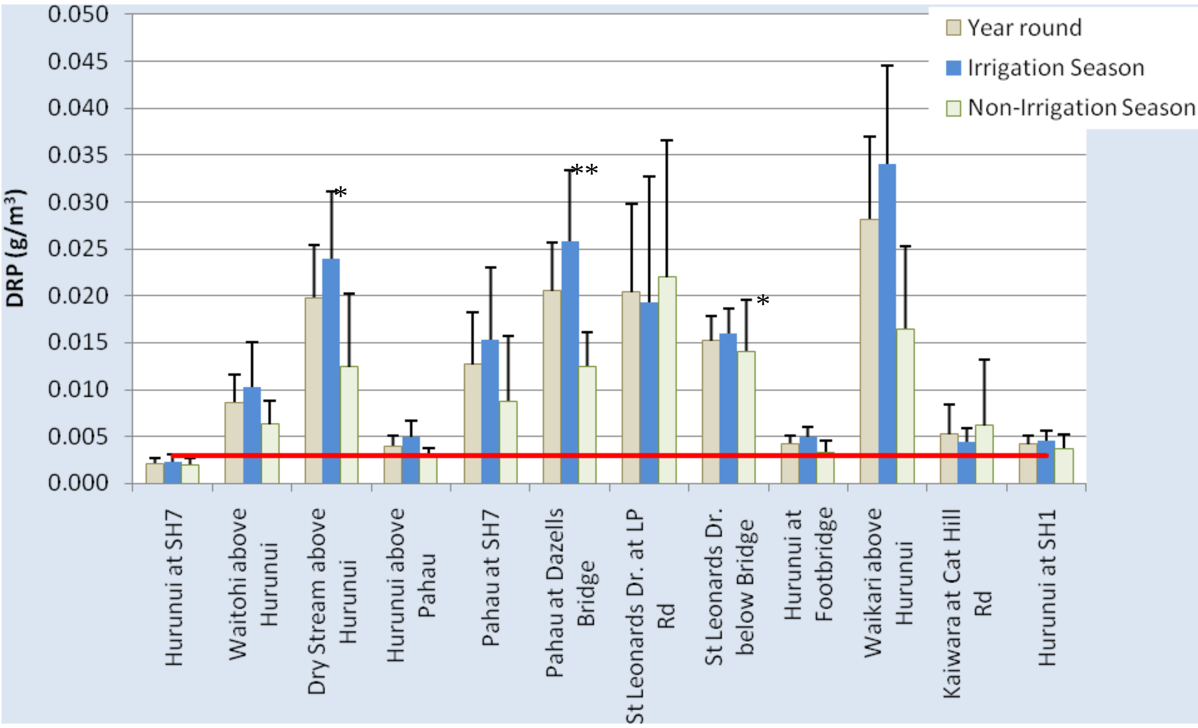

Figure 4: Mean DRP concentrations (g/m^3) ± 95% confidence interval year round, during the irrigation season and outside the irrigation season. * indicates significant difference (* for p<0.05; ** for p<0.01) between irrigation and non-irrigation season (two-sided Mann-Whitney Test)

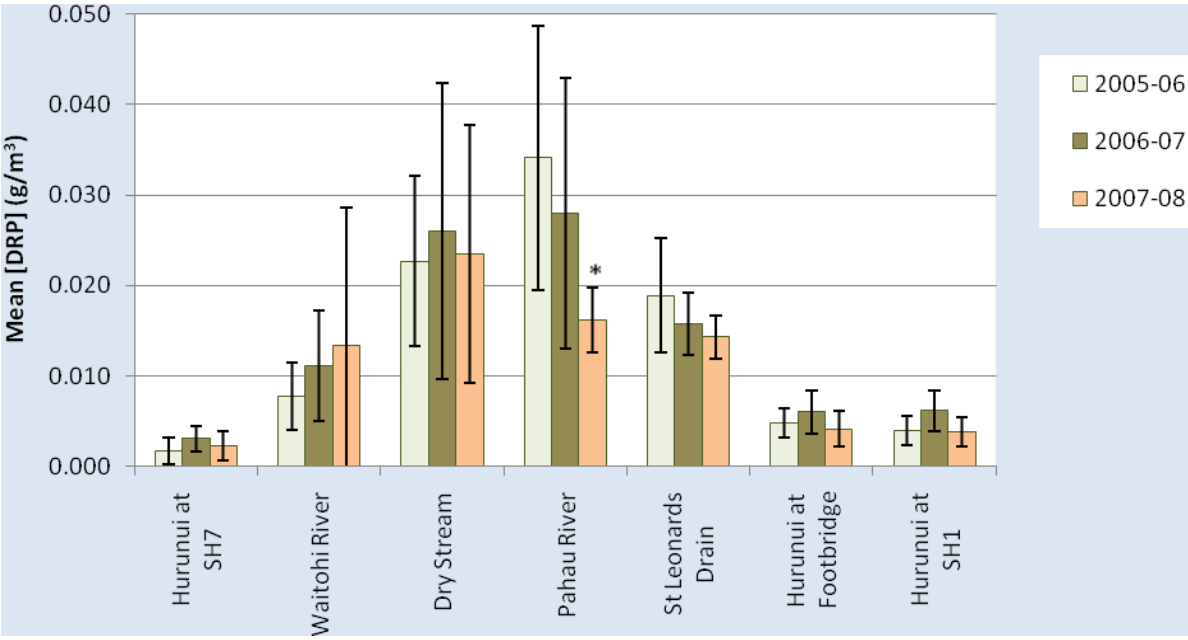

Figure 5: Mean DRP concentration (g/m^3) during three consecutive irrigation seasons (October to April inclusive). *indicates significant different (p<0.05) from 2005-06 irrigation season (two-sided Mann-Whitney Test)

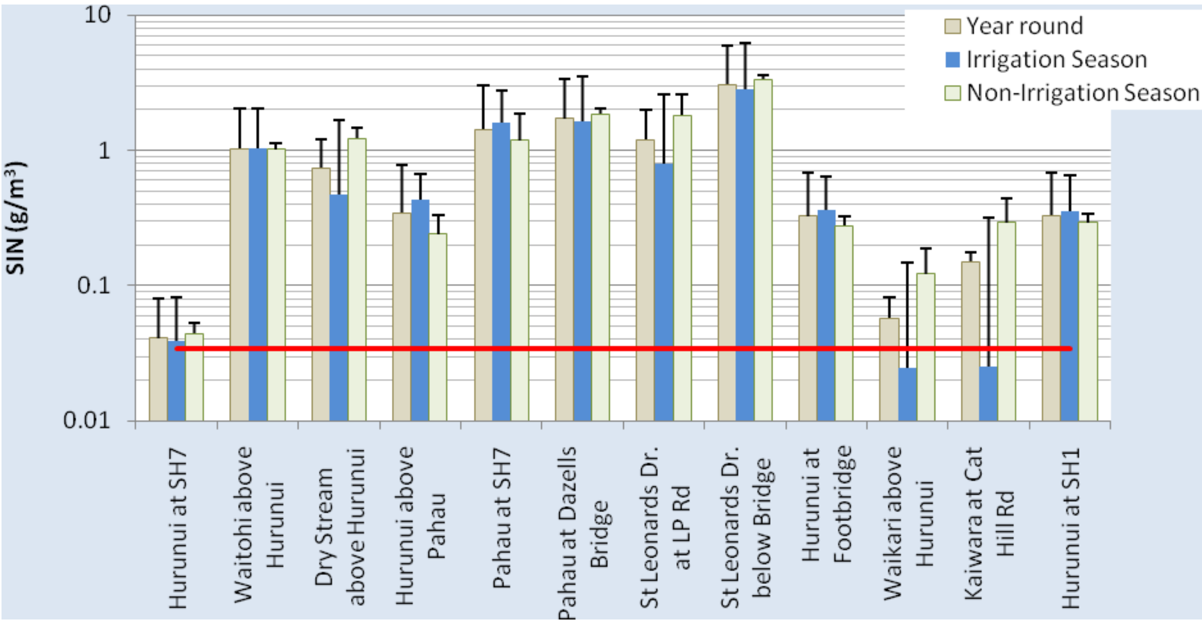

Figure 6: Mean SIN concentrations (g/m^3) ± 95% confidence interval year round, during the irrigation season and outside the irrigation season. No significant differences were found between irrigation and non-irrigation season (two-sided Mann-Whitney Test)

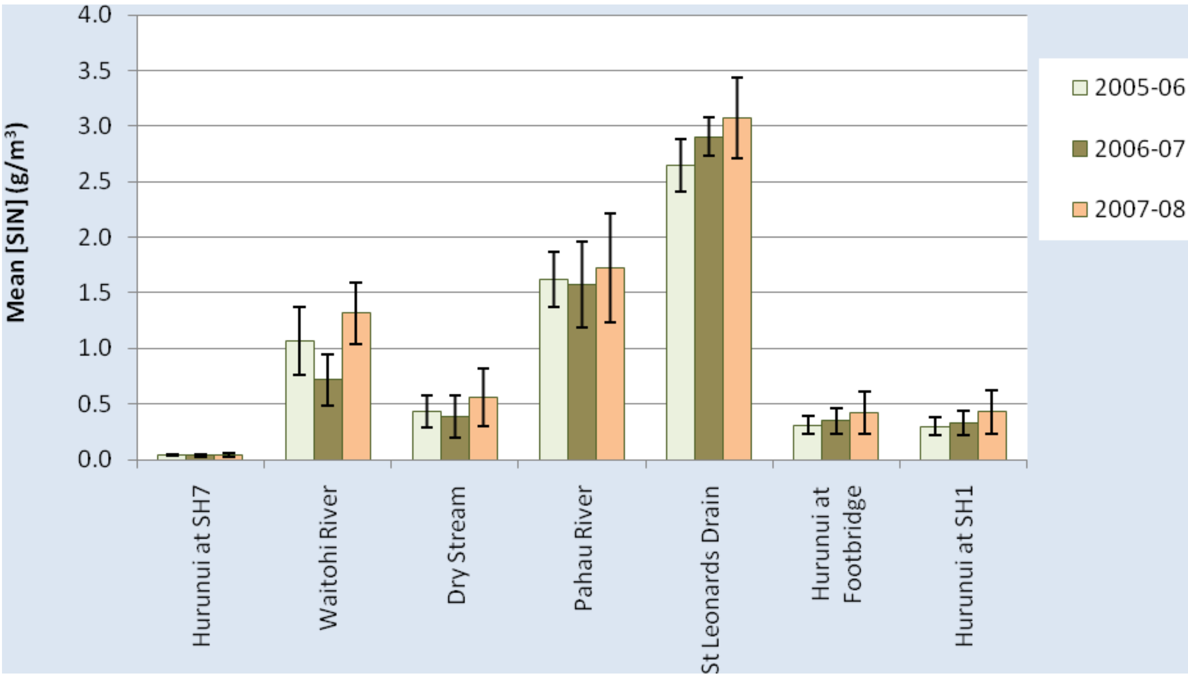

Figure 7: Mean SIN concentration (g/m^3) during three consecutive irrigation seasons (October to April inclusive)

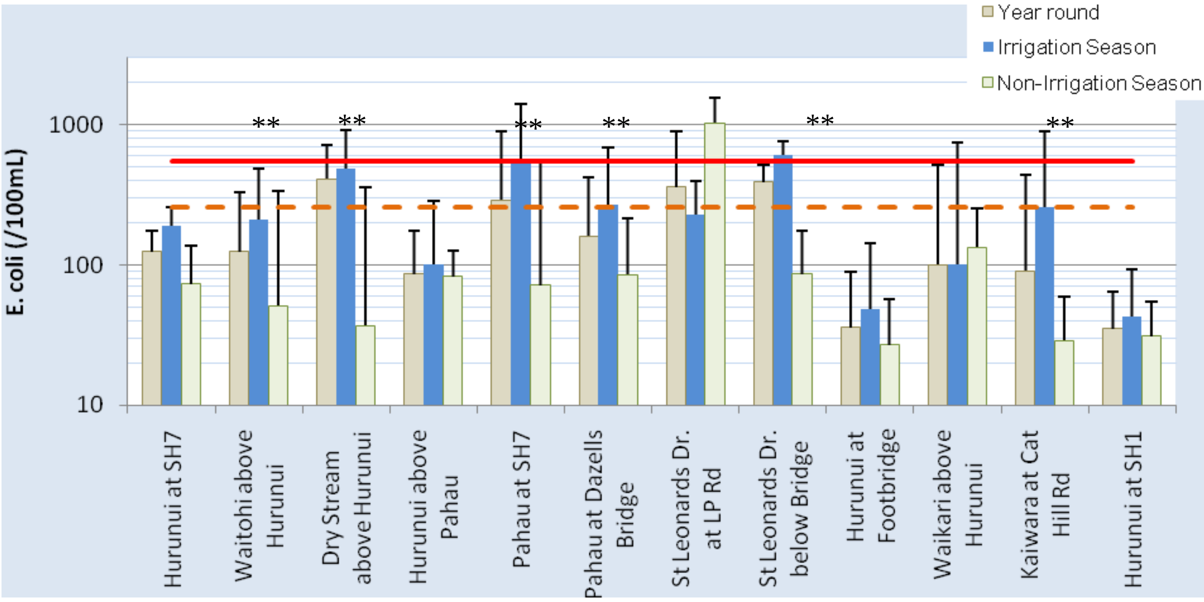

Figure 8: Median E. coli concentrations (/100mL) ± 95% confidence interval when the flow in the Hurunui River is below flood flows (3 times median flow), year round, during the irrigation season and outside the irrigation season. * indicates significant difference (* for p<0.05; ** for p<0.01) between irrigation and non-irrigation season (Mann-Whitney Test). The dotted orange line represents the 2002 MfE microbiological guidelines threshold for "amber/alert" level, and the solid red line represents the threshold for the "red/action" level (MfE, 2002)

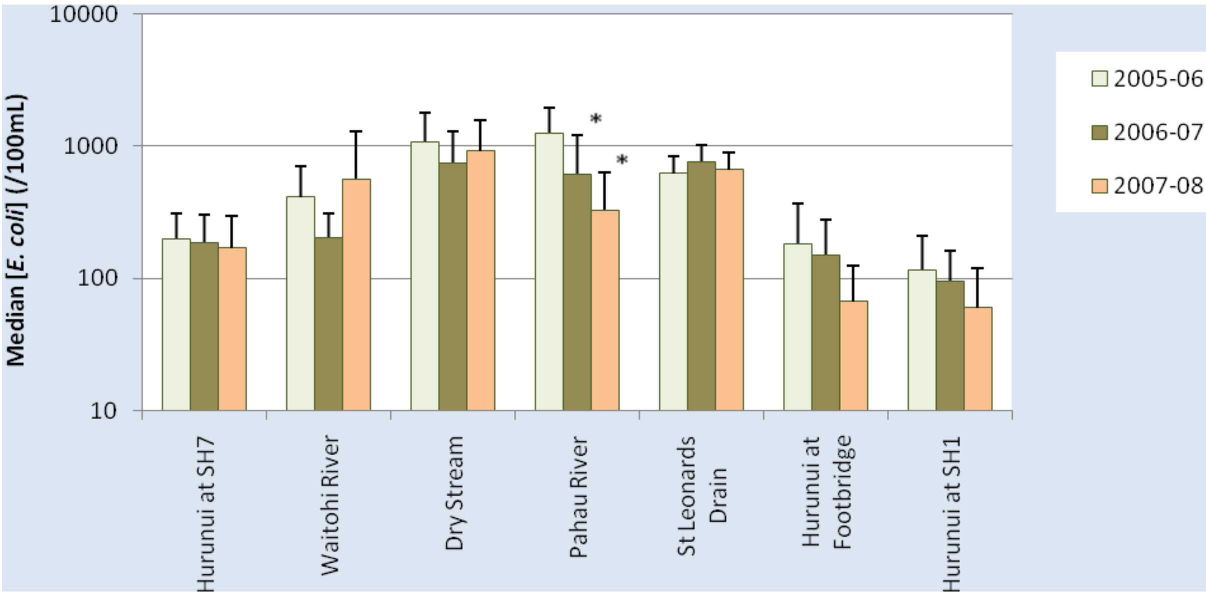

Figure 9: Median *E. coli* concentration (/100mL) during three consecutive irrigation seasons (October to April inclusive). *indicates significant different (p<0.05) from 2005-06 irrigation season (two-sided Mann-Whitney Test)

4. Contaminant loads analysis

4.1. Hurunui River

As explained in section 2.5 of this report, annual contaminant load estimates can only be reliably undertaken at sites where continuous river flow data are available, i.e. at three Hurunui River sites: Mandamus, SH7 and SH1.

The water quality data collected by Environment Canterbury at SH7 and SH1 spans two complete water years (1 July-30 June): 2005-06 and 2006-07. These data plus data for the first nine months of the 2007-08 year were used to produce a provisional estimate of the annual contaminant loads.

The water quality data collected by NIWA were only available until the end of the 2006 calendar year. Only the 2005-06 year was common to all three sites. To provide more elements of comparison, calculations were also undertaken for the 2004-05 year and provisional estimates were produced using the first 6 months of the 2006-07 year. All provisional estimates should be used with due caution.

The poor correlation between the contaminant concentration and river flow (Appendix B) allows using the averaging method to calculate the annual loads. Similarly, the good linear correlation between contaminant flux and river flow allows using the ratio approach (Beale estimator).

Estimated annual DRP loads carried by the Hurunui River are in the order of 3.5 to 6 tonnes at the top end of the middle catchment (Mandamus and SH7), and 6 to 10 tonnes at the bottom end (SH1), or an increase of 45-82 % (Table 3).

Estimated annual SIN loads increase 360 to 580% between SH7 (56-81 Tonnes/year) and SH1 (350-500 tonnes/year) (Table 4).

Annual *E. coli* load increase by one order of magnitude between Mandamus and SH7 (from 0.1 to 1.3-3.5 10^{15}/year), then decrease slightly at SH1 (0.9 to 1.8 10^{15}/year) (Table 5).

Some increase in contaminant loads are generally expected when moving downstream, as the river grows larger. However, the flow statistics for the Hurunui River between 1 July 2004 and March 2008 are remarkably similar at both ends of the middle catchment (e.g. median flow of 33.5 m^3/s downstream of the Mandamus confluence and 33.1 m^3/s at SH1). Thus, the observed changes in contaminant loads are unlikely to be primarily due to an increase of water volumes carried by the river. Rather, they are an indication of a change in water quality.

Table 3: Annual DRP load in tonnes per year (T/Y)

Site	Period	2004-05		2005-06		2006-07		2007-08	
		Year- round	Irrigation season	Year-round	Irrigation season	Year-round	Irrigation season	Year-round[3]	Irrigation season
Hurunui at Mandamus	Averaging method	3.0	2.0	3.6	1.7	-	-	-	-
	Ratio estimation	3.5 ±1.0	1.9 ±1.1	4.6±1.3	2.1 ±0.6	5.5[4]±3.1	-	-	-
Hurunui at SH7	Averaging method	-	-	3.3	2.0	6.9	5.3	2.5	1.5
	Ratio estimation	-	-	4.1 ±1.3	2.4 ±2.3	5.9 ±1.2	4.9 ±1.4	3.7 ±1.5	3.5 ±2.2
Hurunui at SH1	Averaging method	-	-	6.0	3.0	10.0	8.5	4.5	2.2
	Ratio estimation	-	-	7.1 ±2.6	3.4 ±2.5	9.7 ±2.7	8.2 ±3.0	8.0 ±1.4	5.2 ±2.2

Table 4: Annual SIN load in tonnes per year (T/Y)

Site	Period	2004-05		2005-06		2006-07		2007-08	
		Year- round	Irrigation season	Year-round	Irrigation season	Year-round	Irrigation season	Year-round[1]	Irrigation season
Hurunui at Mandamus	Averaging method	39	15	36	9				
	Ratio estimation	46 ±18	12 ±4.2	46 ±17	9.6 ±3.6	92 ±72[2]			
Hurunui at SH7	Averaging method	-	-	56	23	87	59	42	22
	Ratio estimation	-	-	64 ±16	25 ±9	81 ±10	55 ±14	54 ±12	46 ±18
Hurunui at SH1	Averaging method	-	-	381	183	483	256	347	182
	Ratio estimation	-	-	357 ±99	151 ±103	377 ±62	245 ±84	507 ±123	318 ±190

Table 5: Annual *E. coli* load (10^{15}/Y)

Site	Period	2004-05		2005-06		2006-07		2007-08	
		Year- round	Irrigation season	Year-round	Irrigation season	Year-round	Irrigation season	Year-round[1]	Irrigation season
Hurunui at Mandamus	Averaging method	-	-	0.1	0.05	-	-	-	-
	Ratio estimation	--	-	0.1	-	0.1[2]	-	-	-
Hurunui at SH7	Averaging method			1.3	0.9	3.5	1.1	1.2	0.7
	Ratio estimation			1.5		2.1		1.1	
Hurunui at SH1	Averaging method			0.9	0.7	1.8	1.2	0.5	0.3
	Ratio estimation			1.0		1.8		0.8	

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[3] Provisional estimate based on the first 9 months of the 2007-08 water year.

[4] Provisional estimate based on the first 6 months of the 2006-07 water year.

4.2. Tributaries contributions

Continuous flow records are not available for the Hurunui tributaries, thus annual contaminant loads cannot be reliably estimated. However, the contribution made by each sub-catchment to the total measured inputs to the Hurunui catchment can be calculated for each monitoring date.

Although this provides a very useful insight into the sources of contaminants at the catchment and sub-catchment scales, one needs to be aware of the limitations of such method before using its results. In particular, the method does not account for contaminant consumption (nutrients) or die-off (*E. coli*) in the river system, nor does it include any inputs/outputs to the system *via* groundwater. Thus, the paragraphs below refer to the measured inputs to the system, which may be sensibly different from the total inputs.

Subcatchment yields were also calculated as the ratio of contaminant load to the catchment area.

4.2.1. DRP

The Upper Hurunui (above SH7) and the Pahau catchment are by far the biggest contributors to the total measured DRP inputs to the Hurunui catchment (Figure 10), contributing on average just under 40% of the total measured inputs each. The Kaiwara River makes a negligible contribution.

The Pahau River, Dry Stream and St Leonard Drains contributions increase at low river flows (Figure 10). Similarly, the mean contributions from the Pahau River and Dry Stream increase considerably during the irrigation season compared to the rest of the year (Figure 11), possibly due to the irrigation practices in these catchments. The Waikari River dries out during dry periods, so has no contribution when the Hurunui River is low.

The Pahau River, Dry Stream and St Leonards Drain also have the highest DRP yields (i.e. the amount of DRP transported by the river/stream by unit of catchment surface area). Estimated mean DRP yields are generally higher during the irrigation season in these three catchments, although the difference is significant only for the Pahau catchment (at Dalzell's Bridge). It is also interesting to note that the mean DRP yield for the whole Pahau catchment is 97± 28 g/ha/Y, but is only 42 ± 49 g/ha/Y in the upper catchment (above SH7), which points to much increased rates of DRP loss to the waterways in the lower Pahau catchment.

4.2.2. SIN

As per the DRP, the Pahau catchment has the highest mean contribution to the total measured SIN inputs to the Hurunui catchment. However, the close second is the St Leonards Drain, which contributes more than the Hurunui catchment above SH7. Together, the Pahau River and St Leonards Drain catchments contribute an average of 79.5% of the measured SIN inputs (Figure 12).

The contribution of the Pahau River increases moderately when the flow in the Hurunui River is low (Figure 12), and during the irrigation season (Figure 13).

The St Leonards Drain catchment appears to have by far the highest SIN yield (19 ± 1.8 kg/ha/Y), followed by the Pahau River catchment (8.0 ± 1.1 kg/ha/Y). At the other end of the spectrum are the Hurunui catchment above SH7 (0.4 ± 0.1 kg/ha/Y) and the Waikari River catchment (0.03 ± 0.04 kg/ha/Y).

4.2.3. E. coli

The upper part of the Hurunui catchment (above SH7) is by far the biggest contributor, with an average of 64%. The Pahau catchment is the second biggest contributor, with approximately 18% of the total measured input. St Leonards Drain and Dry Stream make moderate contributions (9 and 7% respectively).

The contributions from the Pahau, St Leonard's Drain and Dry Stream are markedly higher during the irrigation season (45% of the total inputs) than during the rest of the year (16.3%).

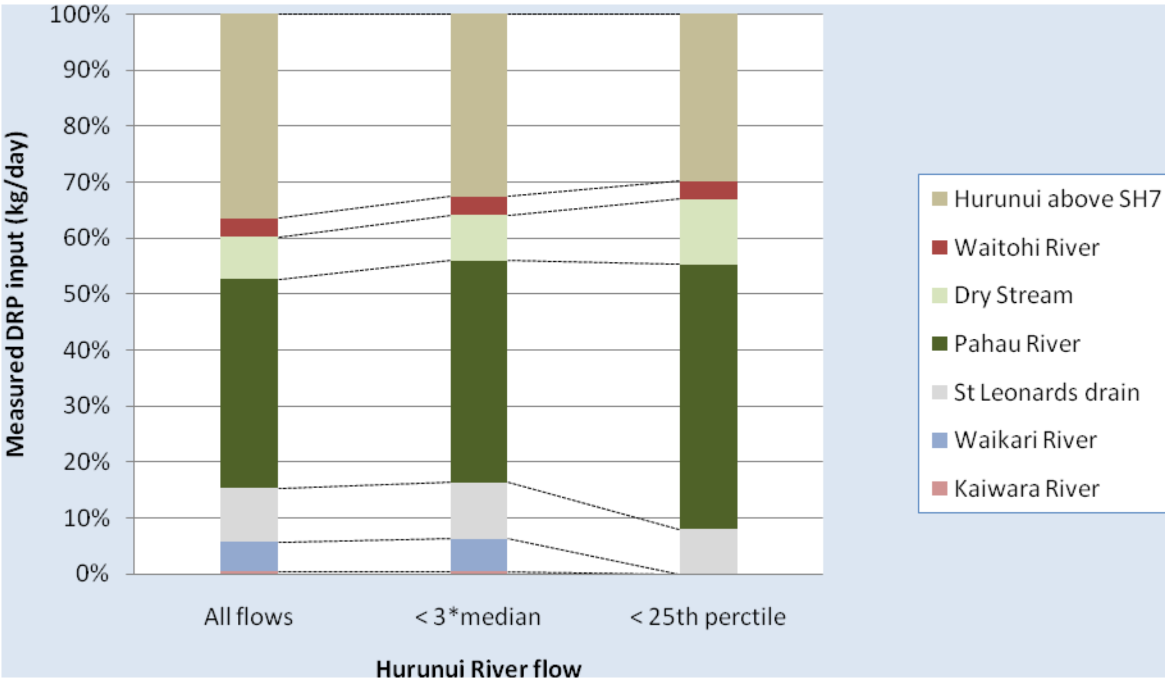


Figure 10: Mean contributions of different parts of the Hurunui catchment to the total measured daily DRP inputs to the catchment, at all river flows, when the river flow is below flood flows (<3 times median) and at low river flows (< 25th percentile)

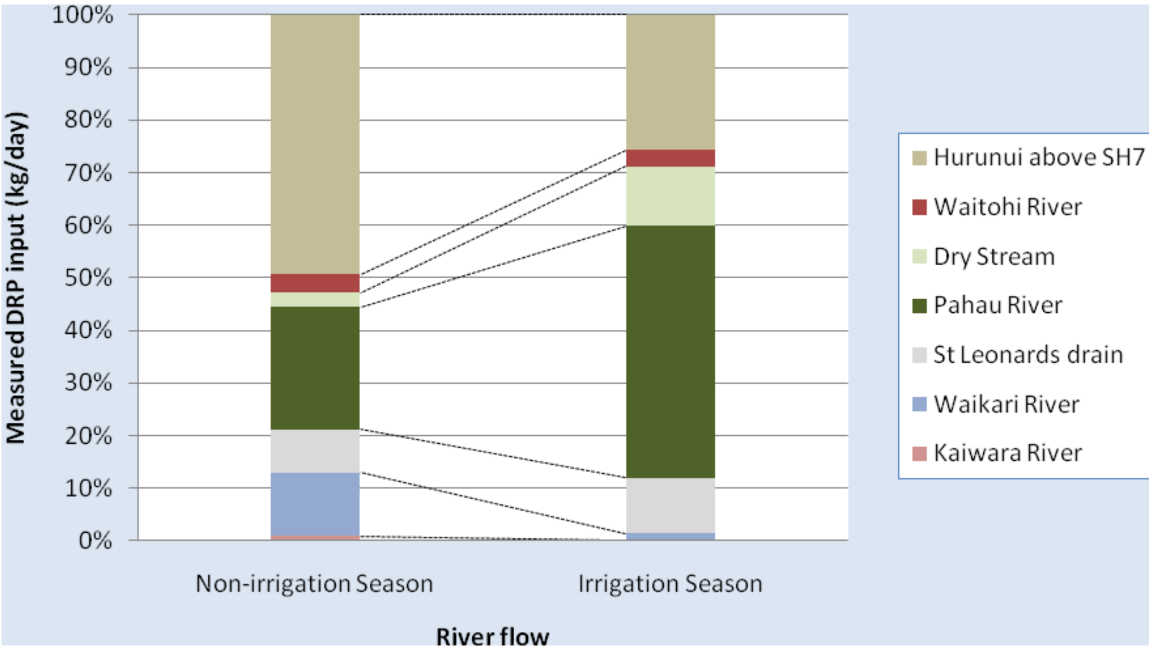


Figure 11: Mean contributions of different parts of the Hurunui catchment to the total measured daily DRP inputs to the catchment, outside and during the irrigation season

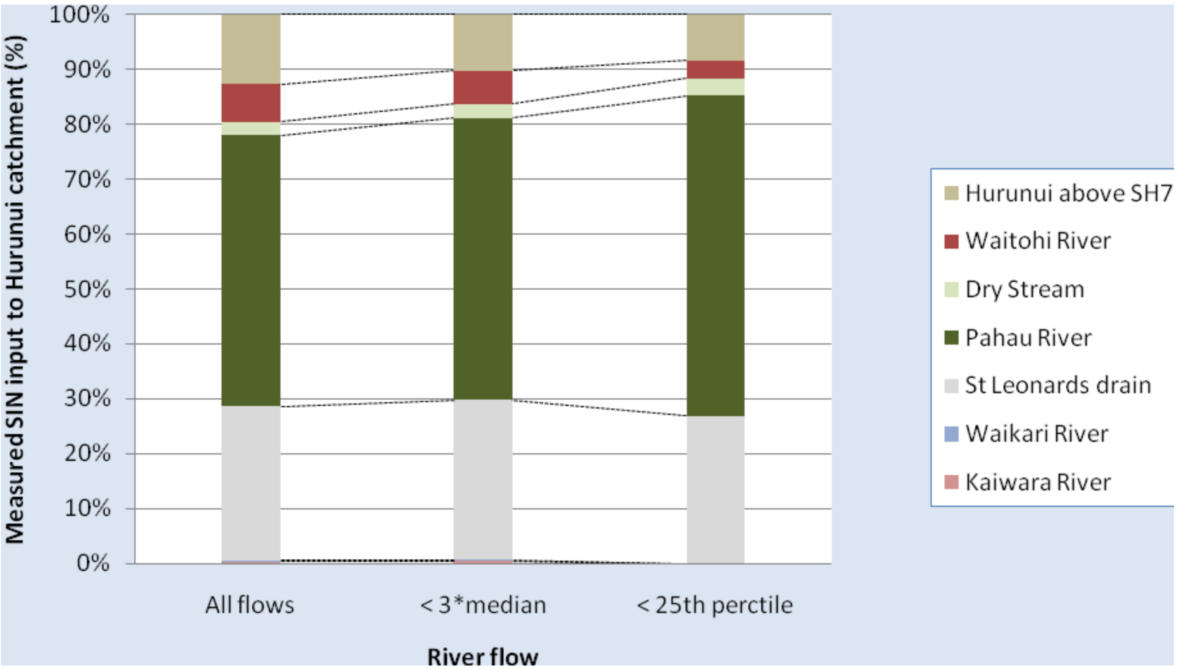


Figure 12: Mean contributions of different parts of the Hurunui catchment to the total measured daily SIN inputs to the catchment, at all river flows, when the river flow is below flood flows (<3 times median) and at low river flows (< 25th percentile)

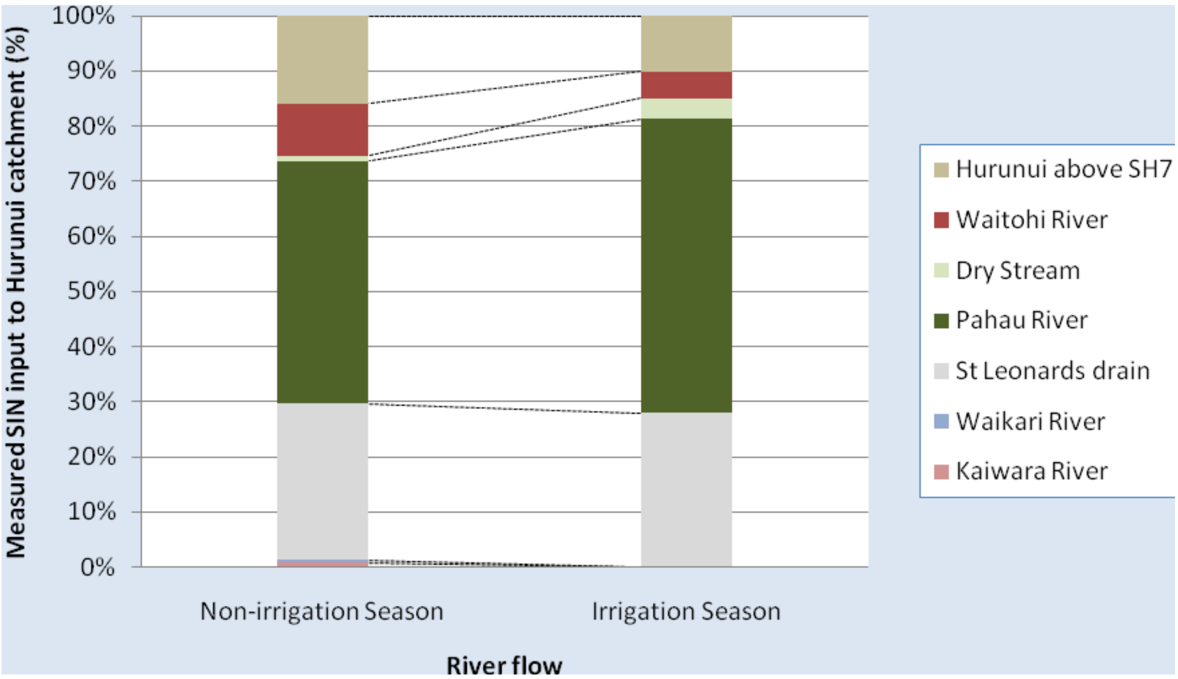


Figure 13: Mean contributions of different parts of the Hurunui catchment to the total measured daily SIN inputs to the catchment, outside and during the irrigation season

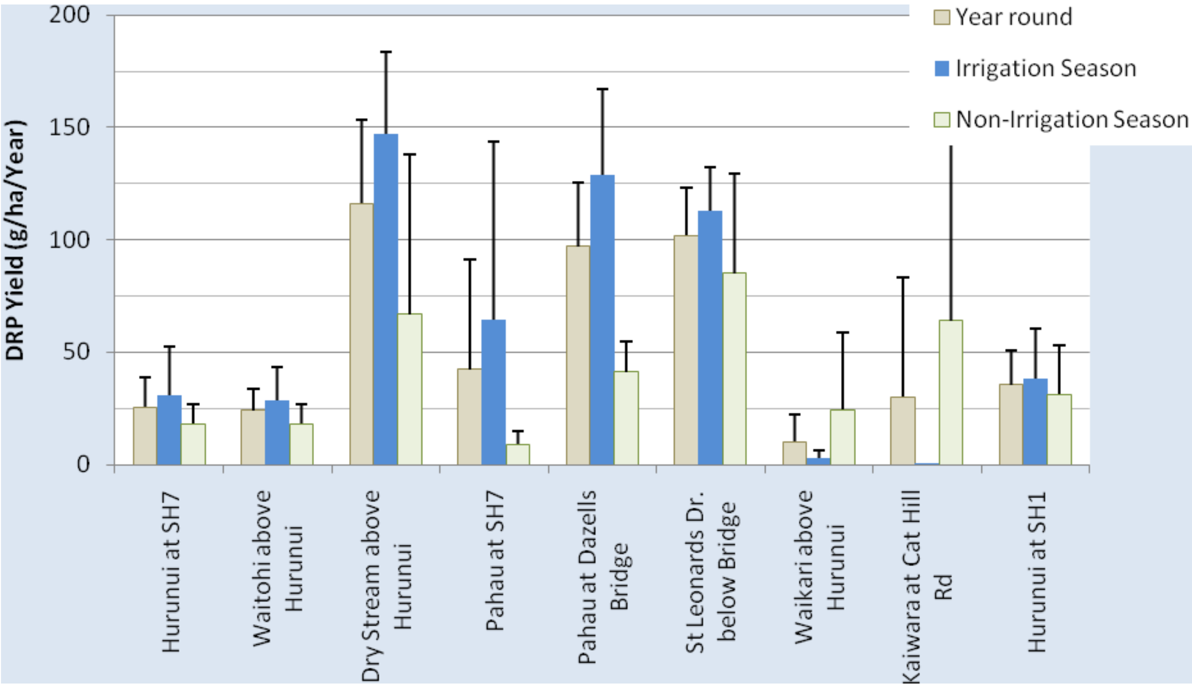


Figure 14: Mean DRP Yields (g/ha/year) from different parts of the Hurunui catchment, year-round and during and outside the irrigation season

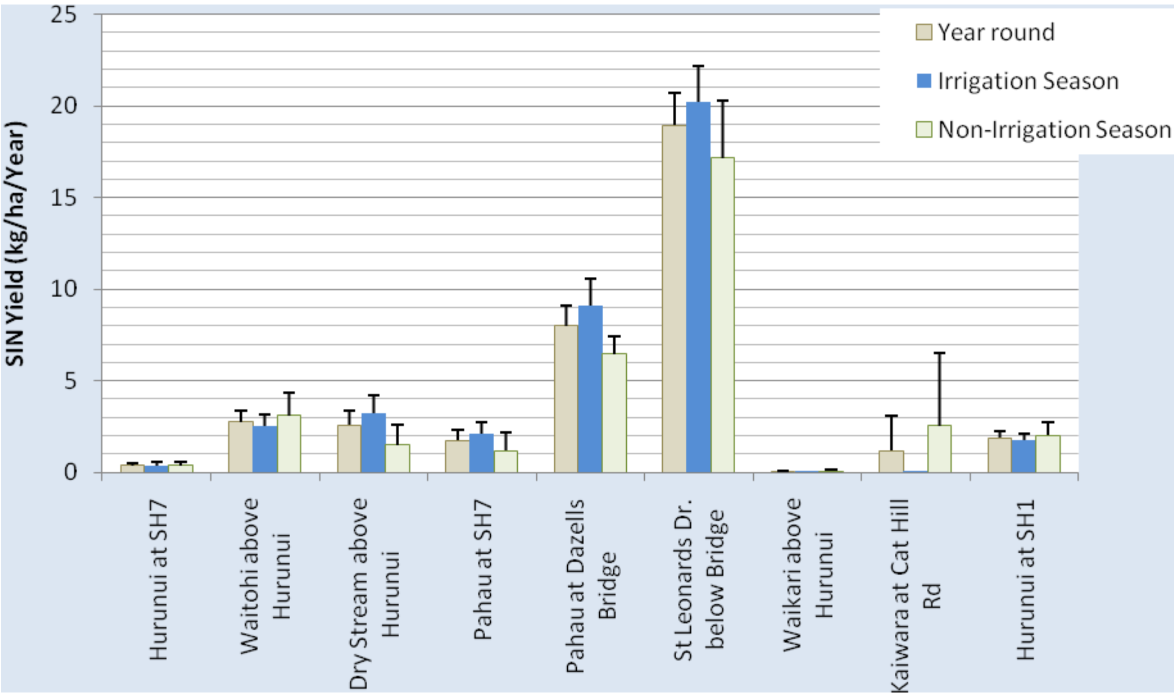


Figure 15: Mean SIN yields (kg/ha/year) from different parts of the Hurunui catchment, year-round and during and outside the irrigation season

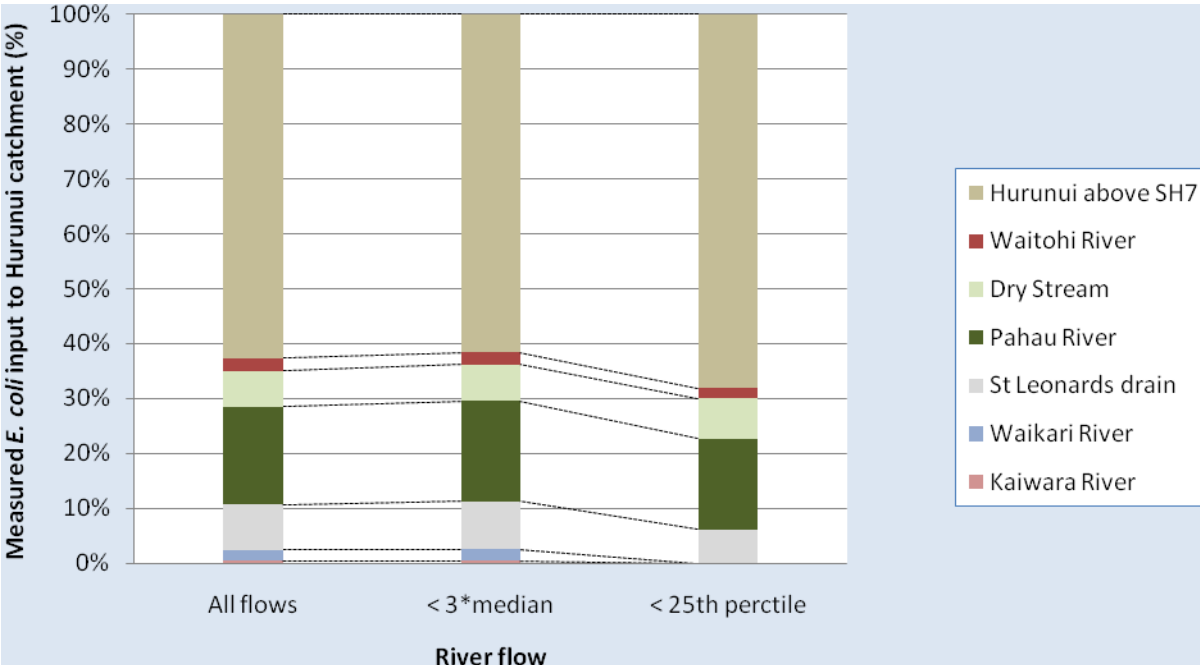


Figure 16: Mean contributions of different parts of the Hurunui catchment to the total measured daily *E. coli* inputs to the catchment, at all river flows, when the river flow is below flood flows (<3 times median) and at low river flows (< 25th percentile)

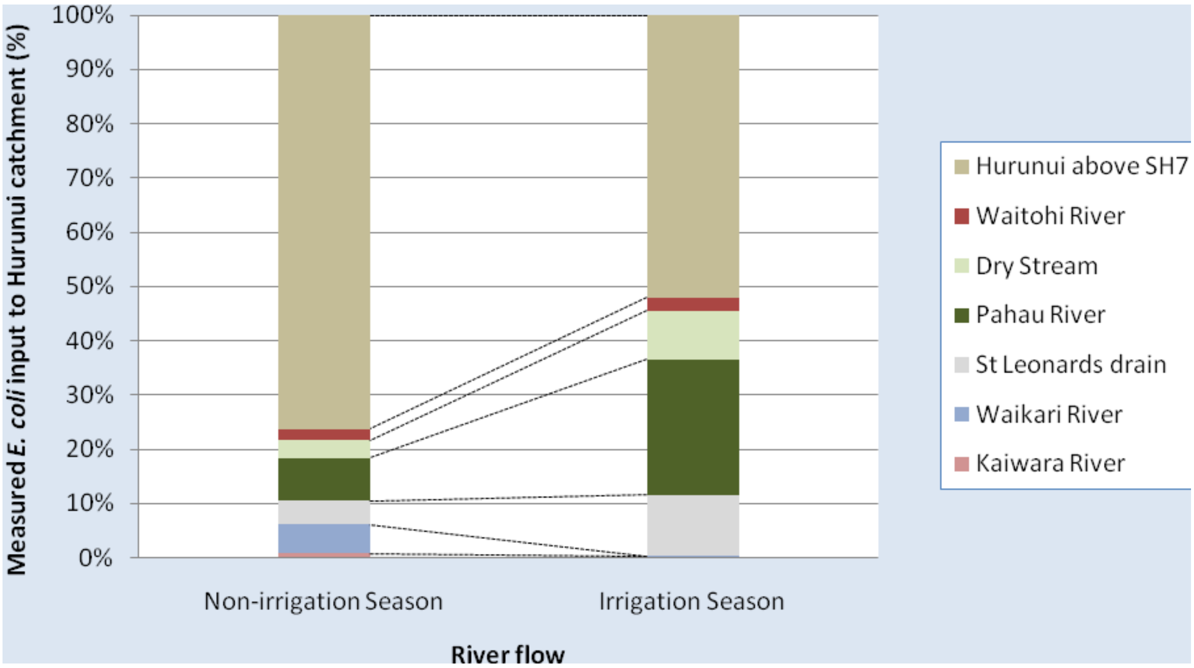


Figure 17: Mean contributions of different parts of the Hurunui catchment to the total measured daily *E. coli* inputs to the catchment, outside and during the irrigation season

5. Discussion and Conclusions

5.1. Water quality issues of the Hurunui River

5.1.1. Nutrient enrichment

Based on available data, nutrient enrichment and associated excessive periphyton growth appear to be the predominant water quality issue in the middle Hurunui catchment.

A significant degradation of the Hurunui River water quality for both DRP and SIN is observed between the upper and lower reaches of the middle Hurunui catchment. Guideline levels are complied with (DRP) or marginally exceeded (SIN) at the SH7 site, but breached at both downstream sites (Footbridge and SH1).

It is estimated that the Hurunui River carries annually 3.5 to 6 tonnes of DRP at the top end of the study area (SH7) and 6 to 10 tonnes at the bottom end (SH1), or an increase of 45- 82 %. Estimated annual SIN loads increase 360 to 580% between SH7 (56-81 Tonnes/year) and SH1 (350-500 Tonnes/year).

Analysis of the SIN/DRP ratios indicates that periphyton growth in the upper part of the middle catchment (SH7) is likely to be predominantly phosphorus-limited, but temporary switches to nitrogen-limited conditions cannot be excluded. Primarily due to nitrogen enrichment, the lower Hurunui River reaches appear to be phosphorus-limited. As a consequence, it is recommended that management emphasis be placed on reducing the DRP inputs to the system to reduce the occurrence of excessive periphyton growth. However, national experts agree that managing only one nutrient is a strategy fraught with risk, and recommend that both nitrogen and phosphorus be managed (whilst placing a higher priority on the limiting nutrient) (Wilcock *et al.* 2007).

5.1.2. Bacterial contamination

The mainstem Hurunui River has generally acceptable microbiological water quality. Most tributaries have high numbers of indicator bacteria, and are likely to be unsuitable for contact recreation or as a source for stock drinking water.

Interestingly, the pattern observed with the nutrients does not apply to faecal contamination: although most tributaries do exhibit degraded microbiological water quality, no significant degradation of the Hurunui River mainstem is observed when moving downstream in the catchment. On the contrary, the percentage of compliance with the microbiological water quality guidelines for recreational waters (MfE 2002) is better at the two downstream sites than at the SH7 site. This can be explained by bacterial die-off – likely to be relatively quick in a wide, unshaded river like the Hurunui- and deposition on the stream bed. The source of the moderate faecal contamination observed at SH7 is unknown, and should be investigated.

5.2. Sources of contamination

5.2.1. Tributaries

Most tributaries of the middle Hurunui catchment reaches have elevated (i.e. above guideline levels) concentrations of both DRP and SIN. The Pahau River, St Leonards Drain and Dry Stream generally have the highest concentrations of both nutrients.

Additional water quality measurements in the upper St Leonards Drain are generally similar to those at the bottom of the catchment, indicating that sources of contamination are likely present in the upper as well as in the lower parts of these catchments. This also appears to be true for SIN and *E.coli* in the Pahau catchment. However, there is an increase in DRP concentrations, loads and yields in the lower Pahau compared to the part of the catchment (above SH7), indicating more intense DRP contamination downstream of SH7.

The calculation of the contribution of each sub-catchment to the total measured contaminant inputs to the catchment provides some information on the source of nutrient enrichment in the lower Hurunui River. The following conclusions can be drawn:

- The Pahau River appeared to be the biggest contributor of both DRP (39%) and SIN (51%);
- Put together, the Pahau River, St Leonards Drain and Dry Stream contributed on average 57.4 % of the total DRP measured inputs;
- The Pahau River and St Leonards Drain contributed nearly 80% of the total SIN inputs;
- The lower Pahau, St Leonards Drain and Dry Stream catchments had the highest DRP yields;
- St Leonards Drain catchment has by far the highest SIN yield, followed by the Pahau catchment.

When considering *E.coli* loads, the Hurunui above SH7 was by far the biggest contributor (64%), followed by the Pahau River (18 %).

5.2.2. Influence of irrigation practices

Analysis of water quality data under different river flow conditions and during /outside the main irrigation season indicates that:

- 50 to 85% of the annual DRP load in the Hurunui River occurred during the irrigation season;
- The DRP concentrations in the Pahau River, Dry Stream and St Leonards Drain were significantly higher during the irrigation season than during the rest of the year
- The accumulated relative contribution of the Pahau River, Dry Stream and St Leonards Drain increase during periods of low river flow (i.e. when irrigation is most likely to occur) and during the main irrigation season to approximately 70% of the total measured DRP inputs;
- Irrigation season did not appear to have a major influence on SIN concentrations or loads;
- Similarly to DRP, *E. coli* concentrations in a number of tributaries are significantly higher during the irrigation season.

Irrigation practices in the Culverden basin, particularly the discharge of wipe-off waters directly to the waterways has been singled out as a possible cause of degraded water quality.

Diffuse sources of *E. coli* and phosphorus to waterways are generally associated with particles carried in surface runoff. On the other hand, inorganic nitrogen (particularly nitrates) is highly soluble and tends to reach the waterways via subsurface/ groundwater flows.

The results summarised above support the fact that irrigation practices are a likely causing a significant input of DRP and *E. coli* in the Pahau River, St Leonards Drain and Dry Stream. Soluble inorganic nitrogen, dominated by nitrate in the Hurunui system, probably reaches the surface waterways via subsurface/groundwater paths.

5.3. Improvements over time

Monitoring records used in this study encompassed three near-complete irrigation seasons. Three seasons is generally considered too short a record to obtain a robust conclusion on the presence of significant temporal trends using standard statistical tests (such as the seasonal Kendall test). However, simple statistical tests have shown significant improvements in DRP and *E. coli* concentrations in the Pahau River between the 2005-06 and the 2007-08 irrigation seasons. This may be indicating that recently implemented changes in the management of the wipe-off water, including capture in ponds for re-use and/or treatment have been successful in reducing DRP losses from agricultural land to the Pahau River.

It is noted however, that these improvements have not been associated with any significant improvement in the Hurunui River mainstem downstream of the Pahau River confluence. Furthermore, the DRP, *E. coli* and SIN concentrations remain elevated – generally well above guideline levels- in the Pahau River and other tributaries, including St Leonards drain and Dry Stream.

5.4. Recommendations

5.4.1. Management implications

Periphyton growth in the middle and lower Hurunui River is likely to be predominantly phosphorus-limited. The direct management implication is that DRP should be considered as the priority nutrient for management. It should be noted however, that the Hurunui River may naturally switch from P-limited to N-limited conditions (as evidenced by upper catchment results), and management of nitrogen is also recommended, which is consistent with the recommendations of Wilcock *et al.* (2007).

The Pahau River and St Leonards drain catchments are the biggest contributors to the DRP loadings in the Hurunui River, and should be the priority targets for management action.

5.4.2. Further monitoring

Further monitoring is recommended both in the Hurunui River mainstem and its tributaries, in particular to monitor changes in water quality which may occur as a result of changed farming practices. One critical observation will be whether the burgeoning trend of water quality improvements observed in the Pahau River is confirmed in the next irrigation seasons, and whether it translates into improvements in the Hurunui River mainstem.

Further monitoring in the tributary catchments, particularly the Dry Stream, Pahau and St Leonards Drain catchments, is also recommended to try and pinpoint the sources/ areas of contamination. Similarly, additional monitoring upstream of SH7 could be undertaken to identify the source(s) of *E. coli* contamination in the Hurunui River mainstem.

It is also recommended to undertake regular monitoring of periphyton cover and biomass in the Hurunui River mainstem to provide more formal supporting evidence to the anecdotal observations of algal proliferations on the riverbed.

It is also recommended that the monitoring programme be rationalised to account for the conclusions of this study. In particular:

- Results at Footbridge and SH1 have been remarkably similar during the whole monitoring period, and it is suggested that monitoring at one of the two downstream sites could be stopped. On balance, it is recommended to maintain the SH1 site as it is also a flow monitoring site:
- It is also recommended to only monitor the tributaries which have a significant contaminant load contribution to the Hurunui River: Waitohi River, Dry Stream, Pahau River and St Leonards Drain.

5.4.3. Further monitoring

A study similar to this one is recommended in 2-4 years. The availability of a five-year dataset will allow proper evaluation of temporal trends (*i.e.* has the water quality improved or degraded?).

REFERENCES

1. **Biggs B. (2000).** New Zealand Periphyton Guidelines: Detecting, Monitoring and Managing Enrichment of Streams. Prepared for the Ministry for the Environment by the National Institute for Water and Atmospheric Research (NIWA).
2. **Hayward S. (2001).** Hurunui River. Results of water quality monitoring: January 1989 to December 1999. *Environment Canterbury technical Report U01/55.*
3. **Houlbrooke D J. (2007).** Evaluation of wipe-off management practices on border dyke irrigated land in the Pahau catchment. *Prepared fro Environment Canterbury.*
4. **MfE (2002).** Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. *Ministry of Health and Ministry for the Environment. Updated in June 2003. MfE Number 474. ISBN 0-478-24091-0.*
5. **Mosley M. P. (2002).** Hurunui River: instream values and flow regime. *Prepared for Environment Canterbury. Report R02/1. ISBN 1-86937-437-1.*
6. **Wilcock B., Biggs B., Death R., Hickey C., Larned S. and Quinn J. (2007)**. Limiting nutrients for controlling undesirable periphyton growth. *Prepared for Horizons Regional Council. NIWA Client Report HAM2007-006.*

APPENDICES

Appendix A: Summary of data – all river flows/year round

		Flow (L/	Temp (°C)	DO (g/m^3)	DO Sat (%)	Cond (mS/m)	pH	E. coli (/100 mL)	*E. coli* (10^9/day)	DOC (g/m^3)	DRP (g/m^3)	DRP Load (kg/day)	NH_4-N (g/m^3)	No_x-N (g/m^3)	SIN (g/m^3)	SIN Load (kg/da	SIN/ DRP	TN (g/m^3)	TP (g/m^3)	TSS (g/m^3)	Turb (NTU)	TDS (g/m^3)	Periph. - long filaments	Periph. thick mats (%)	Periph. LF>30 or TM>60	Periph. -total cover (%)
Hurunui River At SH7	Average	43	11	11	99	7	7.7	158	4378	1	0.002	11	0.011	0.030	0.041	167	31	0	0	13	6	42	3	21	0	48
	Min	15	4	8	87	6	7.0	13	380	1	0.001	1	0.003	0.003	0.005	14	5	0	0	0	0	32	0	0	0	0
	5%ile	16	6	9	89	6	7.3	25	746	1	0.001	1	0.003	0.003	0.008	18	5	0	0	1	0	33	0	0	0	0
ALL DATA	10%ile	18	7	9	91	6	7.5	28	900	1	0.001	1	0.003	0.005	0.012	28	8	0	0	1	0	33	0	0	0	10
	25%ile	24	8	10	97	7	7.7	55	1790	1	0.001	2	0.007	0.014	0.025	52	12	0	0	1	0	36	0	0	0	20
	median	32	11	11	100	7	7.8	102	3736	1	0.002	4	0.011	0.026	0.035	96	20	0	0	2	1	43	0	10	0	40
	75%ile	44	15	12	103	7	7.8	245	6246	1	0.003	9	0.014	0.040	0.053	174	36	0	0	4	3	46	5	43	0	80
	90%ile	94	17	12	104	8	7.9	370	7639	1	0.005	37	0.018	0.055	0.066	442	63	0	0	55	27	50	10	61	1	90
	95%ile	12	17	12	106	8	7.9	460	10015	1	0.005	58	0.021	0.068	0.085	502	95	0	0	76	34	51	14	69	1	90
	Max	13	18	13	109	8	8.0	520	13728	1	0.006	63	0.024	0.130	0.143	682	158	1	0	110	48	53	15	70	1	95
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							78		92	81				50								100	88	88	
	N. of Samples	36	36	35	35	36	36	36	36	12	36	36	36	36	36	36	36	36	36	36	36	6	24	24	24	22
Waitohi River 1.6km Upstream	Average	83	11.7	10.3	94.0	14.8	7.6	305.9	179.6	1.3	0.009	0.6	0.0	1.0	1.0	66	200	1.1	0.0	3.5	2.2	95.2	2.2	22.1		54.3
	Min	15	3.1	7.7	81.3	10.0	7.0	5.0	2.1	0.8	0.002	0.0	0.0	0.4	0.4	16	25	0.5	0.0	0.3	0.2	81.0	0.0	0.0		0.0
	5%ile	28	6.8	8.2	82.4	11.0	7.2	14.8	6.5	0.8	0.003	0.1	0.0	0.4	0.4	29	33	0.5	0.0	0.3	0.3	82.5	0.0	0.0		0.0
ALL DATA	10%ile	34	7.3	8.6	84.8	12.5	7.5	24.5	12.4	0.8	0.003	0.1	0.0	0.5	0.5	33	39	0.6	0.0	0.7	0.3	84.0	0.0	0.0		6.5
	25%ile	46	8.9	9.4	92.3	14.0	7.5	52.5	28.4	1.0	0.004	0.2	0.0	0.7	0.7	37	91	0.9	0.0	0.9	0.4	87.8	0.0	0.0		25.0
	median	54	12.3	10.1	94.6	15.0	7.6	125.0	62.6	1.2	0.006	0.3	0.0	1.0	1.0	47	155	1.2	0.0	1.4	0.6	91.5	0.0	5.0		50.0
	75%ile	97	14.4	11.2	97.6	16.0	7.7	272.5	151.0	1.3	0.009	0.8	0.0	1.3	1.3	86	272	1.4	0.0	2.5	1.5	98.3	0.0	35.0		83.8
	90%ile	16	15.8	12.0	99.8	17.0	7.7	435.0	333.6	1.8	0.017	1.4	0.0	1.4	1.4	134	420	1.6	0.0	5.6	3.0	110.0	10.0	78.5		97.0
	95%ile	23	16.1	12.2	102.3	17.3	7.8	1575.	1008.3	2.3	0.021	1.8	0.0	1.5	1.5	147	440	1.6	0.1	10.5	6.9	115.0	16.8	80.0		100.0
	Max	35	19.8	13.3	105.4	18.0	8.0	72.2	1415.9	2.9	0.052	3.4	0.0	1.8	1.8	218	664	2.3	0.1	43.0	30.0	120.0	20.0	90.0		100.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							72		33	13.9				0.0								100	79	79	
	N. of Samples	34	36	36	36	36	36	36	34	12	36	34	36	36	36	34	36	36	36	36	36	6	34	34	34	34
Dry Stream Above Hurunui Conf. NW	Average	10	12.5	10.7	100.1	9.8	7.7	665.5	746.2	1.0	0.020	1.6	0.021	0.722	0.743	35.6	74.0	0.8	0.0	13.6	8.9	63.8	1.1	26.3		47.6
	Min	0.0	3.2	7.3	75.2	6.0	7.3	3.0	0.0	0.6	0.002	0.0	0.003	0.083	0.100	0.0	5.7	0.1	0.0	0.3	0.3	40.0	0.0	0.0		0.0
	5%ile	0.0	7.4	8.8	83.6	7.0	7.4	12.4	0.0	0.7	0.003	0.0	0.007	0.104	0.118	0.3	7.5	0.2	0.0	0.6	0.3	42.8	0.0	0.0		0.0
ALL DATA	10%ile	2.9	7.7	9.0	90.8	7.0	7.4	19.4	0.0	0.7	0.004	0.0	0.009	0.132	0.154	0.6	9.2	0.2	0.0	1.2	0.5	45.5	0.0	0.0		4.0
	25%ile	39	8.8	9.7	95.8	8.0	7.6	91.0	47.8	0.8	0.009	0.4	0.012	0.260	0.279	15.2	16.5	0.3	0.0	1.9	1.7	52.3	0.0	0.0		17.5
	median	92	11.7	10.9	102.0	9.0	7.7	410.0	304.2	0.8	0.014	1.6	0.016	0.480	0.512	28.0	28.3	0.6	0.0	7.9	4.0	57.5	0.0	15.0		50.0
	75%ile	15	15.7	11.8	105.0	11.0	7.8	610.0	700.4	1.3	0.025	2.4	0.022	0.830	0.839	48.6	72.5	0.9	0.1	21.0	8.2	77.0	0.0	42.5		82.5
	90%ile	18	18.3	12.5	107.7	14.0	8.0	2400.	1766.5	1.6	0.040	3.4	0.032	2.060	2.074	72.5	208.3	2.3	0.1	41.0	29.4	88.5	5.0	76.0		91.0
	95%ile	28	18.5	12.8	109.0	15.0	8.1	2400.	3062.6	1.7	0.053	4.2	0.045	2.440	2.464	83.8	286.0	2.5	0.1	46.0	33.6	91.3	5.5	80.0		95.0
	Max	31	18.9	13.3	114.3	16.0	8.2	2400.	6191.8	1.7	0.073	5.9	0.110	2.500	2.544	147.1	554.0	2.7	0.1	59.0	54.0	94.0	10.0	80.0		95.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							36		55	9				0								100	79	79	
	N. of Samples	34	33	33	33	33	33	33	33	11	33	34	33	33	33	33		33	33	33	33	6	19	19	19	19

		Flow (L/	Temp (°C)	DO (g/m^3)	DO Sat (%)	Cond (mS/m)	pH	E. coli (/100 mL)	*E. coli* (10^9/day)	DOC (g/m^3)	DRP (g/m^3)	DRP Load (kg/day)	NH_4-N (g/m^3)	No_x-N (g/m^3)	SIN (g/m^3)	SIN Load (kg/da	SIN/ DRP	TN (g/m^3)	TP (g/m^3)	TSS (g/m^3)	Turb (NTU)	TDS (g/m^3)	Periph. - long filaments	Periph. thick mats (%)	Periph. LF>30 or TM>60	Periph. -total cover (%)
Hurunui River Above Pahau	Average	42	11.6	10.2	93.1	8.8	7.5	154.5	6380.3	0.6	0.004	17.3	0.015	0.329	0.345	924	119	0.4	0.0	9.4	5.8	58.3	5.8	18.4		40.5
	Min	17	4.0	7.5	73.8	6.6	6.8	24.0	534.9	0.5	0.001	1.5	0.003	0.003	0.015	64	11	0.1	0.0	0.3	0.3	45.0	0.0	0.0		0.0
	5%ile	18	7.2	7.8	77.7	7.0	7.0	34.4	580.9	0.5	0.001	3.0	0.003	0.046	0.057	287	13	0.1	0.0	0.4	0.3	46.0	0.0	0.0		0.0
	10%ile	20	7.2	8.7	81.6	7.0	7.2	35.0	697.2	0.5	0.001	3.4	0.006	0.131	0.139	582	16	0.2	0.0	0.7	0.4	47.0	0.0	0.0		12.0
	25%ile	25	8.8	9.4	89.9	8.0	7.5	48.0	1638.5	0.6	0.002	5.6	0.010	0.185	0.192	656	52	0.2	0.0	1.0	0.4	49.8	0.0	0.0		17.5
	median	32	11.2	10.3	94.8	8.5	7.6	101.5	2844.7	0.7	0.003	7.6	0.013	0.260	0.272	885	92	0.3	0.0	2.3	0.7	53.0	0.0	10.0		30.0
	75%ile	43	14.6	11.3	98.7	9.3	7.7	172.5	4837.6	0.7	0.005	12.4	0.018	0.420	0.433	1300	191	0.5	0.0	4.7	2.8	63.8	5.0	22.5		70.0
	90%ile	81	16.8	11.8	102.4	11.0	7.7	213.0	17758.3	0.8	0.008	24.4	0.021	0.703	0.721	1384	218	0.7	0.0	35.2	27.2	75.0	23.0	75.0		85.0
	95%ile	11	17.3	11.9	103.0	11.0	7.8	278.5	23669.7	0.8	0.009	62.5	0.028	0.736	0.749	1478	249	0.7	0.0	45.0	31.3	79.0	35.0	75.5		85.5
	Max	14	17.6	12.3	103.9	13.0	7.9	1200.	35059.4	0.8	0.013	157.3	0.070	1.000	1.017	1803	408	1.1	0.1	69.0	39.0	83.0	35.0	80.0		90.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							93		100	57				7								89	84	74	
	N. of Samples	26	28	28	28	28	28	28	26	12	28	26	28	28	28	26	28	28	28	28	28	6	19	19	19	19
Pahau River at SH7	Average	92	13.8	9.7	92.6	11.9	7.6	722.0	369.6	0.9	0.035	1.9	0.020	1.414	1.434	81	136	1.6	0.0	5.5	2.8		1.4	13.6		48.6
	Min	28	8.0	7.9	82.5	8.0	7.4	32.0	14.1	0.6	0.003	0.1	0.009	0.270	0.279	14	5	0.3	0.0	0.9	0.4		0.0	0.0		20.0
	5%ile	31	8.2	7.9	83.4	8.5	7.4	37.0	14.7	0.6	0.004	0.2	0.010	0.324	0.346	15	14	0.5	0.0	0.9	0.4		0.0	0.0		23.0
ALL DATA	10%ile	35	8.5	8.0	84.2	8.9	7.4	41.9	15.4	0.7	0.006	0.2	0.011	0.378	0.413	17	22	0.6	0.0	1.0	0.4		0.0	0.0		26.0
	25%ile	39	10.8	8.3	86.6	9.5	7.5	58.8	77.0	0.7	0.007	0.3	0.013	0.518	0.541	61	54	0.9	0.0	2.8	0.6		0.0	0.0		35.0
	median	56	13.6	9.1	91.3	12.0	7.6	225.0	144.2	0.9	0.010	0.8	0.019	1.085	1.108	89	102	1.4	0.0	4.8	2.0		0.0	0.0		40.0
	75%ile	13	17.8	11.3	98.0	13.8	7.7	1337.	697.2	1.0	0.017	1.2	0.026	2.125	2.140	103	161	2.3	0.0	5.6	3.0		0.0	7.5		60.0
	90%ile	17	18.8	11.4	101.0	15.1	7.8	2040.	818.0	1.1	0.052	3.2	0.028	3.120	3.137	117	262	3.2	0.1	8.7	4.4		4.0	38.0		78.0
	95%ile	21	19.0	11.6	103.6	15.6	7.9	2220.	993.9	1.1	0.151	7.7	0.033	3.210	3.224	137	354	3.4	0.2	13.8	8.7		7.0	59.0		84.0
	Max	25	19.2	11.7	106.2	16.0	7.9	2400.	1169.9	1.1	0.250	12.2	0.038	3.300	3.311	157	445	3.6	0.3	19.0	13.0		10.0	80.0		90.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							50		50	10				0								100	86	86	
	N. of Samples	10	10	10	10	10	10	10	10	2	10	10	10	10	10	10	10	10	10	10	10	0	7	7	7	7
Pahau River at Dalzells Bridge	Average	38	12.3	10.6	98.4	12.9	7.7	495.1	1821.5	0.9	0.021	6.9	0.018	1.7	1.7	567	121	1.8	0.0	18.7	9.8	85.3	1.5	21.5		42.0
	Min	13	4.7	7.9	82.6	10.0	7.3	28.0	37.2	0.7	0.005	1.1	0.003	0.7	0.7	153	25	0.8	0.0	2.1	0.4	65.0	0.0	0.0		0.0
	5%ile	15	8.0	8.6	85.5	10.0	7.4	47.9	86.2	0.7	0.007	1.3	0.005	0.9	0.9	291	28	0.9	0.0	2.6	0.6	67.5	0.0	0.0		0.0
ALL DATA	10%ile	18	8.4	8.9	89.8	10.4	7.5	52.4	121.7	0.7	0.008	1.6	0.006	1.1	1.1	314	33	1.1	0.0	2.8	0.8	70.0	0.0	0.0		0.0
	25%ile	26	9.9	9.6	94.6	12.0	7.6	79.5	215.0	0.7	0.012	3.1	0.011	1.3	1.3	442	69	1.4	0.0	4.1	1.6	77.0	0.0	0.0		22.5
	median	38	11.8	10.6	99.6	13.0	7.7	160.0	600.5	0.8	0.015	4.7	0.015	1.6	1.6	537	101	1.8	0.0	6.3	3.1	85.0	0.0	10.0		45.0
	75%ile	48	15.3	11.7	102.2	14.0	7.8	610.0	1610.4	1.1	0.022	8.2	0.018	2.1	2.1	655	151	2.2	0.0	15.0	7.2	90.8	0.0	35.0		63.8
	90%ile	57	16.9	12.0	105.4	15.0	7.8	1460.	6593.0	1.1	0.038	15.8	0.028	2.3	2.3	816	236	2.5	0.1	33.6	24.6	101.0	10.0	62.0		80.0
	95%ile	59	17.2	12.3	106.1	15.3	7.9	2400.	7215.3	1.3	0.050	19.8	0.043	2.7	2.7	1011	262	2.7	0.1	60.3	32.7	105.5	10.0	80.0		80.3
	Max	62	17.5	12.4	111.2	16.0	8.0	2400.	11359.2	1.6	0.072	22.3	0.110	3.1	3.1	1103	311	3.1	0.2	200.0	110.0	110.0	10.0	80.0		85.0
	Guideline							260		1	0.003				0.034								30	60		40
	%compliance							66		67	0				0								100	90	90	40
	N. of Samples	32	35	35	35	35	35	35	32	12	35	32	35	35	35	32	35	35	35	35	35	6	20	20	20	20

		Flow (L/	Temp (ºC)	DO (g/m³)	DO Sat (%)	Cond (mS/m)	pH	E. coli (/100 mL)	*E. coli* (10⁹/day)	DOC (g/m³)	DRP (g/m³)	DRP Load (kg/day)	NH_4-N (g/m³)	No_x-N (g/m³)	SIN (g/m³)	SIN Load (kg/da	SIN/ DRP	TN (g/m³)	TP (g/m³)	TSS (g/m³)	Turb (NTU)	TDS (g/m³)	Periph. - long filaments	Periph. thick mats (%)	Periph. LF>30 or TM>60	Periph. -total cover (%)
St Leonards Drain Just Below Bridge	Average	12	12.3	9.3	87.6	17.3	7.6	467	532.7	1.1	0.0	1.6	0.0	3.0	3.1	309	243	3.2	0.0	12.9	6.1	107.7	0.0	6.7		26.7
	Min	36	6.8	7.5	76.9	14.0	7.1	33	27.7	0.8	0.0	0.4	0.0	2.1	2.1	113	55	2.2	0.0	5.0	1.6	88.0	0.0	5.0		25.0
	5%ile	72	8.9	7.7	78.0	15.0	7.3	39	30.8	0.9	0.0	0.6	0.0	2.3	2.3	226	101	2.5	0.0	5.6	2.0	90.5	0.0	5.0		25.0
ALL DATA	10%ile	77	9.1	8.1	80.6	15.0	7.4	52	46.0	0.9	0.0	0.7	0.0	2.4	2.5	232	116	2.5	0.0	6.5	2.2	93.0	0.0	5.0		25.0
	25%ile	10	10.5	8.9	83.6	16.0	7.5	145	88.3	0.9	0.0	1.0	0.0	2.6	2.6	270	167	2.8	0.0	7.8	3.3	98.5	0.0	5.0		25.0
	median	12	12.1	9.3	88.3	17.0	7.6	440	471.7	1.0	0.0	1.4	0.0	2.8	2.8	306	222	2.9	0.0	12.0	4.4	105.0	0.0	5.0		25.0
	75%ile	13	14.9	10.0	91.2	18.5	7.7	670	821.1	1.2	0.0	2.0	0.0	3.3	3.3	343	310	3.4	0.0	15.5	6.8	117.5	0.0	7.5		27.5
	90%ile	16	15.6	10.3	93.7	20.0	7.7	980	1202.0	1.5	0.0	2.6	0.0	3.9	3.9	400	384	3.9	0.0	20.2	12.1	125.0	0.0	9.0		29.0
	95%ile	16	15.8	10.5	96.5	20.3	7.9	1046	1265.2	1.7	0.0	3.1	0.0	4.6	4.6	431	439	4.6	0.1	24.6	15.9	127.5	0.0	9.5		29.5
	Max	18	16.4	10.7	104.0	23.0	8.0	1400	1564.5	1.9	0.0	5.7	0.0	4.9	4.9	474	546	5.1	0.1	36.0	27.0	130.0	0.0	10.0		30.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							37		67	0				0								100	100	100	
	N. of Samples	35	35	35	35	35	35	35	35	12	35	35	35	35	35	35	35	35	35	35	35	6	2	3	3	3

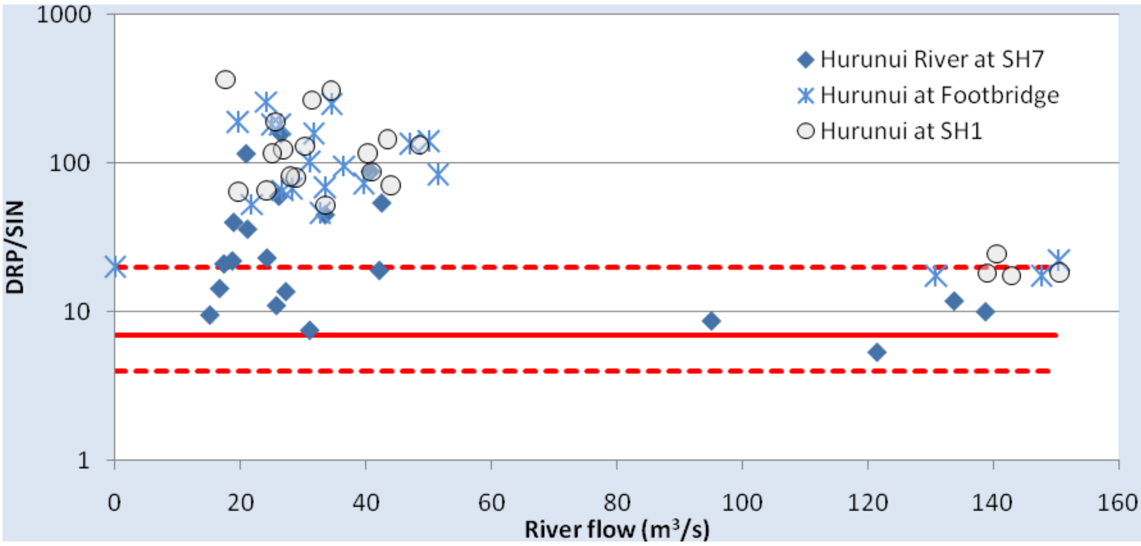
		Flow (L/	Temp (ºC)	DO (g/m³)	DO Sat (%)	Cond (mS/m)	pH	E. coli (/100 mL)	*E. coli* (10⁹/day)	DOC (g/m³)	DRP (g/m³)	DRP Load (kg/day)	NH_4-N (g/m³)	No_x-N (g/m³)	SIN (g/m³)	SIN Load (kg/da	SIN/ DRP	TN (g/m³)	TP (g/m³)	TSS (g/m³)	Turb (NTU)	TDS (g/m³)	Periph. - long filaments	Periph. thick mats (%)	Periph. LF>30 or TM>60	Periph. -total cover (%)
Hurunui River at Footbridge (joint	Average	48	12.8	11.3	106.2	8.6	8.0	98	4283.3	0.8	0.004	18.7	0.012	0.3	0.327	1127	106	0.4	0.0	16.4	7.8	52.7	8.7	27		51.9
	Min	19	4.3	8.5	91.1	6.5	7.2	6	208.9	0.5	0.001	2.4	0.003	0.1	0.075	248	17	0.1	0.0	0.3	0.4	44.0	0.0	0		0.0
ALL DATA	5%ile	23	7.5	9.7	91.5	7.0	7.4	12	346.2	0.6	0.002	3.8	0.003	0.1	0.148	700	19	0.2	0.0	1.0	0.4	44.5	0.0	1		5.0
	10%ile	25	7.8	10.0	94.0	7.0	7.6	16	414.1	0.6	0.002	4.7	0.004	0.2	0.167	782	24	0.2	0.0	1.3	0.6	45.0	0.0	5		20.0
	25%ile	29	9.2	10.7	100.4	8.0	7.7	25	827.5	0.6	0.002	7.0	0.008	0.2	0.226	870	64	0.3	0.0	1.7	0.7	47.3	0.0	10		21.3
	median	36	12.3	11.4	106.2	8.8	7.9	42	1285.1	0.8	0.004	10.2	0.010	0.3	0.305	1027	93	0.4	0.0	2.6	1.4	52.0	0.0	18		50.0
	75%ile	49	16.4	12.0	112.5	9.0	8.2	140	3266.1	0.9	0.006	17.6	0.015	0.4	0.397	1271	132	0.5	0.0	6.5	2.9	54.5	8.8	48		78.8
	90%ile	92	18.6	12.7	115.1	10.0	8.7	200	15943.2	0.9	0.008	24.8	0.018	0.5	0.519	1694	186	0.6	0.1	72.5	39.5	61.0	33	55		90.0
	95%ile	13	19.1	12.8	117.6	10.0	8.8	295	18277.4	1.0	0.009	83.3	0.023	0.6	0.575	2012	251	0.7	0.1	80.3	43.0	64.0	40.0	71		93.8
	Max	15	19.5	12.8	125.8	11.0	9.0	730	21479.4	1.2	0.011	114.9	0.060	0.8	0.759	2099	360	0.8	0.1	120.0	55.0	67.0	50.0	90		100.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							94		92	50				0								88	92	81	
	N. of Samples	34	36	36	36	36	36	36	34	12	36	34	36	36	36	34	36	36	36	36	36	6	26	26	26	26

		Flow (L/	Temp (ºC)	DO (g/m³)	DO Sat (%)	Cond (mS/m)	pH	E. coli (/100 mL)	*E. coli* (10⁹/day)	DOC (g/m³)	DRP (g/m³)	DRP Load (kg/day)	NH_4-N (g/m³)	No_x-N (g/m³)	SIN (g/m³)	SIN Load (kg/da	SIN/ DRP	TN (g/m³)	TP (g/m³)	TSS (g/m³)	Turb (NTU)	TDS (g/m³)	Periph. - long filaments	Periph. thick mats (%)	Periph. LF>30 or TM>60	Periph. -total cover (%)
Waikari R 1 km > Hurunui confl	Average	41	12.8	8.2	75.1	51.0	8.0	331	40.0	5.2	0.0	0.7	0.012	0.0	0.1	2	3	0.3	0.0	1.5	0.7	280.0	30	35.0		68.5
	Min	0	6.1	4.9	49.0	40.0	7.8	3	0.0	3.6	0.0	0.0	0.003	0.0	0.0	0	0	0.1	0.0	0.3	0.2	270.0	0	0.0		0.0
	5%ile	0	7.5	5.0	49.5	42.2	7.8	4	0.0	3.7	0.0	0.0	0.003	0.0	0.0	0	1	0.1	0.0	0.3	0.2	271.5	2	0.0		22.5
	10%ile	0	8.7	5.1	50.3	44.0	7.8	9	0.0	3.7	0.0	0.0	0.003	0.0	0.0	0	1	0.2	0.0	0.3	0.2	273.0	5	0.0		45.0
	25%ile	22	9.4	5.9	55.7	44.8	7.9	63	0.1	4.2	0.0	0.1	0.003	0.0	0.0	0	1	0.2	0.0	0.3	0.3	277.5	11	3.8		52.5
	median	57	13.3	8.0	80.5	48.0	7.9	100	12.4	4.7	0.0	0.1	0.011	0.0	0.0	0	1	0.2	0.0	0.8	0.4	280.0	28	40.0		75.0
	75%ile	19	15.9	10.1	86.4	56.8	8.0	185	29.8	6.1	0.0	0.7	0.020	0.0	0.0	1	1	0.4	0.1	1.5	0.5	282.5	44	48.8		90.0
	90%ile	49	17.3	11.0	96.9	62.6	8.2	569	143.6	7.1	0.0	1.0	0.025	0.0	0.1	4	2	0.5	0.1	3.3	1.1	287.0	61	76.0		95.5
	95%ile	18	18.3	11.6	97.6	64.4	8.2	1416	182.6	7.7	0.1	3.0	0.026	0.2	0.2	11	13	0.6	0.1	4.8	2.5	288.5	66	80.5		97.8
	Max	39	19.5	12.2	97.8	66.0	8.3	2400	216.4	8.4	0.1	5.4	0.027	0.4	0.4	20	27	0.7	0.1	6.6	4.1	290.0	70	85.0		100.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							83		0	0				67								60	80	40	
	N. of Samples	13	12	12	12	12	12	12	12	8	12	12	12	12	12	12	12	12	12	12	12	4	10	10	10	10

		Flow (L/	Temp (°C)	DO (g/m³)	DO Sat (%)	Cond (mS/m)	pH	E. coli (/100 mL)	*E. coli* (10⁹/day)	DOC (g/m³)	DRP (g/m³)	DRP Load (kg/day)	NH_4-N (g/m³)	No_x-N (g/m³)	SIN (g/m³)	SIN Load (kg/da	SIN/ DRP	TN (g/m³)	TP (g/m³)	TSS (g/m³)	Turb (NTU)	TDS (g/m³)	Periph. - long filaments	Periph. thick mats (%)	Periph. LF>30 or TM>60	Periph. -total cover (%)
Kaiwara R at Cat Hill Rd bge	Average	44	13.2	13.4	128.5	41.4	8.4	341	57.4	2.9	0.005	0.7	0.012	0.139	0.151	26	27	0.3	0.0	3.6	2.4	256.7	27.7	26.5		55.8
	Min	0	2.9	10.7	99.9	19.0	7.8	6	0.0	2.1	0.001	0.0	0.003	0.003	0.005	0	2	0.0	0.0	0.7	0.2	130.0	0.0	0.0		15.0
	5%ile	1	5.4	11.0	100.4	20.4	8.1	12	0.2	2.1	0.001	0.0	0.003	0.003	0.005	0	3	0.0	0.0	0.8	0.2	145.0	0.0	3.0		15.0
ALL DATA	10%ile	2	7.0	11.4	103.1	23.4	8.2	20	0.4	2.2	0.001	0.0	0.003	0.003	0.007	0	4	0.1	0.0	0.8	0.2	160.0	1.0	7.0		16.0
	25%ile	28	8.4	12.1	109.6	33.0	8.3	31	1.4	2.3	0.002	0.0	0.004	0.008	0.014	0	5	0.1	0.0	0.8	0.3	207.5	5.0	15.0		25.0
	median	11	11.0	12.8	115.0	42.0	8.4	97	5.0	3.0	0.003	0.0	0.009	0.012	0.019	0	8	0.2	0.0	1.3	0.6	275.0	10.0	25.0		55.0
	75%ile	24	18.8	14.0	132.7	47.5	8.5	235	27.4	3.2	0.006	0.0	0.018	0.019	0.042	0	16	0.2	0.0	3.2	1.7	305.0	35.0	40.0		85.0
	90%ile	89	21.4	16.8	171.3	61.0	8.7	884	68.7	3.5	0.008	0.4	0.026	0.536	0.547	35	53	0.7	0.0	6.1	4.2	335.0	76.0	48.0		93.0
	95%ile	19	23.0	17.8	197.7	61.9	8.8	1560	242.0	3.8	0.014	3.1	0.029	0.730	0.747	125	111	0.9	0.0	12.1	9.9	347.5	84.0	52.0		95.0
	Max	38	24.0	17.9	212.0	64.0	8.9	2400	639.7	4.1	0.027	9.1	0.033	0.940	0.967	326	217	1.2	0.1	25.0	20.0	360.0	90.0	55.0		95.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							80		0	53				60								69	100	69	
	N. of Samples	15	15	15	15	15	15	15	15	9	15	15	15	15	15	15	15	15	15	15	15	6	13	13	13	13
Hurunui River at SH1	Average	53	13.0	11.3	107.0	8.8	8.1	73	3746	0.7	0.004	24.4	0.012	0.319	0.331	1298	127	0.4	0.0	15.9	7.9	57.0	9	25		48.1
	Min	17	4.2	8.6	91.9	6.6	7.3	9	244	0.6	0.001	1.5	0.003	0.120	0.123	553	18	0.2	0.0	0.9	0.3	45.0	0	0		0.0
	5%ile	23	7.5	9.5	93.5	7.0	7.5	15	338	0.6	0.001	2.3	0.003	0.140	0.147	736	18	0.2	0.0	1.0	0.4	46.5	0	1		20.0
ALL DATA	10%ile	25	7.8	10.1	95.7	7.0	7.6	17	513	0.6	0.001	4.1	0.003	0.165	0.175	758	27	0.2	0.0	1.3	0.6	48.0	0	5		20.0
	25%ile	29	9.2	10.7	102.3	8.0	7.8	27	789	0.6	0.002	7.4	0.007	0.235	0.241	875	56	0.3	0.0	1.9	0.7	52.3	0	10		23.8
	median	41	12.4	11.3	107.0	9.0	7.9	37	1456	0.7	0.004	11.4	0.011	0.280	0.290	1083	95	0.3	0.0	2.8	1.9	56.5	10	15		40.0
	75%ile	53	16.8	12.1	113.4	9.7	8.3	87	4464	0.8	0.006	20.3	0.016	0.365	0.377	1483	131	0.4	0.0	9.0	3.9	60.0	10	25		80.0
	90%ile	12	19.1	12.6	115.0	10.0	8.7	175	9761	0.9	0.008	79.7	0.019	0.505	0.517	2039	300	0.5	0.1	70.5	36.5	66.5	19	71		93.5
	95%ile	14	19.6	12.9	117.7	10.3	8.8	225	14822	0.9	0.009	108.1	0.022	0.560	0.572	2239	366	0.7	0.1	81.3	42.0	69.3	29	79		95.0
	Max	15	20.1	13.1	127.3	11.0	9.2	370	19517	1.0	0.012	120.2	0.039	0.750	0.757	4557	494	0.7	0.1	100.0	55.0	72.0	40	80		95.0
	Guideline							260		1	0.003				0.034								30	60		
	%compliance							94		100	47				0								96	88	83	
	N. of Samples	36	36	36	36	36	36	36	36	12	36	36	36	36	36	36	36	36	36	36	36	6	24	24	24	24

Appendix B: Additional Graphs

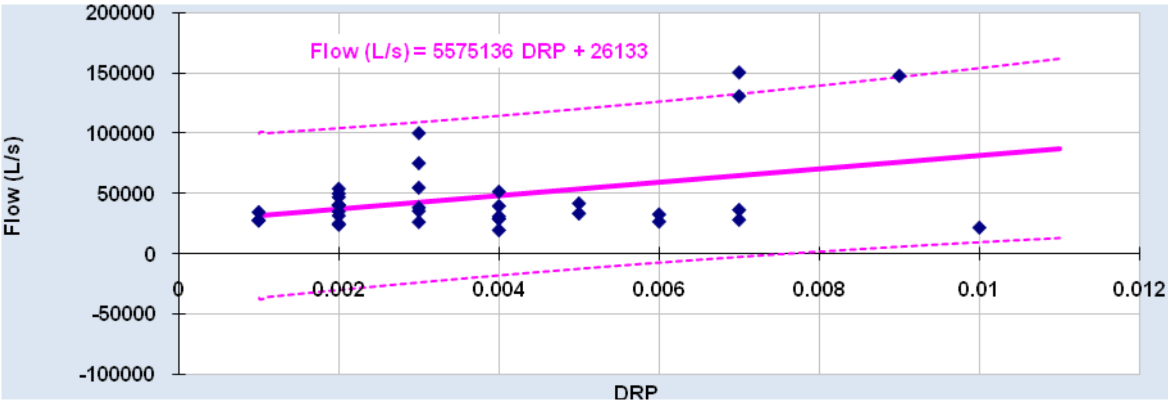
N/P ratios



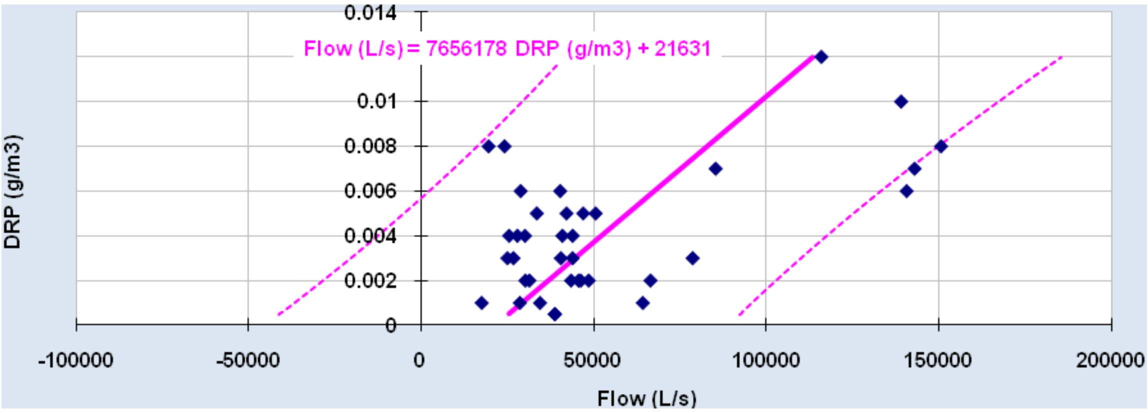
SIN/DRP ratio during the irrigation season (October-April) at three monitoring sites in the upper (SH7), middle (Footbridge) and lower (SH1) parts of the Hurunui Catchment's middle reaches. The solid red bar represents a SIN/DRP ratio of 10, and is the theoretical limit between N-limited and P-limited conditions. Datapoints above the top dotted red line (SIN/DRP=20) indicate P-limited conditions. Datapoints below the bottom dotted red line indicate N-limited conditions. No firm conclusions can be drawn from DRP/SIN ratio for datapoints between the two dotted red lines.

Contaminant/river flow graphs

DRP concentration/river flow: Hurunui at SH7 (R^2=0.451354)

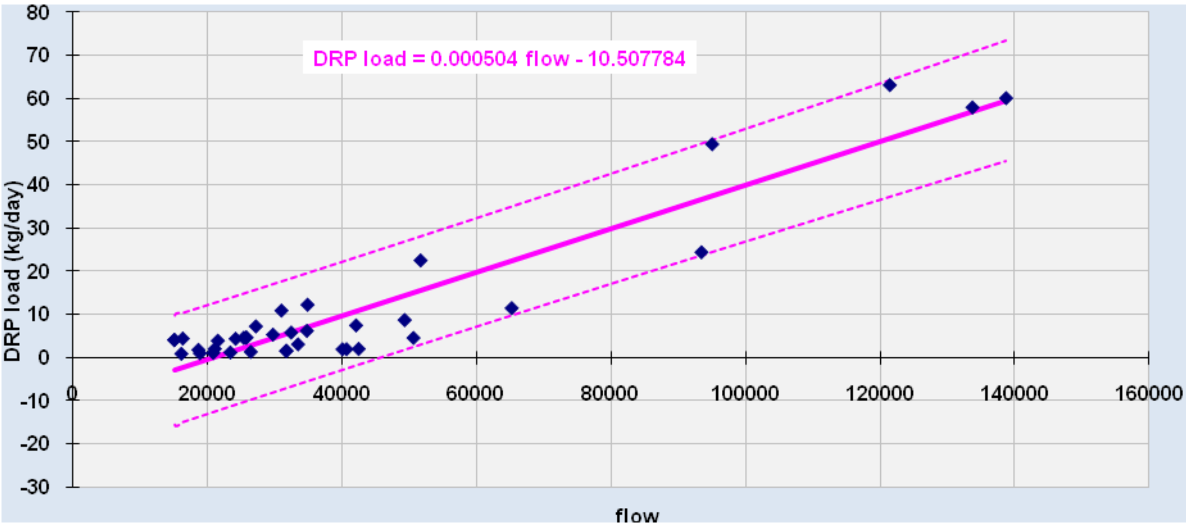


DRP concentration/river flow : Hurunui at SH1 (R^2=0.31)

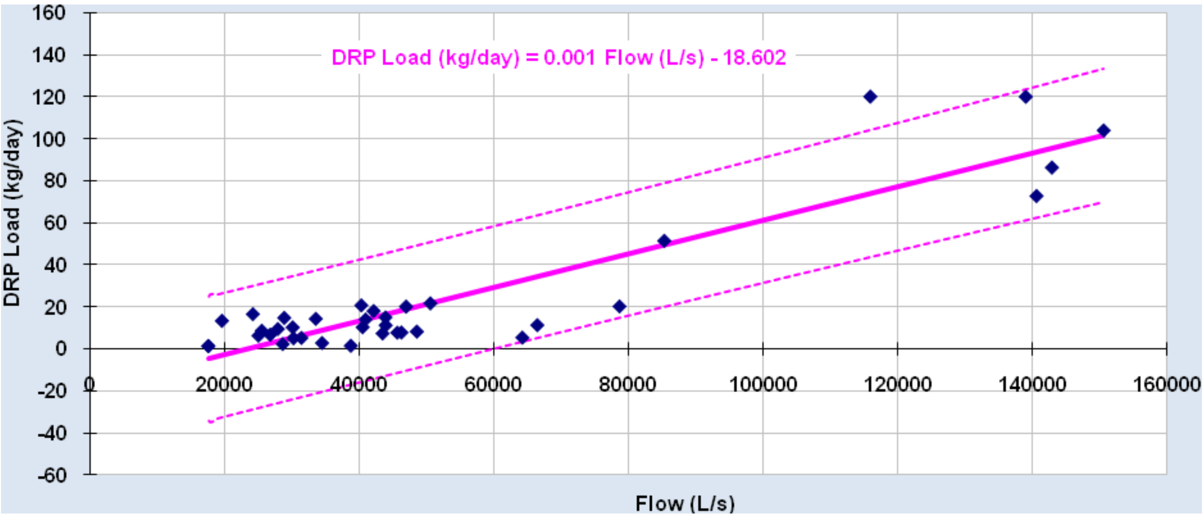


Note: Correlation coefficients were generally lower with log-transformed data.

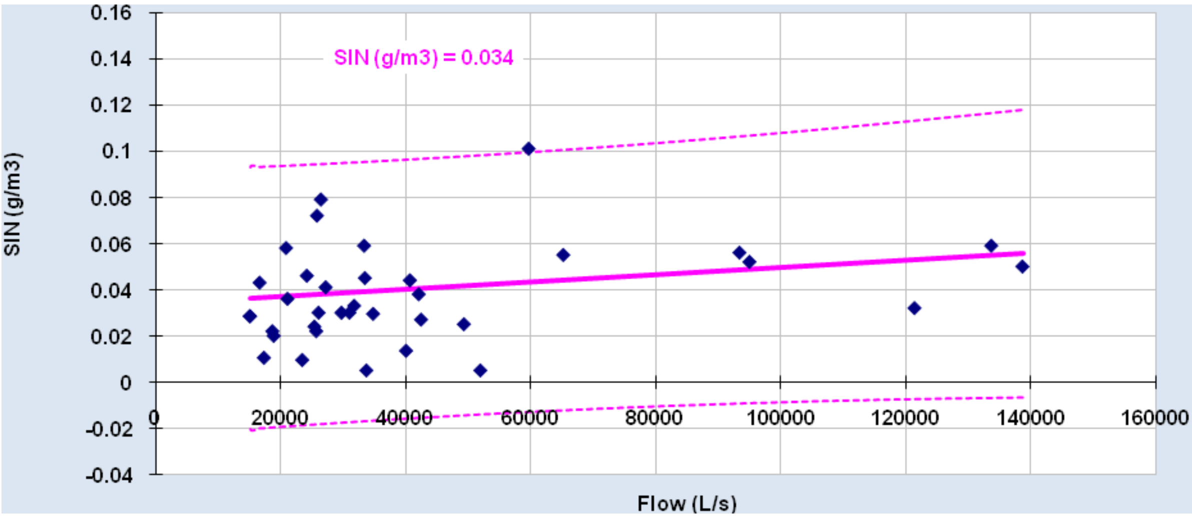
DRP LOAD/river flow: Hurunui at SH7 (R^2=0.88349)



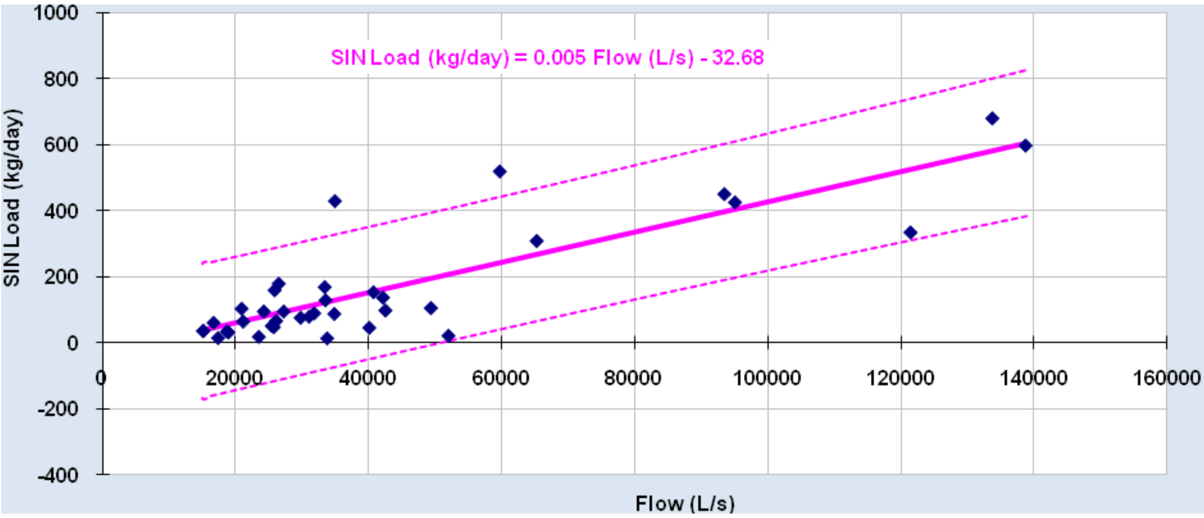
DRP LOAD/river flow: Hurunui at SH1 (R^2=0.82205)



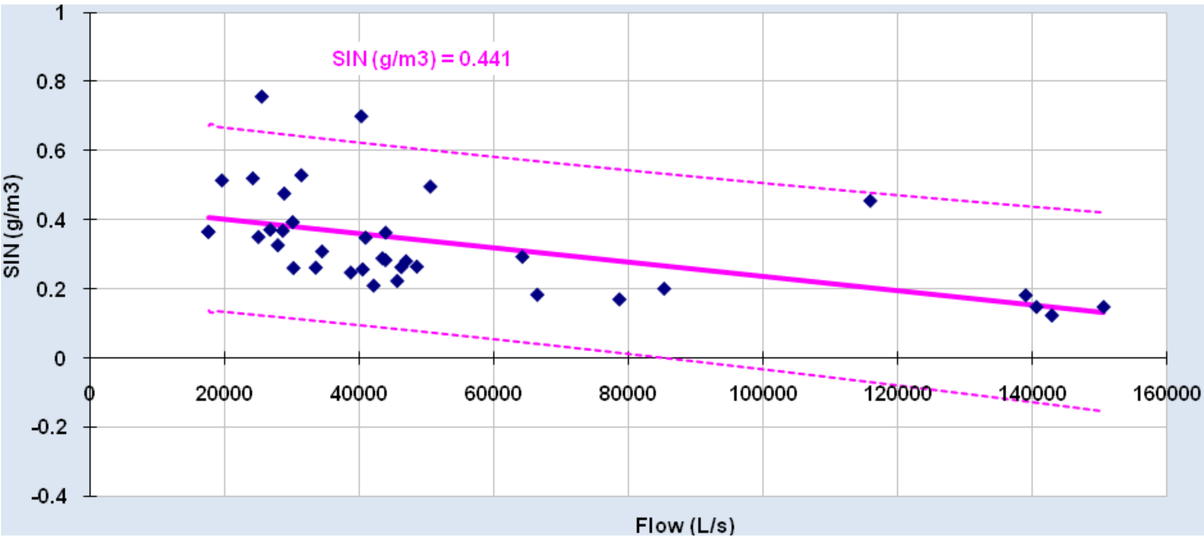
SIN CONCENTRATION/river flow: Hurunui at SH7 (R^2=0.03472)



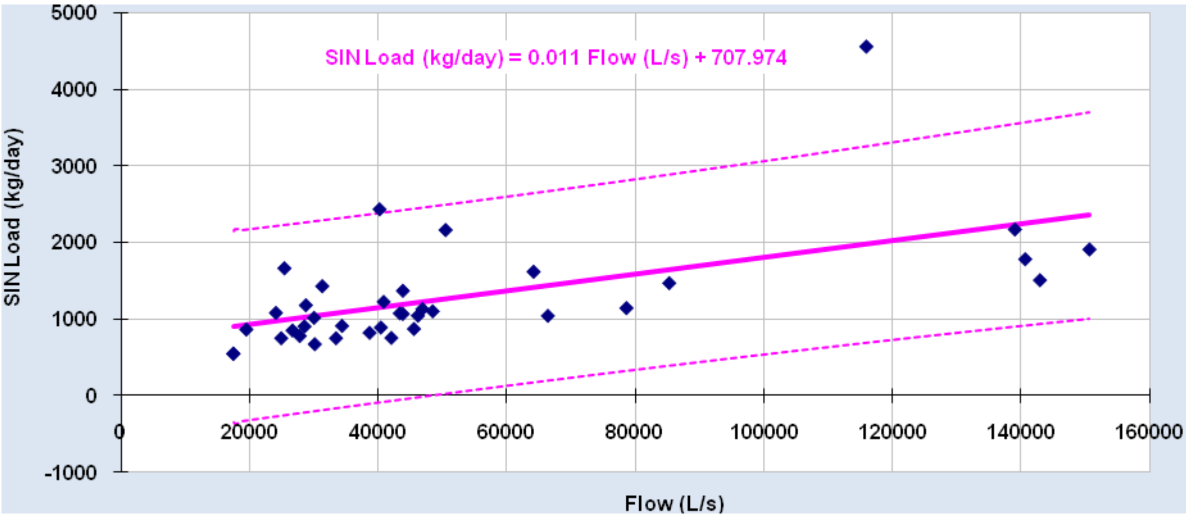
SIN LOAD/river flow: Hurunui at SH7 (R^2=0.71208)



SIN CONCENTRATION/river flow: Hurunui at SH1 (R^2=0.269)



SIN LOAD/river flow: Hurunui at SH1 (R^2=0.32579)



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