Kakanui River Water Quality Report

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Overview

Background

The Otago Regional Council (ORC) is responsible for managing Otago's groundwater and surface-water resources. Although the ORC carries out regular and extensive long-term water quality monitoring as part of its State of Environment (SOE) programme, it has not carried out a targeted short-term monitoring investigation in the Kakanui River catchment.

Why was this targeted investigation deemed necessary?

The investigation was implemented to gain:

- a more accurate understanding of how intensifying land uses can affect water quality and instream ecological values
- an insight into the catchment's groundwater-surface-water interaction.

What has this study found?

- In the Kakanui catchment, changes in land use, especially in the mid- and lower catchment where dairy farm conversions are prevalent, is putting pressure on the naturally good water quality.
- The Kakanui-Kauru Aquifer is very responsive to surface-water flows. Groundwater with high concentrations of nitrogen (N) enters the alluvial gravels in the main-stem Kakanui and Kauru rivers.
- As a result of the input of high N groundwater, the lower Kakanui may not be able to achieve low enough concentrations of N to prevent prolific algal growth.
- Since land-use intensification, Waiareka Creek has experienced increases in N and phosphorus (P) nutrient concentrations.
- Waiareka Creek enters the Kakanui River just upstream of the Kakanui Estuary. The combination of nutrient-rich water from both the Kakanui (N) and Waiareka Creek (P and N) is likely to stimulate algae growth in the estuary.
- Waiareka Creek is naturally silty, and the ecological values found in the creek are representative of that type of habitat. In the lower Kakanui River, a more diverse invertebrate community was found.

What should be done next?

The results from this report will be useful in guiding future policy decisions and in promoting good practice among the community and other stakeholders in order to maintain and enhance water quality in and around the Kakanui River.

Technical Summary

The Kakanui catchment (894 km^2) has three main tributaries: the Kauru River, Island Stream and Waiareka Creek. The Kakanui River's water resource is heavily used for irrigation purposes. The river has three minimum flow sites to manage water quantity, but recently concern has been expressed about agricultural intensification and subsequent degradation of the water quality.

Over the past ten years, land use in the catchment has intensified rapidly. The lower Kakanui and Waiareka Creek are dominated by a mixture of beef/sheep/deer/cropping and, increasingly, dairy farming, particularly since the introduction of irrigation water into the Waiareka Creek catchment.

ORC initiated a ten-month water quality sampling programme in September 2011, with the aim of gaining a better understanding of groundwater-surface-water interaction, water quality and ecological values in the catchment.

This study has found that the Kakanui-Kauru aquifer is largely driven by surface water flows. Groundwater recharge occurs in the alluvial gravels in the Kauru River and the main-stem Kakanui River. A significant input of nitrogen (N) occurs between the upper Kakanui (Clifton) and the lower Kakanui (Mill Dam), which changes the main-stem of the Kakanui from N-limited at Clifton to phosphorus (P)-limited at Mill Dam. This change in chemistry is a result of the high N-groundwater input, sourced mainly from animal waste. The drying up of the Kauru River during the summer months increases the proportion of nutrient-rich groundwater contribution to flow at McCone's.

The nitrate-nitrite-nitrogen (NNN) concentration recommended by Biggs (2000) to prevent algal biomass from exceeding 200 mg/m^2 chlorophyll *a*.is 0.075 mg/l. This biomass is deemed to be a proliferation and can lead to the degradation of higher communities such as trout.

As a result of the input of high N-groundwater, the lower Kakanui is unlikely to achieve low enough concentrations of N to prevent benthic algae from exceeding this target value. This is a change from the late 1990's when Biggs (1998) undertook a similar study and did not find such algal proliferations in the lower Kakanui.

In the Waiareka Creek, long-term trend analysis (1999 to 2012) showed significant increases in NNN, total phosphorus (TP) and dissolved reactive phosphorus (DRP). Shorter-term trend analysis (since 2006) was also conducted to determine whether there were any trends after land-use intensification (enabled by irrigation). While this analysis showed that NNN has continued to increase, no trend was found for TP or DRP concentrations during the period.

During this study, median values of DRP at all three Waiareka sites exceeded guideline values. NNN was low at the upper Waiareka Creek site, but the concentration had increased by up to 23 times at the lower monitoring site at Taipo Road.

The high nutrient concentrations found in the lower Kakanui (NNN) and Waiareka Creek (DRP) are likely to stimulate the proliferation of algae in the Kakanui estuary.

In 2011/2012, the DRP load from Waiareka Creek was 5 kg/day, whereas the DRP load from the Kakanui River was 0.6 kg/day. In contrast, in 2011/12, the NNN load from the Kakanui River was 22 kg/day, compared to 12 kg/day from the Waiareka Creek. In 2012, a wet year, the percentage contribution of nutrients from Waiareka Creek to the Kakanui estuary was about 90% DRP and 35% NNN.

Bacteria concentrations were significantly elevated in Waiareka Creek and above guideline concentrations at all sites (with the exception of the Kauru at Kakanui Valley Road Bridge). The

Kakanui (Clifton), a popular swimming hole, had a high rate (48%) of non-compliance with the recreational water quality guidelines (i.e. *E. coli* concentrations recorded were >260cfu/100 ml, possibly caused by nesting gull colonies in the gorge section of the catchment). The rate of non-compliance (39%) at the upper Island Stream site is also of concern because of its location above intensive farming.

Degraded water quality does not necessarily relate to degraded ecological values. Factors, such as the shallowness of the river, substrate, the condition of the riparian zone or the velocity of the water during periods of high flow, will also affect instream ecology.

The Kakanui River is close to the coast and should be a prime habitat for many diadromous native fish species. Although the water quality at McCone's had high nutrient concentrations, it also had large numbers of native fish and provided the most suitable habitat and plenty of food for eels. The fishery at the Kakanui (Clifton) site was not as good as the other sites, possibly because water velocities are often high at this site, limiting habitat availability or perhaps because of the presence of bedrock, which reduces refuge habitat. Although the Kauru River is ephemeral, which affects the brown trout population, it is a refuge for the lowland longjaw galaxias, which were found in abundance at the two lower sites.

The greatest numbers of brown trout were caught in the Kakanui (Gemmells Crossing), the Kauru (Kakanui Valley Bridge) and Island Stream (Kuriheka). At all other sites, few trout were caught. The Kakanui (McCone's) and Island Stream (Maheno) had large numbers of native fish.

The macroinvertebrate community index (MCI) values for this study show that 'good' MCI values were found at all Kauru River sites, the upper Island Stream site (Kuriheka) and the upper Kakanui site (Clifton). Waiareka Creek, which is slow flowing, with few riffles or coarse, exposed substrate (preferred by many taxa), had an MCI classification of 'poor'. The substrate ranking confirmed that Waiareka Creek had 'poor' substrate, along with Island Stream (Maheno) and Kauru (Kakanui Valley Road), while the upper sites in Island Stream and the Kakanui had the best.

The results from this report will be useful in guiding future policy decisions and in promoting good practice among the community and other stakeholders in order to maintain and enhance water quality in and around the Kakanui River.

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1. Introduction

The Kakanui catchment (894 km^2) has three main tributaries: the Kauru River, Island Stream and Waiareka Creek.

The lower Kakanui and Waiareka Creek are dominated by a mixture of dry-stock and, increasingly, dairy farming. The introduction of irrigation into the Waiareka Creek catchment has seen an increase in dairying and dairy support. (Sheep and beef farms are used during winter for grazing by dairy cattle.) In Waiareka Creek, dairying has increased by 180%, in contrast to land use in the Kauru and upper Kakanui, which are typified by red tussock, native forest, plantation forestry or pasture for red deer, sheep and beef.

Routine State of the Environment (SOE) monitoring has been conducted at two sites on the Kakanui River since 1994 (Clifton Falls and McCone's) and one site on Waiareka Creek since 1999. The water quality in the alluvial gravels of the Kauru River and the main-stem Kakanui River, particularly upstream of Gemmells Crossing, is influenced by groundwater-surface-water interaction. There is very little groundwater-surface-water interaction in Waiareka Creek.

This report documents the results of a 10-month investigation of water quality in the Kakanui catchment. The investigation was initiated due to concern about deteriorating water quality, and anecdotal evidence that instream values (i.e. the fishery) in the lower reaches of the Kakanui River were being compromised by the decline in water quality.

The investigation was undertaken between September 2011 and July 2012 and involved fortnightly testing of surface water. Monthly periphyton monitoring (during the summer) was also undertaken and a one-off assessment was made of aquatic ecological health and substrate condition. The main aim of the investigation was to improve our understanding of surface-water quality and groundwater-surface-water interaction in the Kakanui catchment. The report is split into two main sections. The first section covers groundwater and surface water and how their interaction influences surface-water quality, and the second covers habitat and biological assessment.

The results from this study are anticipated to become part of the future debate of land-use management in the Kakanui catchment.

Figure 1.1 The Kakanui River at McCone's.

2. Background Information

This section outlines the main features of the Kakanui catchment, including:

- general catchment description including climate and geomorphology
- water use and hydrology
- natural values of the Kakanui River
- North Otago Irrigation Scheme
- land use.

2.1 Catchment description

The Kakanui River catchment (Figure 2.1) has an area of 894 km^2. The catchment is contained by the Kakanui Mountains and Pisgah Spur to the west and south. Mt Pisgah is the highest point in the catchment, with an elevation of 1634 m. In the north, the catchment is separated from the Waitaki catchment by rolling hill country. The main tributaries of the Kakanui River are the Kauru River (catchment area 143 km^2), Island Stream (122 km^2) and Waiareka Creek (213 km^2).

From its source in the Kakanui Mountains, the Kakanui River flows north-east for about 40 km, through gorges incised in rolling or downland country, before emerging onto plains at Clifton. It then flows south-eastwards at a gentler gradient through highly developed pastures to be joined further down the widening valley by the broad, gravel-bedded Kauru River. The Kakanui River can be divided into three sections of different character. The upper 32 km of river is generally contained by steep hillsides (10 m/km). The gradient decreases to 3.6 m/km in the 19 km middle reaches, and the lower 9 km of river is low gradient (1.2 m/km). It flows into the Pacific Ocean 10 km south of Oamaru.

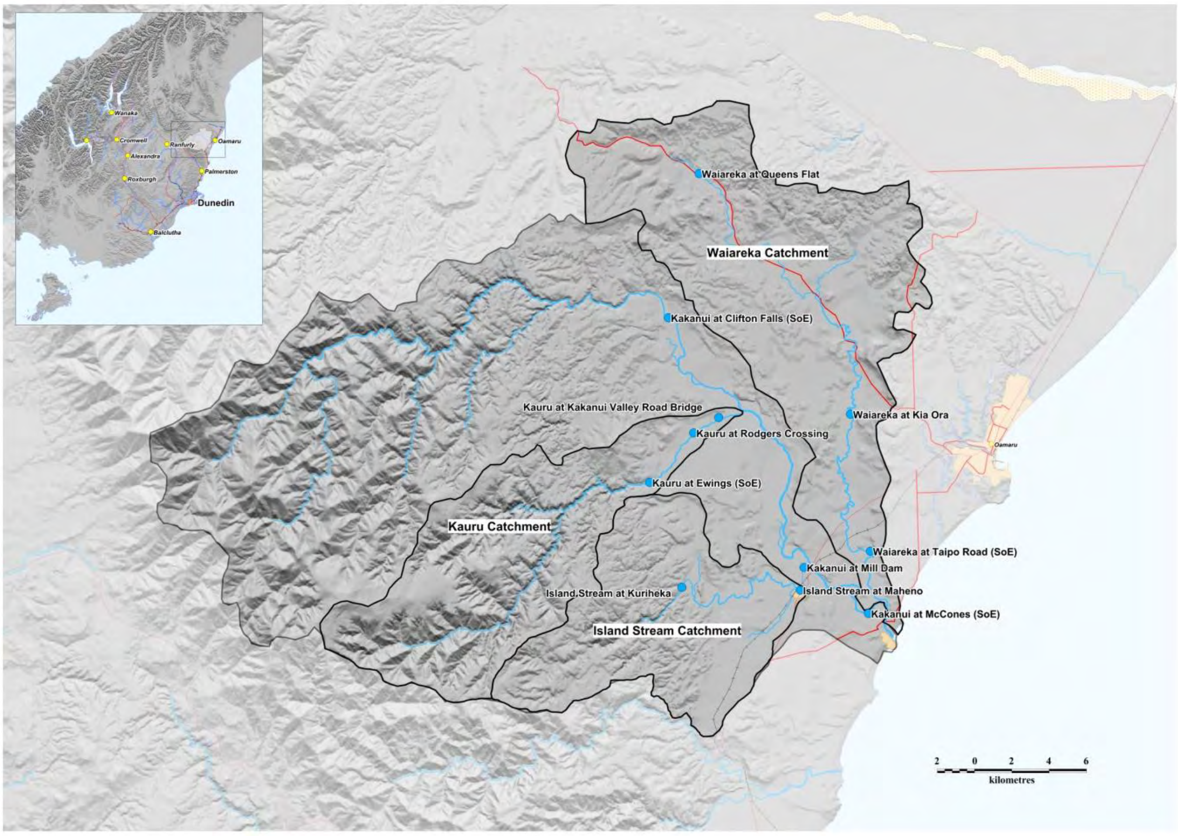

Figure 2.1 Kakanui catchment, showing the Island Stream catchment, Kauru catchment and the Waiareka Creek catchment.

The Kauru River catchment comprises 16% of the total catchment area of the Kakanui River. The Kauru River lies between the catchment of the main branch of the Kakanui and Island Stream catchment and is bound in the south by the Kakanui Mountains. Hector's Stream is the main tributary of the Kauru River, and the catchment rises to an elevation of 1286 m at Siberia Hill.

The Waiareka Creek catchment (210 km^2) is characterised by distinctive downland topography, formed mainly on limestone to the north and east of the Kakanui River catchment. The high porosity of the limestone means that the Waiareka has few tributaries. The Waiareka joins the Kakanui River in the estuary.

The Island Stream catchment (115 km^2) drains the south-eastern portion of the catchment and joins the Kakanui River at Maheno.

2.2 Climate

The Waiareka and Kakanui valleys are situated in the rain shadow of the Kakanui Range. Annual sunshine hours are in excess of 1,800 at Oamaru, with common summer temperatures of around 20°C. The North Otago downland region is well known for its low rainfall. The mean monthly precipitation at three rainfall stations is shown in Table 2.1. The drought seasons had a severe impact on agricultural activity until the North Otago Irrigation Company (NOIC) was granted consent to take water from the Waitaki River to use as irrigation water in the Kakanui catchment.

Table 2.1 shows a marked seasonal variation in rainfall, with the lowest rainfall occurring in the spring and highest in summer. The effectiveness of the summer rainfall is reduced due to high evaporation.

Table 2.1 Mean monthly precipitation in mm.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kauru	94.4	79.7	43.7	50.3	47.7	34	77.1	59.7	57.7	60.1	53.5	76.8	731
Oamaru	47	45.3	27.3	49.6	57.9	32.6	44.1	50.4	32.4	42.2	43.7	52.8	520.4
Clifton	50.4	54	28.7	33.2	46.9	23.5	39.3	25.6	30.5	32.4	38.5	59.1	450.4

2.3 Geomorphology

The upper reaches of the Kakanui River catchment (west of Five Forks, Kauru Hill and Island Stream settlements) are mountainous, rising to a peak elevation of 1643 m at Mt Pisgah. River channels are single-threaded and meandering, passing through native and indigenous forest and tussock land. The lower reaches of the catchment comprise rolling hill country and floodplain, where gentler gradients result in localised braiding, lateral migration of river channels and the active transport and deposition of sediment.

Between Five Forks and the coast, the main channel of the Kakanui River and the lower reaches of the Kauru River follow a meandering path through old river terraces. Gravel deposition is common in the lower reaches of the Kauru River and between its confluence and Gemmells Crossing on the Kakanui River, particularly during flood events.

Between the Kauru River confluence and Maheno, the river has a history of breaking out of the main channel and crossing farmland. River breakout during flood events has also occurred in the lower reaches of the Kauru River.

The channel gradient of the Kakanui is about 1:400 upstream of Maheno and 1:800 downstream.

The Kauru River has a relatively steep gradient and, in its lower reaches, flows in a fairly direct path through the floodplain at a gradient of 1:150. Island Stream and Waiareka Creek have relatively flat gradients. Ponding is a common result of flooding, particularly on the Waiareka Creek floodplain (OCB, 1987).

2.4 Natural values

The Regional Plan: Water for Otago[1] (2004) (RPW) lists many natural values for the Kakanui River, including significant fish and macroinvertebrate diversity, trout spawning and rearing habitat and a significant presence of eels. The catchment also has a high degree of naturalness above Clifton. Lowland longjaw galaxias, koaro and lamprey are found in the catchment.

The Kakanui catchment supports diverse ecosystems. The NIWA Freshwater Fish Database lists numerous species of fish and one species of freshwater crayfish (Table 2.2). Brown trout (*Salmo trutta*) is an introduced species and is the most common fish in the area.

Table 2.2 Fish species present in the Kakanui catchment (NIWA Freshwater Fish Database July 2012).

Common Name	Species Name	Kakanui River	Island Stream	Waiareka Creek	Kauru River
Shortfin eel	*Anguilla australis*	yes	yes	yes	
Longfin eel	*Anguilla dieffenbachii*	yes	yes	yes	yes
Torrentfish	*Cheimarrichthys fosteri*	yes			
Koaro	*Galaxias brevipinnis*	yes			yes
Lowland longjaw galaxias	*Galaxias cobitinis*	yes			yes
Inanga	*Galaxias maculatus*	yes	yes	yes	
Canterbury galaxias	*Galaxias vulgaris*	yes	yes		yes
Lamprey	*Geotria australis*	yes	yes	yes	
Upland bully	*Gobiomorhus breviceps*	yes	yes	yes	yes
Common bully	*Gobiomorphus cotidianus*	yes	yes	yes	yes
Giant bully	*Gobiomorphus gobioides*	yes		yes	
Bluegill bully	*Gobiomorphus hubbsi*	yes			
Redfin bully	*Gobiomorphus huttoni*	yes		yes	
Chinook salmon	*Oncorhynchus tshawytscha*	yes			
Koura	*Paranephrops sp.*	yes			yes
Perch	*Perca fluviatilis*		yes	yes	
Brown trout	*Salmo trutta*	yes	yes		yes
Tench	*Tinca tinca*		yes	yes	

2.5 Water use and hydrology

2.5.1 Minimum flow sites and water allocation

The water resource of the Kakanui River is heavily used for irrigation purposes. There are three minimum flow sites on the river to manage water use:

- Clifton Falls Bridge (400 l/s)
- Mill Dam (250 l/s)
- McCone's (250 l/s).

Table 2.3 shows water allocation in the catchment. The allocation is about four times the minimum flow at McCone's and greater than the median flow at McCone's.

[1] Schedule 1A of the Regional Plan: Water for Otago (2004), p. 267

Table 2.3 Water takes and allocation in the Kakanui catchment.

Reach	Number of takes	Total primary allocation l/s
Upstream of Clifton	8	270
Clifton Falls to Mill Dam	44	1150
Mill Dam to estuary	11	277
Island Stream	14	490
Waiareka Creek	25	460

Groundwater allocation in the Kakanui alluvium is included.

2.5.2 Kakanui River main-stem hydrology

Table 2.4 Flow statistics for 2011-2012 and historical data for each flow site in the Kakanui River catchment.

		Kakanui River at Clifton (l/s)	Kauru at Ewings (l/s)	Kakanui River at Mill Dam (l/s
Catchment area (km2)		294	123	546
7-day low flow (l/s)	2010/11	593	145	562
	Historical	557	126	433
Catchment yield at 7-day low flow (l/s/km2)	2010/11	2.017	1.179	1029
	Historical	1.895	1.024	793
Median flow (l/s)	2010/11	1,521	610	1,998
	Historical	1,514	489	1,949
Mean flow (l/s)	2010/11	3,629	1,348	5,237
	Historical	2,993	1,088	5,333
Historical data record length		Apr 1981 to Jun 2012	Nov 1991 to Jun 2012	Dec 1989 to Jun 2012

2.5.3 Kakanui River tributary hydrology

Table 2.5 Hydrological statistics for the Kauru River, Waiareka Creek and Island Stream catchments for 2011-2012.

Flow site	Kauru – Ewings	Kauru - Rodger's Crossing	Kauru - Kakanui Valley Rd	Waiareka Creek – Taipo Rd	Island Stream - Kuriheka	Island Stream - Maheno
Catchment area (km2)	123	134	139	208	39	116
Minimum flow (l/s)	126	4	44	72	15	0
2010/11 7-day low flow	145	8	62	102	18	7
Catchment yield 7-day low flow (l/s/km^2)	1.18	0.06	0.45	0.49	0.46	0.06
Median flow (l/s)	610	395	323	258	126	221
Mean flow (l/s)	1348	980	1151	456	388	452

2.6 North Otago Irrigation Scheme

On 28 March 2002, the North Otago Downlands Water Company (now NOIC) was granted Water Permit 2001.658 to discharge water from the Waitaki River into Waiareka Creek as part of an irrigation scheme proposal. Under this consent, up to 300 l/s may be discharged at Queen's Flat and up to 1,000 l/s downstream of the Weston-Ngapara Road Bridge at Elderslie. The augmented water flows in the creek to below Cormacks-Kia Ora Road, where it is piped to the farms that have purchased it for irrigation.

A condition of Consent 2001.658 was that the irrigation company maintains a minimum flow of at least 100 l/s in Waiareka Creek at its confluence with the Kakanui River. The irrigation company was also required to install a flow-gauging site in the lower reaches of the Waiareka Creek at Taipo

Road to help manage the creek flow. The scheme, which began in 2006, maintains a flow of 100 l/s at the Taipo Road site while it is operating.

2.7 Land use

Land use in the Kakanui catchment has changed considerably over the last 10 years. Although the upper Kakanui River catchment is typified either by red tussock, mixed broadleaf forest, plantation forestry or by extensive pasture farmed with drystock (red deer, sheep and beef) (McDowell, 2011), the lower Kakanui and Waiareka Creek are dominated by a mixture of dry-stock and, increasingly, dairy farming. The land-use types are shown in Figure 2.2, and Table 2.6 (Agribase, 2012) shows each farm type as total hectares.

Table 2.6 Farm types: Total land area (if over 500 ha) in the Kakanui catchment.

Farm Description	Hectares (ha)
Mixed sheep and beef farming	52,492
Sheep farming	10,073
Dairy cattle farming	6,872
Beef cattle farming	4,168
Deer farming	3,083
Forestry	2,509
Arable cropping or seed production	2,379
Grazing other peoples stock	1,005
Lifestyle block	629
Dairy dry stock	597

The introduction of irrigation into the Waiareka Creek catchment has seen an increase in dairying and dairy support (sheep and beef farms used for grazing during winter by dairy cattle). Table 2.7 shows that, on the irrigated land in the Waiareka catchment, dairying has increased by 180% (from 2075 ha prior to irrigation to 5820 ha subsequent to irrigation). The irrigation company estimates that about 60% of land irrigated is now used in dairying or for dairy support.

Table 2.7 Land Use (ha) in the irrigated land within the Waiareka Creek catchment (NOIC, 2010).

	Dairy	Dairy support	Sheep	Beef	Deer	Arable	Other
Before irrigation	2,075	1,211	5,199	179	0	1,241	27
After irrigation	5,820	933	1,023	883	60	1,193	19

Table 2.8 (reproduced from McDowell, 2011) shows the percentage of total catchment under dairy, dairy support and sheep production. It shows that there has been minimal land-use change in the upper Kakanui between 2000 and 2010, with 98-99% of the area under sheep and beef production.

However, in the lower Kakanui and Waiareka, dairying and dairy support have increased substantially, from 1% (in 2000) to 7% (in 2010) in the lower Kakanui and 8% (2000) to 25% (2010) in the Waiareka.

The 25% (2010) reflects land use in the entire Waiareka catchment, whereas the 60% estimate reflects land-use change on the irrigated land.

Table 2.8 Percentage of total catchment under dairy, dairy support and sheep production. Data based on Agribase (AssureQuality NZ Ltd, 2010) and expert opinion. (Table is reproduced from McDowell, 2011.).

		Dairy	Dairy support	Sheep and beef breeding	Sheep and beef finishing	Total (%)
Upper Kakanui	2000	<1	0	70	29	99
Upper Kakanui	2010	1	0	70	28	99
Lower Kakanui	2000	1	0	70	24	95
Lower Kakanui	2010	5	2	58	20	85
Waiareka Creek	2000	7	1	73	7	88
Waiareka Creek	2010	19	6	51	7	83

Percentages of <100 indicate non-pasture-based land use, comprising a combination of native forest, production forestry, and arable and vegetable production.

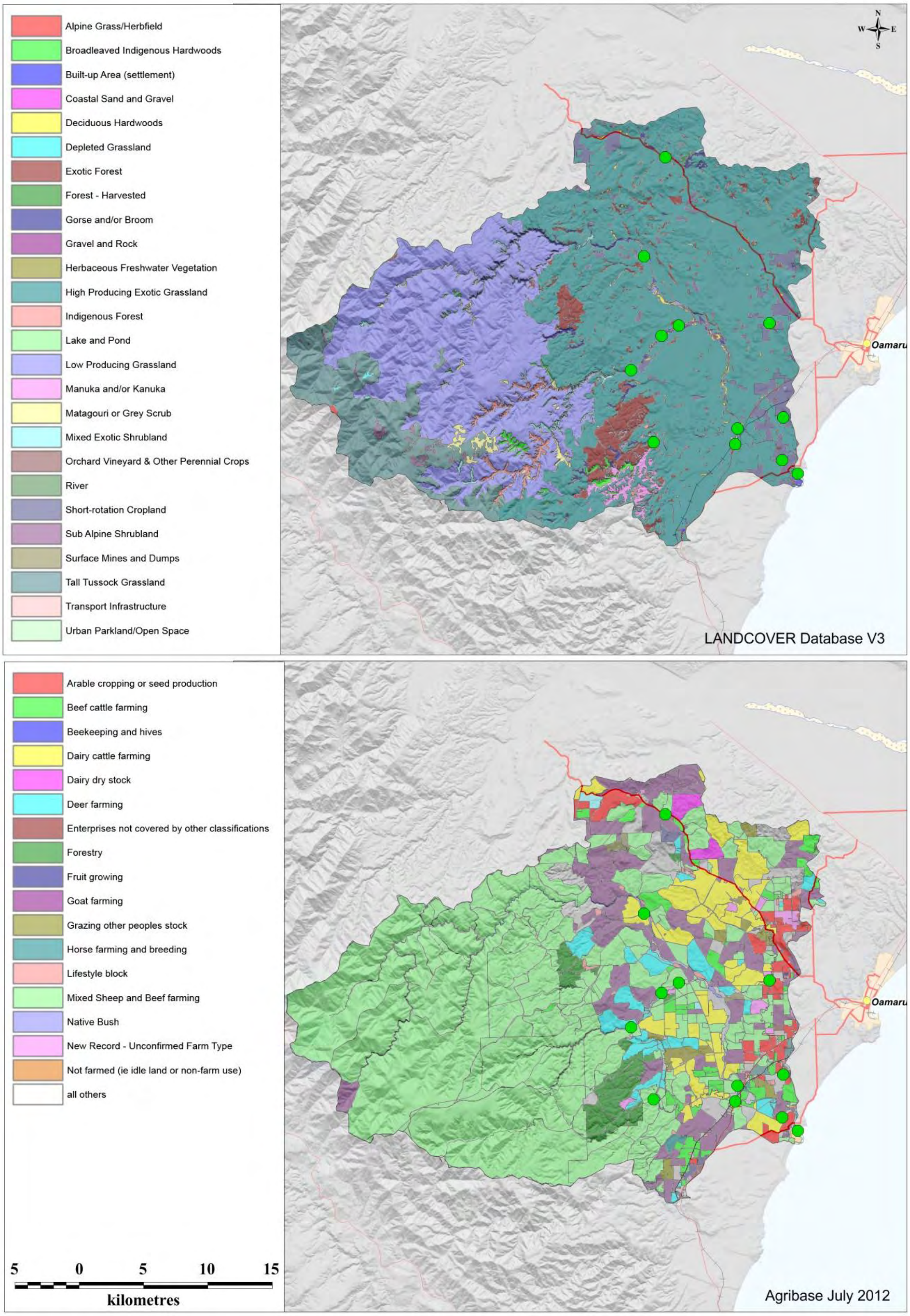

Figure 2.2 **Land use and farm type in the Kakanui catchment.**

3. Kakanui catchment: Groundwater-surface-water interaction

The Kakanui-Kauru alluvium has been a recognised riverine ribbon aquifer since the Otago Catchment Board investigation of the North Otago groundwater resource in the 1980s. The alluvial sands and sandy gravels making up the floodplains of the Kakanui and Kauru rivers are thin and couched within less permeable sedimentary rocks, such as the North Otago tuffs, sandstone/siltstone and quartzose conglomerate.

Table 3.1 lists the estimated alluvial and saturated thicknesses of the Kakanui-Kauru alluvium, based on earth resistivity geophysical surveys across the whole valley floor (Pearson, 1989).

Table 3.1 Estimated gravel thicknesses and storage volumes during low flow (assuming $S_y = 0.15$).

Sub-basin	Area (ha)	Thickness (m)	Saturated thickness (m)	Storage (Mm^3)
Five-Forks	821.9	5.5	3.8	4.7
Kauru	596	6	5.5	4.9
Gemmells	935.4	6.5	5.8	8.1
Southern valley	1355	3.3	2.1	4.3
Total	3708.3	5.0	4.0	22.0

Notes: Mm^3 = million cubic metres. Assume that specific yield, $S_y = 0.15$.

3.1 Geographic patterns in river-groundwater interaction

The sub-basin distinctions made above are not accidental since the transitions from one adjoining sub-basin to another are marked by zones of accentuated river-flow loss to the aquifer or river-flow gain.

River-flow losses are noted below Clifton Falls in the Five Forks sub-basin, from the Kakanui River in the Kauru sub-basin and below the Kakanui-Kauru confluence.

River-flow gains are noted above the Kakanui-Kauru confluence at the bottom of the Five Forks sub-basin and immediately below Gemmells Crossing.

These losses and gains only represent 10-15% of river base flow (ORC, 1993). The lower reach of the Kauru River ceases to flow in dry weather, as the alluvium drains river flow and conducts it underground to the Kakanui River.

Figure 3.1 depicts the relevant features of the Kakanui-Kauru alluvium aquifer.

Seasonally, a much greater turnover of alluvial-aquifer storage occurs, especially as a dynamic response to higher flow events, which has become recognised as a significant pathway for groundwater nitrate nitrogen to enter the Kakanui River.

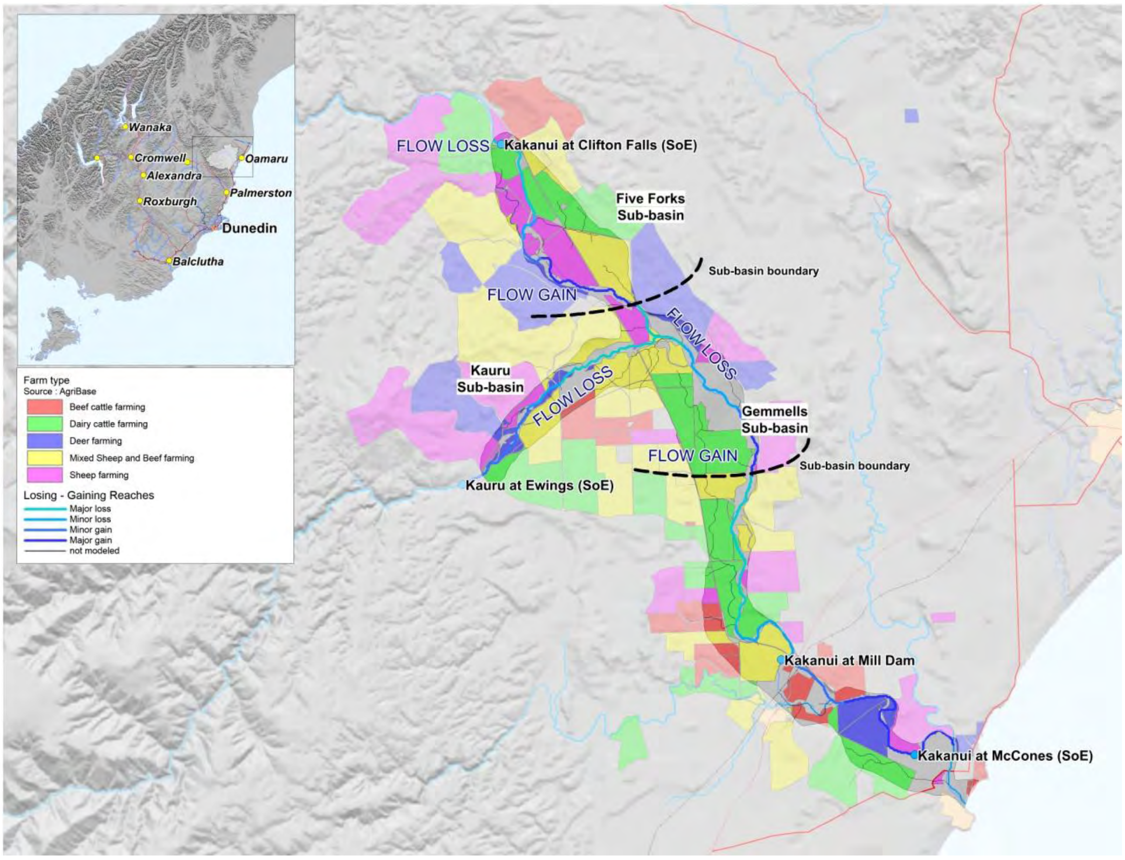

Figure 3.1 **Map of groundwater sub-basins and regions of river-flow gain and loss. The Kakanui-Kauru alluvium is shown in brighter colours adjacent to the river.**

3.2 Event responses

Groundwater levels change seasonally and with high-flow events. The volume of water replenished during a high-flow event, and then drained during flow recession, can represent a high proportion of groundwater storage. Monitoring of groundwater levels across the aquifer from 1986-1989 indicates that fluctuations in groundwater levels responding to high-flow events could comprise 25% of aquifer storage (ORC, 1993). Fluctuations observed in the two bores with a monitoring record - J41/0096 and J41/0256 - show level fluctuations of 0.68 m and 1.45 m, respectively. These fluctuations are 10 to 22% of the average thickness of the Gemmells sub-basin.

The high turnover of groundwater storage in response to high-flow events has implications for nitrate accrual in the aquifer. Any nutrients that accumulate can potentially be displaced by high-flow events. If the interval between high-flow events is sufficiently long, there may be enough time for the aquifer to accumulate nitrate to moderate concentrations. If this occurs, the water released as base flow in the recession following a high-flow event will have sufficient nitrate to exceed the surface-water threshold of 0.075 mg/l (Biggs, 2000, 30 days accrual). The river is particularly vulnerable when the proportion of base flow contributed from the riparian gravels is greatest, which typically occurs towards the end of a long-flow recession.

The nature of the relationship between the river and the riparian gravels changes over the course of the year. Recharge from high flow events is stored in the upper part of each sub-basin and released further down the valley during flow recessions. Thus, groundwater storage fills from the upper part of the system, and the recharge front progressively moves down the system towards the coast. Conversely, during a flow recession, the system drains from the lower part of each sub-basin upwards.

The volume of groundwater stored within the alluvial gravels determines the response at the lower valley to flow events higher in the catchment. At the end of each summer, most of the available dynamic groundwater storage has been drained into the Kakanui River as base flow. At this time, there is typically little response at Mill Dam to a flood higher in the catchment. The extra water entering the catchment during a flood flow is soaked up by riparian gravels in the Kauru, Five Forks and Gemmells sub-basins, thereby replenishing groundwater storage. This loss of flow to groundwater continues until riparian gravel storage is replenished. When the gravels are fully saturated, Mill Dam becomes more responsive. At the end of winter, groundwater storage is typically at full capacity. Some flow loss to riparian gravels occurs during flow peaks when the river stage is high. However, from spring through to summer, the river becomes a draining system for the Kakanui alluvium.

Figure 3.2 shows an example of the river's response to a flood flow during October 1993. This period was chosen because the flow is quite low for October, and demand for irrigation is also low. The plot shows three curves: the combined basin inflow at Clifton Falls and Ewings, the difference between combined inflow and Mill Dam flow and the flow change at Mill Dam as a percentage of inflow. The Mill Dam curves show some fluctuations in response to an irrigation demand of 40-100 l/s.

Figure 3.2 shows that as catchment inflow at Clifton Falls and Ewings drops, the proportion of flow at Mill Dam, provided by base flow, increases with time. The contribution from riparian gravels between the top and bottom of the catchment increases over time to at least 15-20% of total flow.

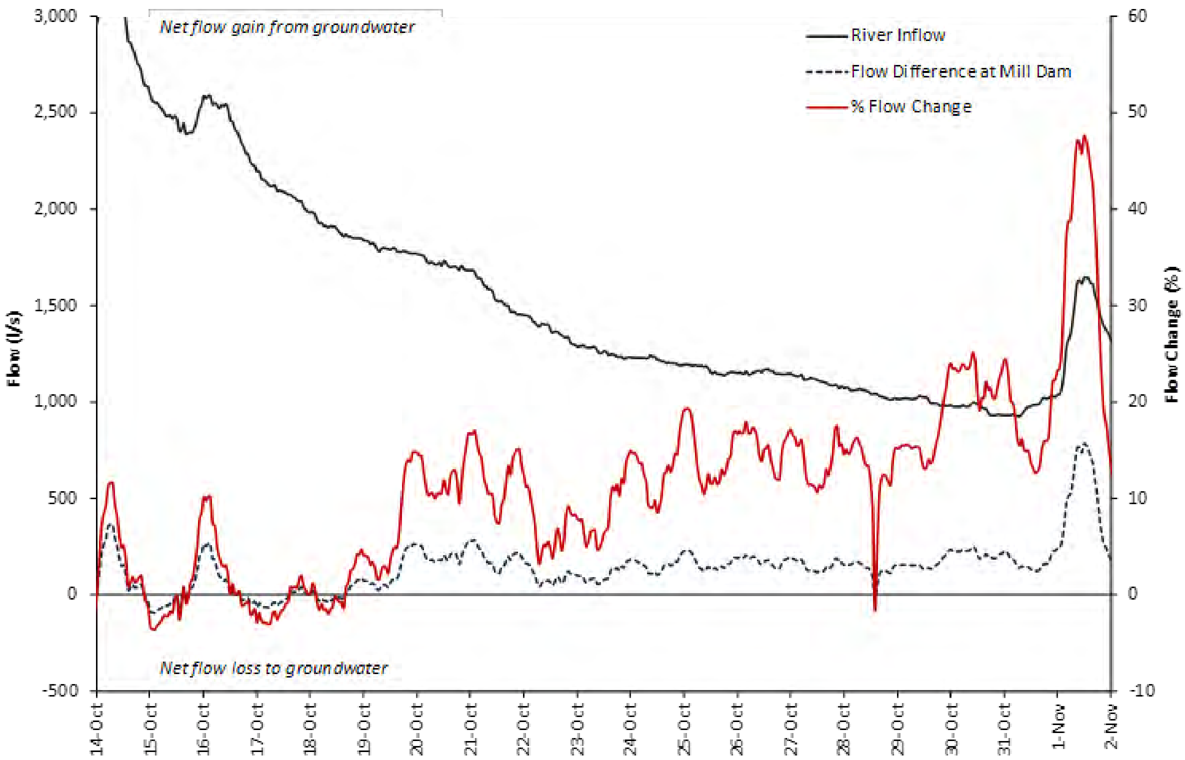

Figure 3.2 Flow recession of October 1993.

Towards the end of a very long-flow recession, the proportion of base flow contributed to the river is expected to decrease again because the hydraulic gradient towards the river flattens in response to the continued drainage of groundwater storage. It is difficult to show this phenomenon with the available data because of interference effects caused by abstraction.

3.3 Influence of the Kauru River

The Kauru River has a large influence on groundwater dynamics in the Kakanui Valley because the Kauru alluvial gravels have a large volume of groundwater storage that freely drains into the main Kakanui Valley. Furthermore, the Kauru River is intermittent, which creates large fluctuations in groundwater outflow to the Kakanui River and alluvium.

That the Gemmells sub-basin groundwater level is distinctly affected by fluctuations in the Kauru River flow and by pulses of river water infiltrating into the aquifer and 'cutting the corner' to the Kakanui River is clear from the fact that the groundwater level response lags the river peak by up to three weeks. Figure 3.3 illustrates this phenomenon.

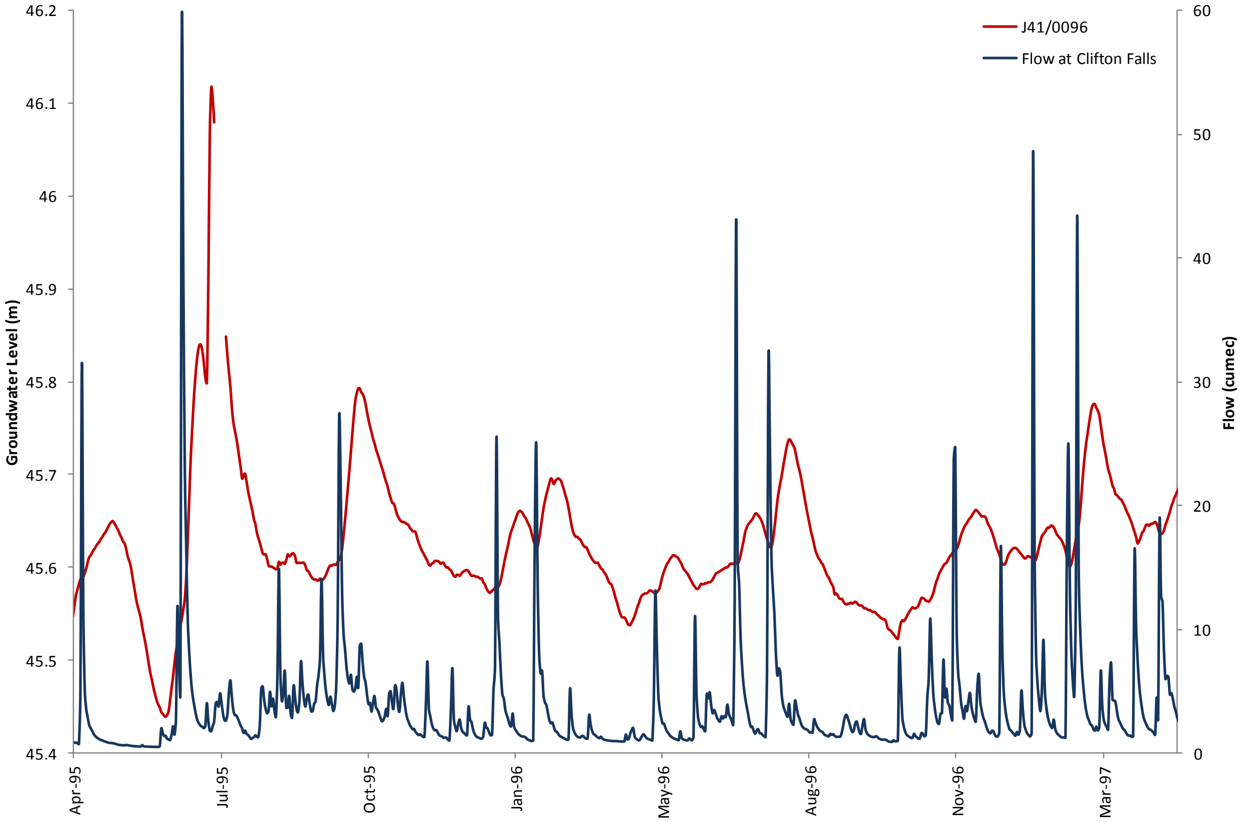

Figure 3.3 Time series of groundwater level at Kakanui-Kauru confluence monitoring bore J41/0096 and Kakanui River flow measured at Clifton Falls.

The Kauru River has been measured as losing between 150 and 250 l/s to the underlying alluvium and groundwater flow (ORC, 2003), although the losses can exceed 500 l/s during high-flow events. The Kauru River may dry up above Rodger's Crossing through riverbed infiltration, depending on the combination of groundwater and river-flow conditions before the low-flow period.

3.4 Alluvial soil drainage

The alluvial aquifer is also recharged by the drainage of excess soil water through the soil profile to the water table. The intensities of soil drainage can be estimated for the five soils over the Kakanui-Kauru alluvium (whether the soil is irrigated or not). Quantitative estimates have been made of soil drainage (also termed 'recharge') in each soil class, which are listed in Table 3.2.

Table 3.2 Soil drainage or recharge estimates for the Kakanui-Kauru alluvium.

Soil class	1	2	3	4	5
Profile available water (PAW)	133	122	103	68	36
Profile readily available water (PRAW)	66	49	46	41	22
Non-irrigated area (ha)	58	3	182	503	1,062
Irrigated area (ha)	275	153	218	668	494
Total area	333	156	400	1,171	1,556
Irrigated recharge (mm)	160	488	168	368	423
Rainfall recharge (mm)	34	38	39	72	107
Irrigated recharge (m^3/y)	441,007	744,926	365,487	2,459,184	2,088,309
Rainfall recharge (m^3/y)	19,370	1,239	71,607	364,031	1,135,362
Combined total mean recharge (m^3/d)	1,261	2,044	1,198	7,735	8,832
Combined total mean recharge (l/s)	14.6	23.7	13.9	90	102
Alluvium total (l/s) 244					

Drainage of soils under irrigation can make up three-quarters of the total catchment infiltration to the water table. There is less seasonality in soil-drainage events under irrigated pasture than non-irrigated land, where winter rainfall dominates the timing.

3.5 Significance to nitrogen dynamics

Nitrogen leaching is usually considered to be greatest during winter when pasture absorbs few nutrients, and non-irrigated soils have their greatest rates of drainage. However, the increased soil drainage from irrigation will allow continued leaching of nutrients through the summer months. The figures shown in Table 3.2 allow for an approximate groundwater budget to be calculated. Land-surface recharge typically comprises around 10% of the median river flow at Mill Dam. However, a light rainfall event during the summer could induce a groundwater-recharge event that comprises 15% of the river flow or an even greater proportion at lower flows.

The land-surface recharge calculations indicate that the aquifer and river are susceptible to elevated N concentrations from leaching throughout the year. The more sensitive, lighter soils coincide with the region of the aquifer that contributes most to river base flow during summer.

The ECAN lookup tables for nitrate leaching indicate that wintering of cows contributes an additional 10 to 15 Kg N/ha/yr of leachate[1], which suggests that winter-leaching rates should be at least 30% higher than the annual values specified in the lookup tables.

While much of the leachate entering the aquifer during winter will be moved through the system quite rapidly, you would expect to find residual nitrate in the aquifer. During summer, ongoing leaching beneath irrigated pasture will continue to maintain nitrate at elevated concentrations. At a conceptual level, it is difficult to see how an annual leaching limit of 30 kg N/ha/yr would improve water quality in the river unless the cows were wintered off as well.

3.6 Current nitrogen status

Few groundwater sample results exist for the Kakanui-Kauru aquifer.
Table 3.3 summarises the available data. All of the samples, with the exception of two, were taken before the mid to late 1980s and do not reflect the current state of intensive land use. Bore J41/0096 was sampled between December 1985 and March 1995. While pasture was irrigated during the 1980s and 1990s, there was very little dairy farming in the catchment. Land

[1] The majority of the area consists of extra light soils. These soils are predicted to leach between 38 and 65 kgN/ha/y, depending on herd density and wintering (Lilburne *et al.*, 2010).

intensification started more recently, around 10 years ago, and has increased significantly in the last three to five years.

Table 3.3 Past nitrate-N values measured in Kakanui-Kauru groundwater.

Site Name	E	N	Samples	Median nitrate-N	Maximum nitrate-N
J41/0095	1426405	5004974	1	0.45	0.45
J41/0096	1427305	5005174	10	1.1	2.5
J41/0094	1425316	5008717	5	3.6	4.6
J41/0256	1428452	5002374	2	0.57	0.92
J42/0057	1429084	4998046	5	13.7	15.8
J42/0015	1430012	4996577	2	2.1	10.8
		Totals:	25	1.6	15.8 (max.)

A bore survey carried out north of SH1 on 10 July 2012 found only two bores that could be accessed for sampling. Samples from these bores between July and September 2012 gave median nitrate-N concentrations of 3.6 mg/l at Five Forks and 15.8 mg/l at Maheno. These values are sufficiently high that the river threshold of 0.075 mg/l would be exceeded even if the base-flow contribution was very low at the time.

The difference in nitrate concentration between the two sites stems from the differing degree of groundwater-surface-water interaction. At Five Forks, the degree of river interaction is great, so the river replenishes the groundwater reservoir is on a regular basis. The Maheno site receives very little recharge from the river and most of its recharge is from land-surface infiltration. Consequently, the nitrate concentrations at Maheno are much greater.

The average groundwater-nitrate concentration for the whole Kakanui-Kauru system can be estimated from the median river concentration if a suitable base-flow contribution is assumed. Applying a range of base flows of 5-15% of river flow gives an estimated groundwater concentration of just 0.5 to 1.6 mg/l nitrate-N. Groundwater contribution to the Kakanui River has been gauged as being up to 17% of the flow, and the recession curves suggest it could reach 25%. It follows that the surface-water threshold for NNN of 0.075 mg/l (Biggs, 2000) could be breached with a groundwater concentration of less than 0.4 mg/l.

3.7 Significance to water quality management

The Kakanui-Kauru alluvium contains light, fertile soils that allow the ready passage of soil-water and dissolved nitrate-N. The alluvium also has low relief and is well drained, which makes it suitable for irrigation and intensive grazing systems. Since leaching through the soil profile predominates, nitrate-N is the principal nutrient loss from these grazing systems. The groundwater dissolved nitrate-N enters the Kakanui River by the dynamics described above.

The Waiareka Creek catchment behaves in a different manner, as the 2008 investigation into the North Otago Volcanic Aquifer shows. While the Kakanui-Kauru alluvium has generally thin and low profile available water capacity (PAW), the soils within the Waiareka Creek catchment have distinctly higher PAW (up to 600 mm) and deep profiles (up to 900 mm). Waiareka catchment soils have lower soil drainage rates than Kakanui-Kauru soils (14% versus 35%, respectively). The subsoil substrata in the Waiareka Creek catchment are also less permeable.

The result is that substantially lower nitrate-N bearing soil drainage occurs, but the drainage concentrations are higher than for the Kakanui-Kauru alluvium. The soil-water balance in the Waiareka catchment has a greater degree of surface drainage and overland flow to drains and creeks. Nutrient losses to surface water by overland flow tend to favour phosphorus mobility because phosphorus is normally immobilised in any passage through the soil profile.

4. Kakanui catchment: Assessment of surface-water quality

This section outlines the temporal and spatial pattern of surface-water quality in the Kakanui catchment. In particular, it discusses:

- water quality guidelines
- historical trends in water quality
- water quality in the Kakanui catchment (September 2011 to July 2012).

4.1 Water quality guidelines

Guideline standards were drawn from three sources (Table 4.1). The ANZECC (2000) guidelines are referenced for NH_4, TN and TP, while the biologically available nutrients (DRP and NNN) are referenced against the New Zealand Periphyton Guidelines (Biggs, 2000). The MfE (2002) guidelines are referenced for bacteria.

No New Zealand suspended solid guidelines exist. However, Hay *et al*. (2006) proposed a guideline of 0.75 NTU to minimise adverse effects on trout. The SS guideline of 1.16 mg/l was derived from a regression equation (R^2=0.884), based on turbidity and SS (2001 to 2011) from two sites on the Kakanui River (McCone's and Clifton).

Table 4.1 Physico-chemical and microbiological analytes and guideline values.

Analyte	Unit	Guideline value	Ecological effect
NH_4	mg/l	<0.9*	High levels of ammonia are toxic to aquatic life, especially fish. The level of total ammonia in water should be less than 0.9 mg/l to be safe for fish. Ammonia in waterways comes from any organic source under reducing conditions, but is generally from either waste waters or animal wastes (dung and urine).
TN	mg/l	<0.614*	Encourages the growth of nuisance aquatic plants. These plants can choke waterways and out-compete native species. High levels can be due to runoff and leaching from agricultural land.
NNN	mg/l	<0.075**	The biologically available component of TN, an excess of which may cause nuisance algal growths.
TP	mg/l	<0.033*	Encourages the growth of nuisance aquatic plants, which can choke up waterways and out-compete native species. High levels can be a result of either waste water or, more often, runoff from agricultural land.
DRP	mg/l	<0.006**	The biologically available component of TP, an excess of which may cause nuisance algal growths.
E. coli	cfu Per 100ml	<126*** (^1) <260 (^2)260-550 (^3) <550	*E. coli* bacteria are used to indicate the risk to human health and to stock from drinking water contaminated with harmful micro-organisms (e.g. from human or animal faeces).
SS	mg/l	<1.16^^	Suspended solids (SS) smother larger substrate, reducing available habitat for macroinvertebrates and fish. Nutrients may attach to sediments. High levels may affect clarity and photosynthesis. Foraging range is also affected even when the increases occur at very low levels.

*ANZECC & ARMCANZ (2000), **Biggs (2000) – more than 30 days accrual, ***MfE (2002), ^MfE/ MoH (2003) ^1 = acceptable level, ^2 = alert level, ^3 = action level, ^^ Hay *et al*. (2006): This value is based on taking the 0.75 NTU (turbidity) guideline recommended by Hay (2006), and applying a regression equation, based on turbidity and SS data from the Kakanui River.

4.2 Long-term Kakanui catchment water quality monitoring

The Kakanui (Clifton, McCone's), the Kauru (Ewings) and Waiareka Creek (Taipo Road) are part of the ORC State of the Environment (SOE) monitoring programme.

Guidelines and explanations for good surface-water quality are shown in Table 4.1; briefly, they are set at 0.01, 0.033, 0.444, 0.9, and 0.614 mg/l and 126 cfu/100 ml for DRP, TP, NNN, NH_4, TN (ANZECC 2000) and *E. coli* (ANZECC, 1992), respectively. The New Zealand Periphyton Guidelines (NZPG, 2000) are set at 0.006 and 0.075 mg/l for DRP and NNN, respectively.

In this study, the nutrient results (NNN, TN, DRP, TP, NH_4) from the Kakanui and Kauru rivers exactly reflect the historical situation. The difference in nutrient values between the upstream site (Clifton) and the downstream site (McCone's) is significant, with NNN being nine times higher at McCone's than at Clifton Falls (Table 4.2).

Table 4.2 Summary statistics for nutrients and bacteria at the SOE sites in the Kakanui catchment. Dates vary: 1992 at Clifton Falls and McCone's, 1992 at Ewings (no data 1995 to 2000) and 1999 at Waiareka Creek.

	TN mg/l	NNN mg/l	NH4 mg/l	TP mg/l	DRP mg/l	*E. coli* cfu/100ml
Kakanui Clifton Falls 28/07/92-5/07/12						
No. of samples	84	124	123	117	123	79
Minimum	0.023	0.003	0.005	0.001	0.001	1
Maximum	1.06	0.22	0.04	0.926	0.017	24200
Mean	0.133	0.019	0.009	0.019	0.004	536
Median	0.11	0.012	0.005	0.007	0.003	94
Kakanui at McCone's 28/07/92-5/07/12						
No. of samples	116	153	153	150	153	106
Minimum	0.05	0.003	0.003	0.003	0.001	1
Maximum	0.8	0.691	0.071	0.15	0.021	980
Mean	0.269	0.129	0.01	0.012	0.004	105
Median	0.23	0.09	0.005	0.009	0.003	37
Kauru at Ewings 28/07/92-5/07/12						
No. of samples	52	74	74	73	74	52
Minimum	0.05	0.003	0.005	0.003	0.001	1
Maximum	0.29	0.29	0.06	0.73	0.026	1200
Mean	0.14	0.025	0.008	0.018	0.005	184
Median	0.14	0.013	0.005	0.007	0.003	77
Waiareka Creek 4/08/99-7/08/12						
No. of samples	95	98	98	95	98	95
Minimum	0.39	0.001	0.005	0.018	0.001	2
Maximum	4.65	2	0.85	1.8	1.68	18000
Mean	1.133	0.247	0.052	0.236	0.172	472
Median	0.89	0.056	0.03	0.18	0.122	80

Seasonal Kendall analysis was undertaken for the sites, using data available between 1992 and 2012 (over six seasons, as ORC monitors bi-monthly). The trend test calculates the probability of finding a trend slope at least as big as that measured, or whether a trend existed at all. The result is the p-value. If the p-value is small enough, a statistically significant trend exists. P-values of 0.05 or less are regarded as indicating that a trend is statistically significant at the 95.0% confidence level (i.e. unlikely to be due to chance).

Figure 4.1 shows significant trends in water quality in the Kakanui (1992 to 2012). The significant increasing N in the lower Kakanui is confirmed by this trend analysis. NNN and TN show a significant increase at McCone's. Trend analysis of P (1992 to 2012) indicated a significant increase in DRP in both the upper and lower Kakanui (Clifton Falls and McCone's). NH_4 at McCone's showed a significant decrease over the same period.

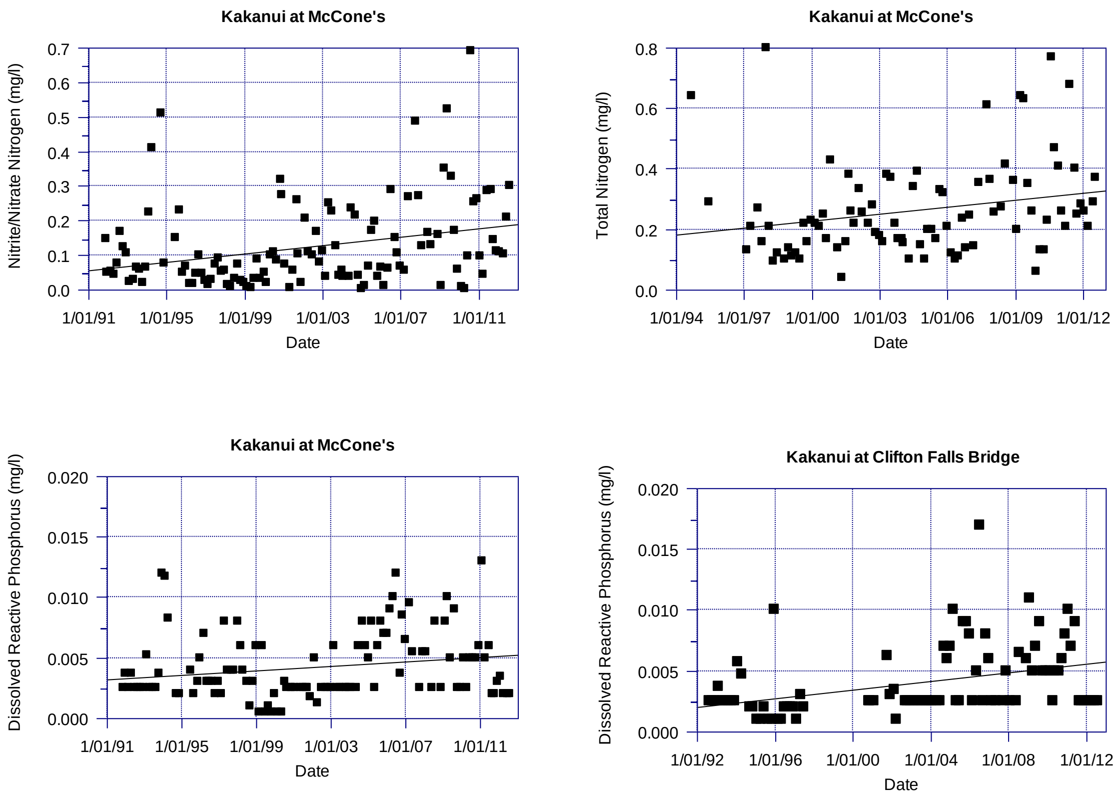

Figure 4.1 Water quality trends (1992 to 2012) in the Kakanui at Clifton Falls and McCone's.

Figure 4.2 shows that changes in water quality in Waiareka Creek began to appear at about the same time (2007) as land-use intensification. In Waiareka Creek, a significant increase in NNN occurred between 1999 and 2012. Figure 4.2 shows that this is due to rapidly increasing concentrations of NNN after about 2006. Waiareka Creek has also seen a significant upward trend in DRP (1999 to 2012), although trend analysis (2006 to 2012) shows that this upward trend has not continued. Waiareka Creek has seen a significant decrease in NH_4 (1999 to 2012). Trend analysis of *E. coli* from 2001 to 2011 indicated a significant decrease in *E. coli* in the Kauru at Ewings.

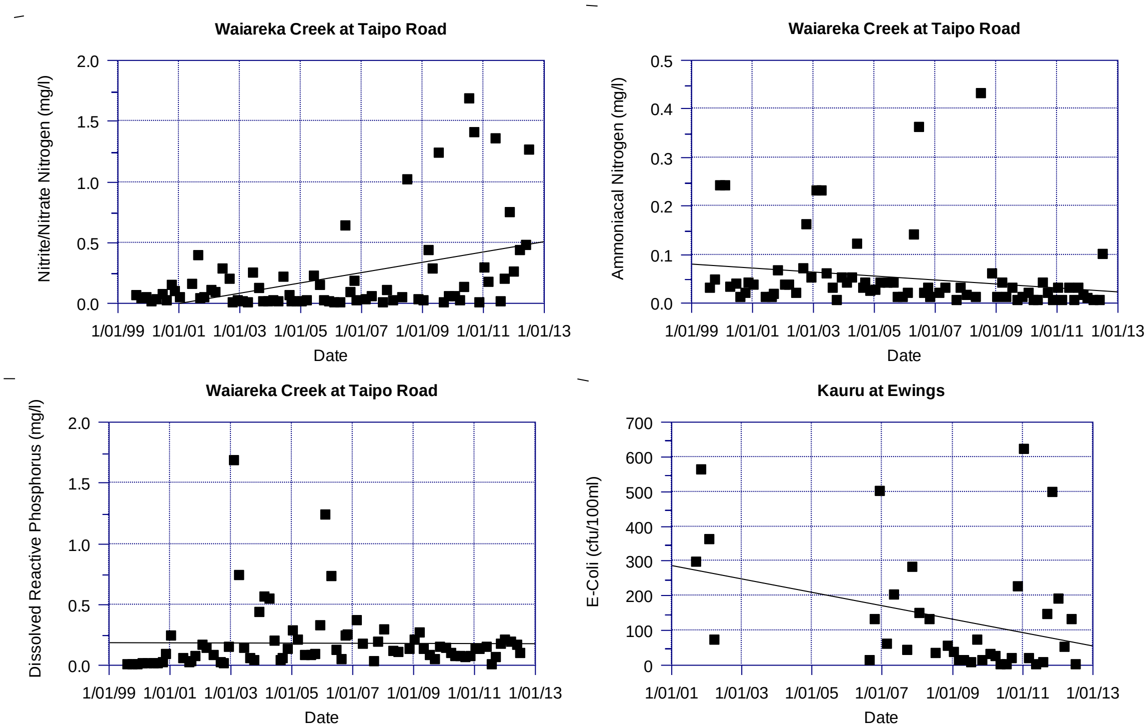

Figure 4.2 Water quality trends in Waiareka Creek (1999 to 2012) and the Kauru (2001 to 2012).

4.3 Water quality (September 2011 to July 2012)

This section provides an assessment of the water quality monitoring undertaken during the 11 months of this study. The results from the monitoring at the three SOE sites - Kakanui River (Clifton Falls and McCone's) and Waiareka Creek (Taipo Road) - are compared to the long-term SOE monitoring data.

Eleven sites were sampled fortnightly, on the same day, between September 2011 and July 2012. The sites included three sites on the main-stem Kakanui River, three sites on the Kauru River, two sites on Island Stream and three sites on Waiareka Creek. These sites are shown in Figure 2.1.

At each river site, water samples were collected for analysis. Analytes included total phosphorus (TP), total nitrogen (TN), nitrite-nitrate-nitrogen (NNN), ammoniacal nitrogen (NH_4), dissolved reactive phosphorus (DRP), *Escherichia coli* (*E. coli*) and SS.

Continuous flow was monitored at all sites, except Waiareka Creek at Kia-Ora, where a virtual flow measurement was substituted. Water quality data were flow adjusted, as most of the variables affecting water quality are correlated with flow, either positively or negatively. In catchments dominated by diffuse source pollution (rather than point source pollution), pollutants (like total phosphorus or *E. coli*) are generally positively correlated with flow, and concentrations increase in high flows because of runoff from land during wet weather or mobilisation from in-channel stores.

Throughout this section each graph has two bars. The darker column shows the median value for all data (regardless of flow conditions), and the lighter column represents times of lower flow (i.e. when the river has its highest recreational use, such as fishing and swimming). Throughout this report, the term 'lower flow' refers to 'below median flows'.

4.4 Nutrients

Nitrogen and phosphorus are essential nutrients for the growth of aquatic plants and algae, which are an important part of any healthy stream ecosystem. However, excessive concentrations of these nutrients can lead to proliferations of algae and macrophtyes, which may compromise a range of instream values, such as amenity, native fish conservation and recreation (Biggs, 2000).

In New Zealand, two national guidelines are commonly used to assess nutrient concentrations:

1. The *New Zealand Periphyton guidelines* (Biggs, 2000) provide a range of suggested thresholds that are related to flow conditions for the dissolved nitrogen and phosphorus concentrations required to control periphyton growth. (High-flow events tend to scour out periphyton growth.) The guideline values relevant to the Kakanui catchment are 0.075 mg/l soluble inorganic nitrogen (NNN) and 0.006 mg/l DRP; these values relate to '30 mean days of accrual'.

2. The *ANZECC guidelines* (ANZECC, 2000) provide default trigger values for total and dissolved nitrogen and phosphorus for assessing the risk of adverse effects in slightly disturbed ecosystems. These trigger values are based on the 80th percentile of a distribution of reference data and have the following values for lowland rivers: 0.614 mg/l for TN and 0.033 mg/l for TP.

The concentrations at which nitrogen or phosphorus start to have an adverse effect on ecosystem health or amenity values vary from site to site and catchment to catchment. For example, a stream with primarily muddy substrate may be more resistant to nuisance blooms than a rock or cobble-bottomed stream (given similar concentrations of nutrients) (MfE, 2009).

The extent and opportunity for plant growth depends largely on the time of year. Below median flow is used to represent the growing season because flows below median flow usually occur during the summer months and coincide with the best growing conditions for periphyton.

The two main nutrients available for plant growth are NNN and DRP.

4.4.1 Total nitrogen (TN)

All organisms need nitrogen for the basic processes of life: to make proteins, grow and reproduce. Nitrogen is very common and found in many forms. Inorganic forms include nitrate (NO_3), nitrite (NO_2), ammonia (NH_4^+ and NH_3) and nitrogen gas (N_2). Organic nitrogen is found in the cells of all living things and is a component of proteins, peptides and amino acids. TN is affected by wastewater effluent, agricultural runoff, animal waste, fossil fuels and industrial discharges (MfE, 2009).

Figure 4.3 shows that TN concentrations followed similar patterns to NNN, with a significant increase in TN between Clifton Falls and Mill Dam. The only sites to exceed the ANZECC guideline (Figure 4.3) were Waiareka Creek (all sites), Island Stream (Maheno) and Fuchsia Creek.

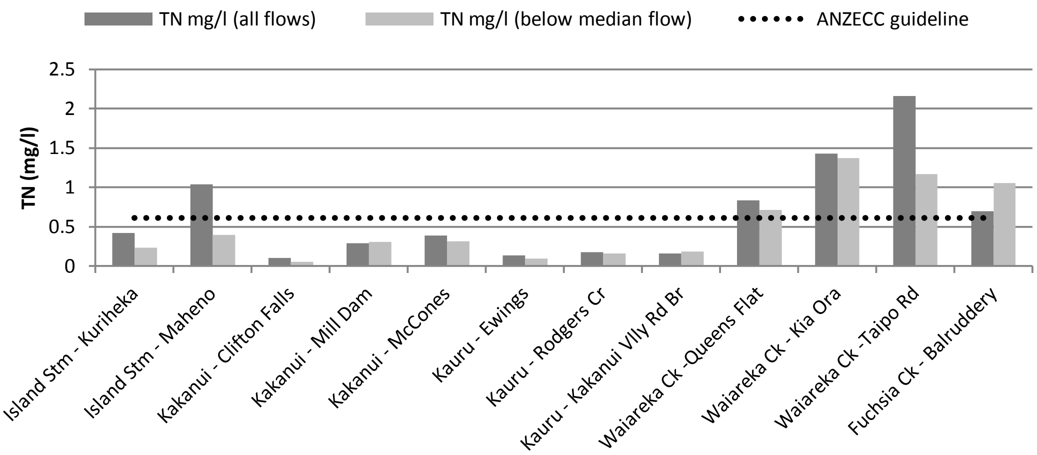

Figure 4.3 Median total nitrogen concentration at each river site over the sampling period.

4.4.2 Total phosphorus (TP)

TP is a measure of all the forms of phosphorus, dissolved or particulate, found in a sample. Phosphorus is a natural element found in rocks, soils and organic material as it clings tightly to soil particles. TP is affected by waste-water effluent, fertilisers, animal waste, urban development and industrial discharges (MfE, 2009).

The ANZECC (2000) trigger value for TP is 0.033 mg/l. Figure 4.4 shows that at all flows, TP concentrations were below the guideline level at Island Stream (Kuriheka), Kakanui (all sites) and the Kauru (Rodger's Crossing and Kakanui Valley Road). At lower flows, the median concentration at Island Stream (Maheno) dropped below the guideline level (Figure 4.4). The Waiareka Creek sites stand out as having the highest TP concentrations. The lighter riparian gravels in the Kakanui allow indirect infiltration, hence the lower P concentrations; whereas the heavier soils of Waiareka Creek are more conducive to direct effluent runoff, hence the higher P concentration.

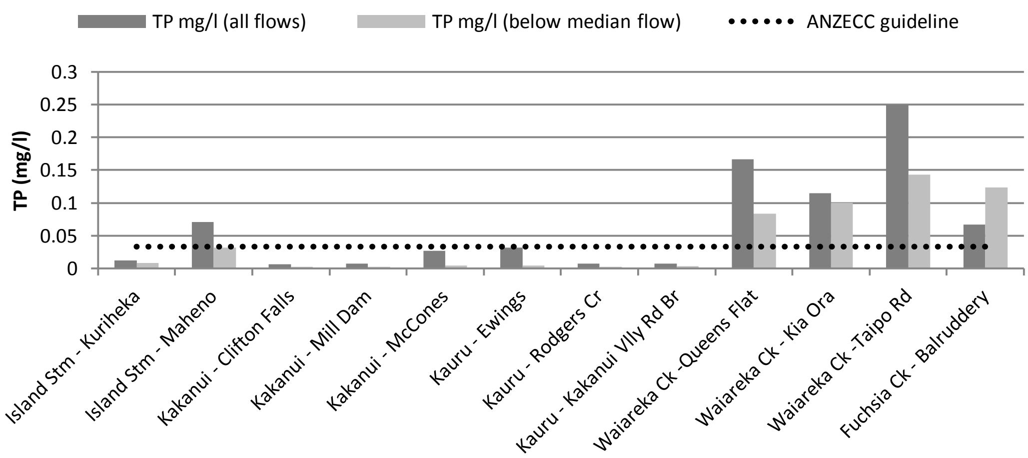

Figure 4.4 **Median total phosphorus concentration at each river site over the sampling period.**

4.4.3 Nitrite-nitrate-nitrogen (NNN)

NNN is the nitrogen available for plant growth and is beneficial up to a point, but may easily become a nuisance. NNN is by far the most common bioavailable form of N in surface waters and better reflects bioavailability than TN. NNN is affected by waste-water effluent, agricultural runoff, animal waste, fossil fuels and industrial discharges.

In the Kakanui catchment, the New Zealand Periphyton Guideline value for soluble inorganic nitrogen[2] is 0.075 mg/l (shown in Figure 4.5 as the dotted line). The Kakanui (Clifton) and the Kauru (all sites) have little available NNN (Figure 4.5), with median values below the New Zealand Periphyton Guideline level. At lower flows, NNN increases relative to all flows at the Kakanui sites and the Kauru (Rodger's Crossing and Kakanui Valley Road Bridge).

The lower Kakanui sites (Mill Dam and McCone's) and the two lower Kauru sites (Rodger's Crossing and Kakanui Valley Road Bridge) show a significant increase in NNN compared to their upper catchment sites. This is a result of groundwater contribution to flow, coupled with N leaching from effluent and urine patches, which is common in irrigated landscapes. Waiareka Creek has high NNN concentrations compared to the rest of the catchment.

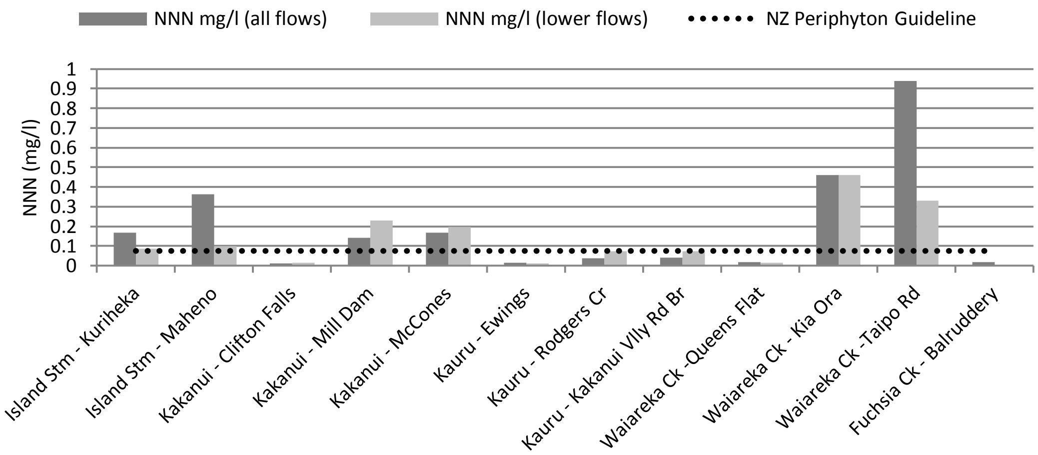

Figure 4.5 Median nitrite-nitrate-nitrogen concentration at each river site over the sampling period.

[2] NNN has been substituted for SIN, due to the ammoniacal nitrogen content being negligible.

4.4.4 Dissolved reactive phosphorus (DRP)

DRP is a measure of orthophosphate, the filterable (soluble, inorganic) fraction of phosphorus, which is directly taken up by plant cells. Phosphorus is often found to be the growth-limiting nutrient, because it occurs in the least amount relative to the needs of plants. DRP is affected by waste-water effluent, fertilisers, animal waste, urban development and industrial discharges (MfE, 2009).

In the Kakanui catchment, the New Zealand Periphyton Guideline value for DRP is 0.006 mg/l. The DRP levels were generally below this guideline level (Figure 4.6). However, Waiareka Creek (all sites), Island Stream (Maheno) and Fuchsia Creek exceeded the New Zealand Periphyton Guideline concentration at both all flows and low flows (Figure 4.6).

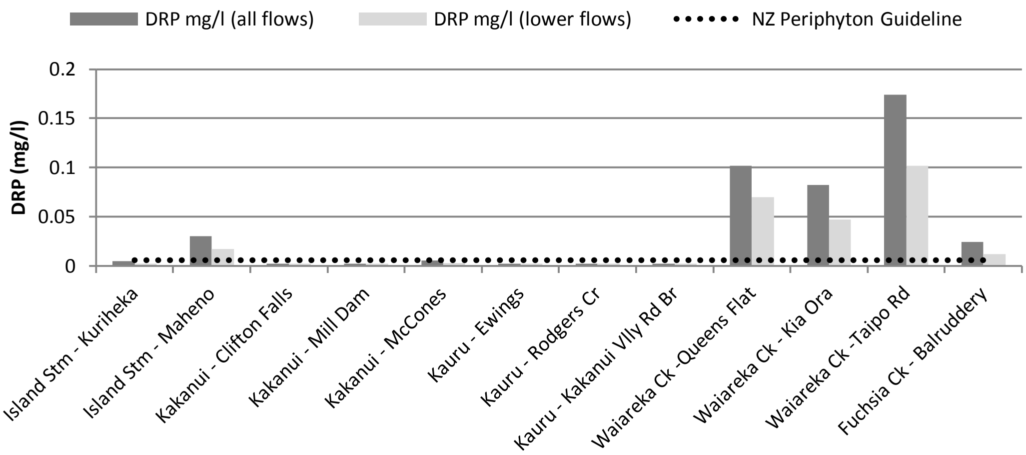

Figure 4.6 Median dissolved reactive phosphorus concentration at each river site over the sampling period.

4.4.5 Nitrogen: phosphorus ratio

The excessive growth of algae or macrophytes is only possible if nutrients - particularly NNN and DRP, which are biologically available for plant uptake - are available. If one of these nutrients is in low supply (limiting nutrient), then plant growth is restricted. Adding a limiting nutrient will stimulate plant growth more than adding any other element.

If either of the guidelines for nitrogen or phosphorus is exceeded, algal proliferation does not necessarily follow. Given sufficient light, suitable water temperatures and substrate conditions, the extent to which nutrient concentrations will lead to nuisance plant growth is controlled largely by the relative abundance of dissolved nitrogen to phosphorus (i.e. the soluble inorganic nitrogen (SIN):DRP ratio (MfE, 2007)).

Redfield *et al.* (1963) published data that indicated a molar ratio of N, and P of 16:1 was reasonably constant during phytoplankton growth. If considerably more than 16 moles of N are present for each mole of P, then growth is predicted to be P-limited, and if considerably less than 16 moles of N are present for each mole of P, growth is predicted to be N-limited. On a mass basis (mg/l), the Redfield N: P ratio is 7:1. In this study, an N:P ratio of <7:1 for N-limitation and >15:1 for P-limitation (mass basis) has been used (McDowell, 2009). These ratios have also been used by MfE (2007).

Figure 4.7 shows the NNN:DRP ratio for each site. Kakanui (Clifton), Kauru (Ewings), Waiareka Creek (all sites) and Fushia Creek were N-limited. Sites with P-limitation include Island Stream (Kuriheka), Kakanui (Mill Dam, McCone's), Kauru (Rodger's Crossing and Kakanui Valley Road Bridge). There is a an obvious difference between the upper Kakanui (Clifton) and the two lower sites (Mill Dam and McCone's), which suggests that nutrients, particularly N, are being added with base flow from groundwater. (P has low mobility under oxidised groundwater and soil conditions.)

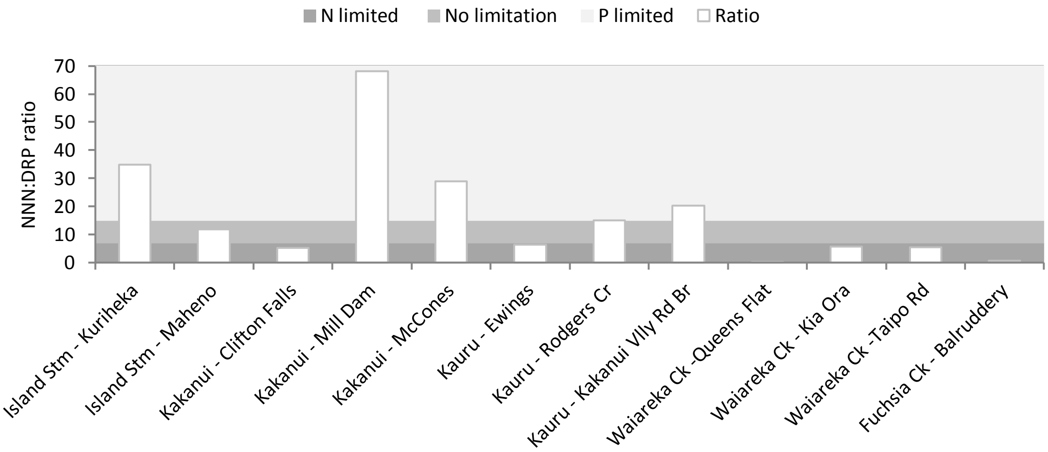

Figure 4.7 NNN:DRP ratio. The dark grey area indicates possible N-limitation, and the light grey area indicates possible P-limitation.

So that this can be examined more closely, the NNN:DRP ratio for the Kakanui sites (every sampling occasion) are shown in Figure 4.8. The upstream site at Clifton Falls generally tends towards being N-limited. However, moving downstream, at the Mill Dam and McCone's sites, the situation changes dramatically, with all results showing P-limitation, the ratio being considerably more than 15:1.

At the downstream site (McCone's), and to a lesser extent, Mill Dam, the tendency towards N-limitation occurred seasonally, during summer. McCone's had excessive algae growth during summer, and the presence of the algae probably influenced the NNN:DRP ratio by removing N from the river.

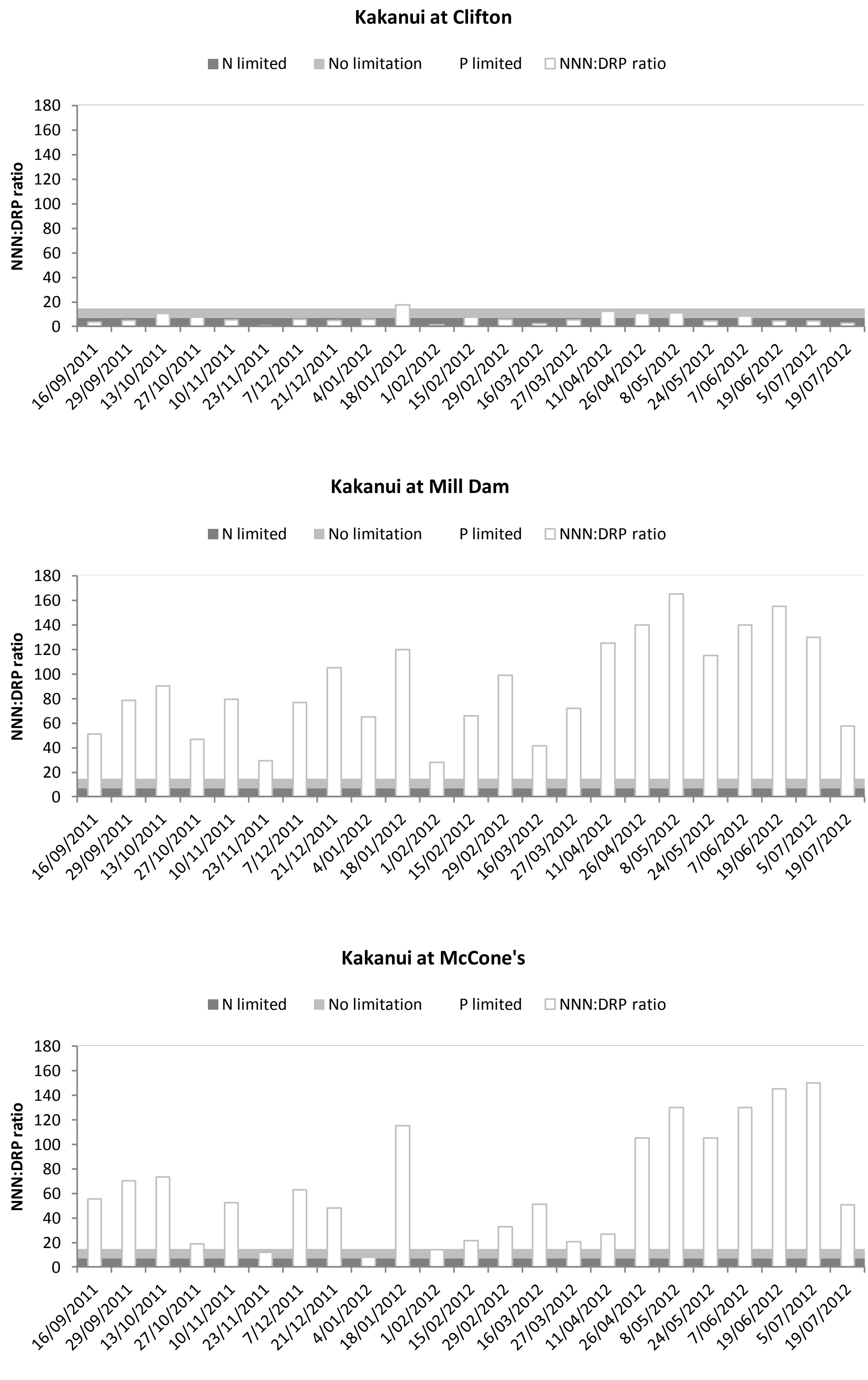

Figure 4.8 NNN:DRP ratio. The dark grey area indicates possible N-limitation, and the white area indicates possible P-limitation.

4.4.6 Ammoniacal nitrogen (NH4)

Ammoniacal nitrogen can, at sufficiently high concentrations, be toxic to fish and other aquatic life. In farmed catchments, elevated concentrations are generally due to direct discharges of effluent, paddock runoff or stock access to streams. High concentrations are most likely to occur when stream flows are low, and when cattle use streams for drinking water.

Ammonia is found in water in two forms: ammonium ion (NH_4^+) and dissolved, unionised (no electrical charge) ammonia gas (NH_3). Total ammonia is the sum of ammonium and unionised ammonia. The dominant form depends on the pH and temperature of the water. The form of ammonia changes easily when pH changes. As pH increases, H^+ concentration decreases, and OH^- concentrations increase, which increases the amount of aqueous NH_3. When the pH is below 8.75, NH_4^+ predominates. At pH 9.24, about half of aqueous NH_3 is transformed to NH_4^+. Above pH 9.75, NH_3 predominates. Unionised ammonia (NH_3) is much more toxic to aquatic organisms than the ammonium ion (NH_4^+).

ANZECC recommends adopting a trigger value of 0.9 mg/l NH_4 for pH 8 and 20°C to adequately protect 95% of species. NH_4 was the only parameter that did not exceed guideline levels (0.9 mg/l) at any of the river sites (Figure 4.9). The highest values were found in Island Stream at Maheno and Waiareka Creek at Taipo Road.

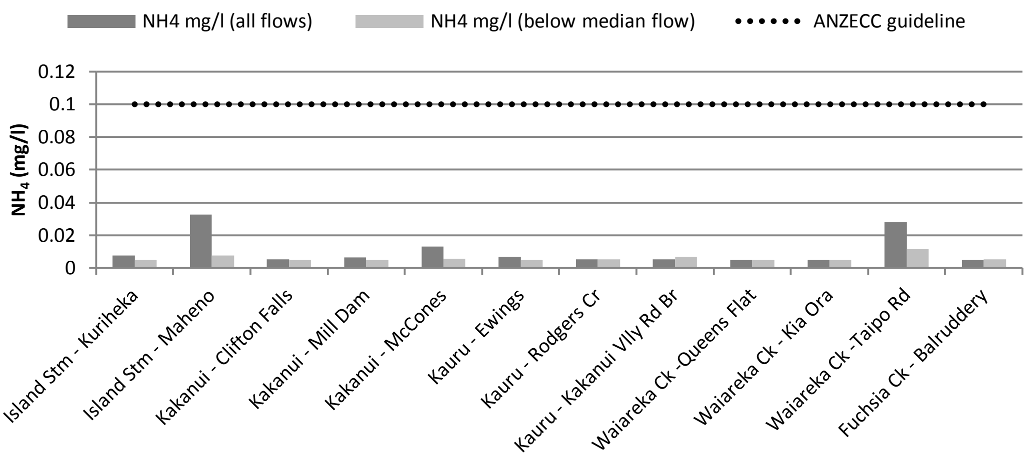

Figure 4.9 Median ammoniacal nitrogen concentration at each river site over the sampling period.

4.5 Faecal contaminants

Faecal contamination of waterways poses a public health risk. Illness may be contracted as a result of ingesting (including eating fish and shellfish) water containing bacterial, viral and protozoal pathogens that occur in faecal material. Faecal material reaches streams in numerous ways, including runoff from the land, effluent-pond discharges (e.g. Smith *et al.*, 1993), stock and water fowl defecating directly into the water (e.g. Davies-Colley *et al*., 2004), overland runoff after rain and septic-tank discharges.

The indicator commonly used to assess this risk is *E. coli*, a faecal coliform bacterium that originates in the gut of warm-blooded animals and indicates the presence of other potentially harmful microbes. Pathogens are typically present in such small amounts that it is impractical to monitor them directly (MfE, 2009).

Several reference values and guidelines are used for interpreting *E. coli* data (Table 4.1). ANZECC 1992 guidelines recommend a season median of 126 *E. coli*/100 ml. Figure 4.10 shows that *E. coli* concentrations are generally above the guideline at all flows, but at below median flow, only Kakanui (Mill Dam), Waiareka Creek (Taipo) and Fuchsia Creek are significantly elevated.

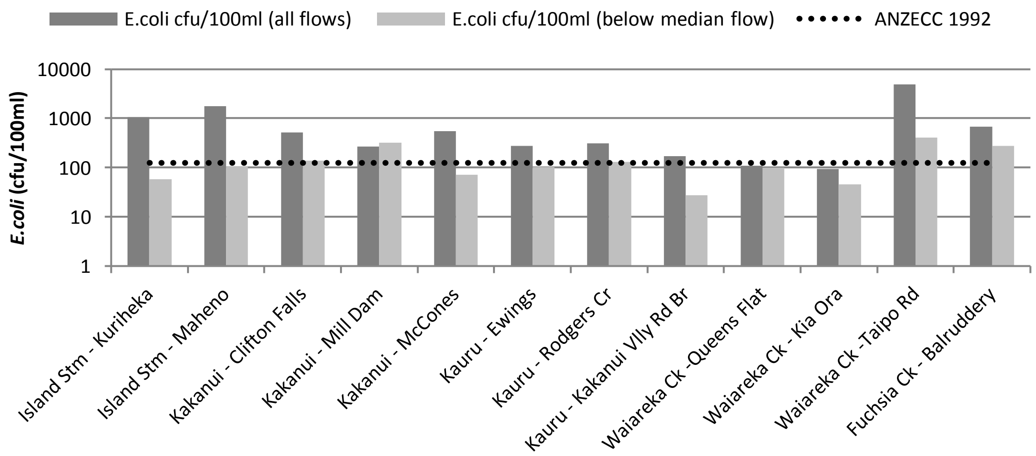

Figure 4.10 Median *E. coli* concentration at each river site over the sampling period.

4.6 Sediments and visual quality

SS and turbidity are important indicators of aquatic habitat and visual quality and affect human values such as fishing, swimming and amenity. If concentrations of SS are too high for prolonged periods, there may not be enough light for species to navigate and feed effectively, and juvenile recruitment or passage of fish into catchments may be limited (Richardson and Jowett, 2001). As fine sediments settle out of the water column, benthic habitats may be smothered (MfE, 2009).

High SS concentrations are commonly associated with higher flows and are also naturally elevated in catchments with soft (erosion-prone) geology or sandy-bottomed streams. However, high SS and turbidity (which generally result in low visual clarity (ANZECC, 2000)) may also indicate stream bank and paddock erosion associated with poor land management (MfE, 2009).

In this study, turbidity was not measured, and therefore the 0.75NTU guideline (Hay, 2006) could not be applied directly. The SS guideline of 1.16 mg/l was derived from a regression equation, based on turbidity and SS (2001 to 2011) from two sites on the Kakanui River (McCone's and Clifton). The SS value equivalent to 0.75NTU should become the SS guideline.

The problem is that the laboratory level of detection is 3.0 mg/l. Samples at this level are routinely expressed as 1.5 mg/l (i.e. the level of detection divided by 2), which is still above the guideline limit of 1.16 mg/l. With a guideline level so low, it is unclear whether it is met when many of the sites have a median value of 1.5 mg/l. (Figure 4.11).

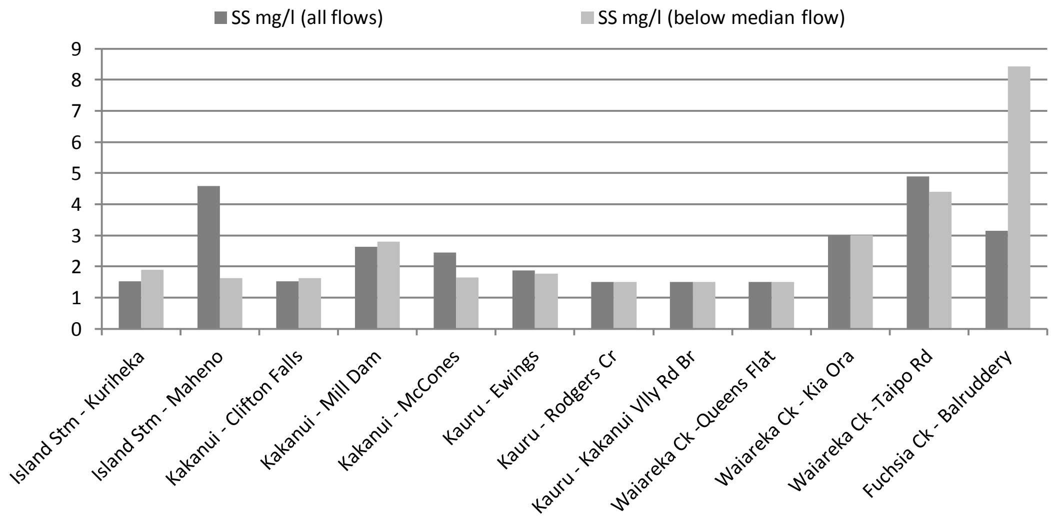

Figure 4.11 Median suspended solid concentration at each river site over the sampling period.

5. Algae

This section provides an assessment of algae and includes:

- algal community composition (all sites)
- chlorophyll *a* concentrations at three sites (Clifton, Gemmells, McCone's)
- accrual periods to determine the frequency and duration of algal proliferations
- algal biomass and nutrient concentrations.

5.1 Algal community composition

Algal samples were collected at ten sites in January 2012 (Waiareka at Queen's Flat not sampled), with one composite sample collected from each site. Algal samples were collected by selecting three stones at each site, taken from one quarter, one half and three quarters of the stream width. At each collection point, a stone was randomly selected and removed to the river bank. A 25 cm^2 area of each stone surface was scrubbed into a tray, using a small brush, and rinsed with river water. The scrubbings from the three stones were pooled and transferred to a sample container using river water. The sample was transported to the laboratory and preserved in formaldehyde.

In the laboratory, each sample was mixed thoroughly. Three aliquots were removed to an inverted microscope settling chamber and allowed to settle for 10 minutes. Samples were analysed according to the 'relative abundance using an inverted microscope' method outlined in Biggs and Kilroy (2000). Samples were inspected under 200-400x magnification to identify algal species present, using the keys of Biggs and Kilroy (2000), Entwisle *et al*. (1988) and Moore (2000). Algae were given an abundance score ranging from 1 (rare) to 8 (dominant), based on the protocol of Biggs and Kilroy (2000). Internal quality assurance procedures were followed.

The relative abundance of taxa was determined on subsamples. Algae were given an abundance score ranging from 1 (rare), 2 (rare-occasional), 3 (occasional), 4 (occasional, common), 5 (common), 6 (common abundant), 7 (abundant) to 8 (dominant), based on the protocol of Biggs and Kilroy (2000).

Algal community composition at Clifton Falls is shown in Appendix 2. Filamentous green algae were rare until February. Filamentous red algae were dominant in September, but did not reappear. The diatoms were dominated by *Didymosphenia geminata,* although plenty of other species of diatom were present.

Algal community composition at Gemmells Crossing, Clifton Falls, is shown in Appendix 2. *D. geminata* dominated the algal community throughout the summer period.

Algal community composition at McCone's is shown in Appendix 2. Filamentous green algae were much more common than at the other sites, although not abundant. Again *D. geminata* dominated the algal community throughout the summer period.

5.2 Chlorophyll a analysis

Algal samples were collected on a monthly basis (October to February) from riffles at three sites (Clifton, Gemmells and McCone's).

Algal samples were collected by selecting five stones at each site, taken at equal distances across the stream width. At each collection point, a stone was randomly selected and removed to the river bank. A 50 mm diameter circle of each stone surface was scrubbed into a tray, using a small brush, and rinsed with river water. The scrubbings from the five stones were pooled and transferred to a sample container using river water. The sample was then frozen.

In the laboratory, each sample was tipped into a glass beaker and blended for about 30 seconds or until the mixture was free of obvious clumps of material. The blended liquid was then made up to a known volume (e.g. 100 ml). The total amount of chlorophyll *a* was calculated using a standard formula (Biggs and Kilroy, 2000) and scaled to the number of milligrams of chlorophyll *a* per m^2 of streambed.

It should be noted that the abundance of *Didymomosphenia geminata* may contribute significantly to the chlorophyll *a* concentration found in the Kakanui River. The results for the three Kakanui River sites that were sampled monthly are shown in Table 5.1. On four of the five sampling occasions, McCone's had the highest concentration of chlorophyll *a*. Figure 5.1 shows photos of algae at the three sites. McCone's has more algae than Gemmells or Clifton.

Figure 5.1 Algae at (a) Clifton Falls, (b) Gemmells Crossing and (c) McCone's on 3 November 2011.

The monthly chlorophyll *a* results for Clifton Falls and McCone's are shown in Table 5.1. Clifton Falls exceeds 60 mg/m^2 chlorophyll *a* on one sampling occasion, while McCone's exceeds 60 mg/m^2 chlorophyll *a* on two occasions and 200 mg/m^2 chlorophyll *a* on one occasion. Dodds *et al.* (1998) suggested that the transition from oligotrophic to mesotrophic streams occurs when chlorophyll *a* biomass exceeds 60 mg/m^2, and the transition from mesotrophic to eutrophic streams occurs when biomass exceeds 200 mg/m^2. Biggs (2000) proposed a guideline of 50 mg/m^2 chlorophyll a to protect benthic biodiversity and 200 mg/m^2 chlorophyll to protect trout habitat and angling.

Table 5.1 Monthly chlorophyll *a* results. Highlighted cells show when concentrations of 60 and 200 chlorophyll *a* (mg/m²) have been exceeded. ANOVA - *P* is the probability statistic of a one-way ANOVA to determine whether the mean monthly chlorophyll *a* at the sites is significantly different at the 95% confidence interval.

Date	Clifton	Gemmells	McCone's	ANOVA-*P* (2df)
29/09/2011	3.5	23.6	217.1	
3/11/2011	0.4	3.1	78.9	
9/12/2011	27	7.1	33.8	
11/01/2011	70.4	14.5	49.5	
9/02/2011	12.1	15.4	81.9	
Mean chlorophyll *a* (mg/m^2)	22.68	12.74	92.24	≤0.05

To test whether there was a statistically significant difference in mean chlorophyll *a* concentrations between sites, analysis was carried out after transforming the raw data into natural logarithms to correct for a non-normal distribution in the data, as required by the ANOVA test. The results are shown in Table 5.1.

There was a statistically significant difference in mean chlorophyll *a* in the riffles.
The maximum chlorophyll *a* was found at McCone's. At this site, the mean value exceeded the 60 mg/m^2 proliferation criteria for chlorophyll *a*. (Note that this criterion was set before *Didymosphenia geminata* arrived in New Zealand.)

5.3 Accrual periods

The frequency and duration of algal proliferations in streams rely, in part, on the hydrologic regime of the stream. The Kakanui generally has extended periods of low flow in the summer, due to natural low flows exacerbated by water extraction for irrigation. Mean days of accrual were determined as the average time between flood events >3x the median flow.

Flow data and chlorophyll *a* concentrations at Clifton Falls and McCone's are shown in Figure 5.2.

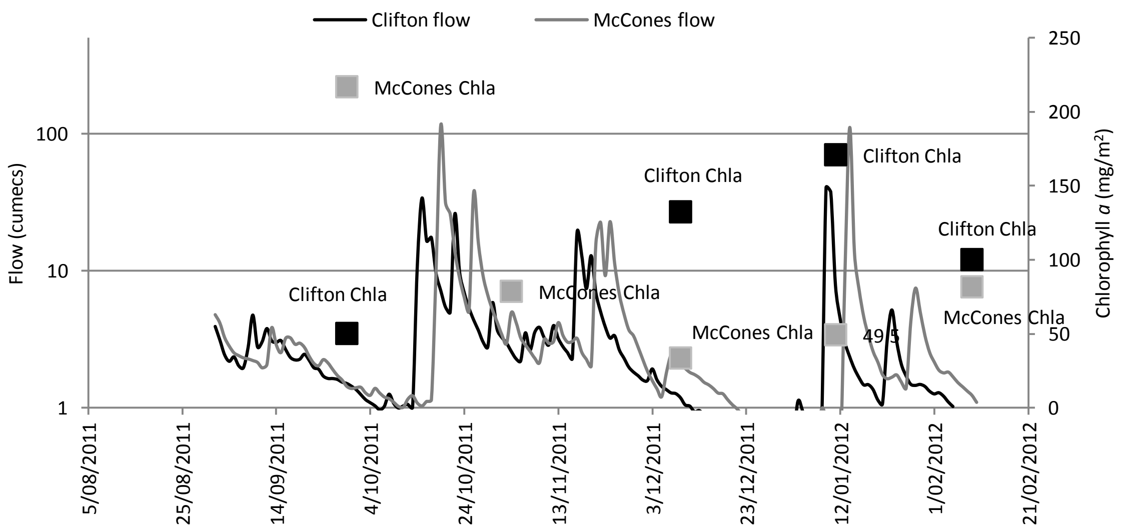

Figure 5.2 Chlorophyll *a* (mg/m²) concentrations (dark grey squares Clifton, light grey squares McCone's) and flow (cumecs).

Linking periphyton biomass to stream nutrient concentrations is very difficult. The accrual days affect which nutrient guideline to use (as proposed in the New Zealand Periphyton Guideline (MfE, 2003) (Table 5.2)). The longer the accrual period, the more likely the build up of periphyton and therefore the lower the nutrient concentration guideline. However, Biggs (2000) does not define a method for setting a time interval or 'filter period' between flood peaks for which the 'flood' is assumed to be a single event.

The filter period has been applied variously as a 5-day interval (Snelder *et al.*, 2004) and a 10-day interval (Snelder *et al.*, 2005) (i.e. removing events <5 and <10 days from the accrual period).

Table 5.2 Nutrient concentration suggested to prevent maximum chlorophyll *a* concentrations in N-imited stream communities in New Zealand (Biggs, 2000).

Days of Accrual	SIN (soluble inorganic N) mg/l	SRP (soluble reactive P) mg/l
20	0.295	0.026
30	0.075	0.006
40	0.034	<0.0028

In this report, the entire data record has been used to define accrual periods. Table 5.3 shows the results when applying a 5-day filter, and
Table 5.4 shows the results for when no filter is applied. A 5-day filter returns longer accrual periods than using a 0-d filter.

Using the data with a 5-day filter and a 0-day filter gives very different outcomes (accrual days), as seen in Table 5.3 and Table 5.4. In both accrual periods, the response at McCone's is less than that at Clifton, which is a reflection of responses only occurring at McCone's when the alluvial gravels are saturated.

Table 5.3 Accrual days in the period (all record 10/4/81 to 11/6/12) with a 5-day filter.

Catchment	Time period	Mean	Median	Upper quartile	Events/year
Kakanui Clifton	10/4/81 to 11/6/12	36.8	26	45.0	4.6
Kakanui McCone's	18/1/03 to 11/6/12	29.2	22	25	4.8

Table 5.4 Accrual days in the period (all record 10/4/81 to 11/6/12) with a 0-day filter.

Catchment	Time period	Mean	Median	Upper quartile	Events/year
Kakanui Clifton	10/4/81 to 11/6/12	26.7	13	35.8	6.6
Kakanui McCone's	18/1/03 to 11/6/12	21.4	11	26	6.7

There is a shift from a 20-day accrual to a 30-day accrual when a filter is applied, which changes the suggested nutrient limits. However, the shift is minimal, and in these instances, common sense and local knowledge need to be used.

5.4 Algal biomass and nutrients

Nutrients are also important in influencing the accrual of algal biomass. Biomass levels >150-200 mg/m^2 chlorophyll *a* are very conspicuous in streams and can compromise the use of rivers (Biggs, 2000). Various studies have been undertaken to determine the concentration of nutrients at which algal biomass exceeds 200 mg/m^2 chlorophyll *a.* Horner *et al.* (1990) concluded that the concentrations were >0.003 mg/l DRP after 17 days, and Walton (1990) concluded that the concentration was 0.005 mg/l DRP after 21 days. Biggs (2000) concluded that to prevent maximum biomass from exceeding 200 mg/m^2 chlorophyll *a* in streams with accrual periods of >30 d, mean monthly dissolved nutrient concentrations must be quite low (e.g. 0.075 mg/l NNN and 0.006 mg/l DRP).

The concentration of NNN at Clifton Falls and McCone's is shown in Figure 5.3. Between September and March (prime algae growth season), McCone's recorded concentrations of NNN in exceedence of 0.075 mg/l on every occasion bar one, but at Clifton Falls, all sites were well below this concentration.

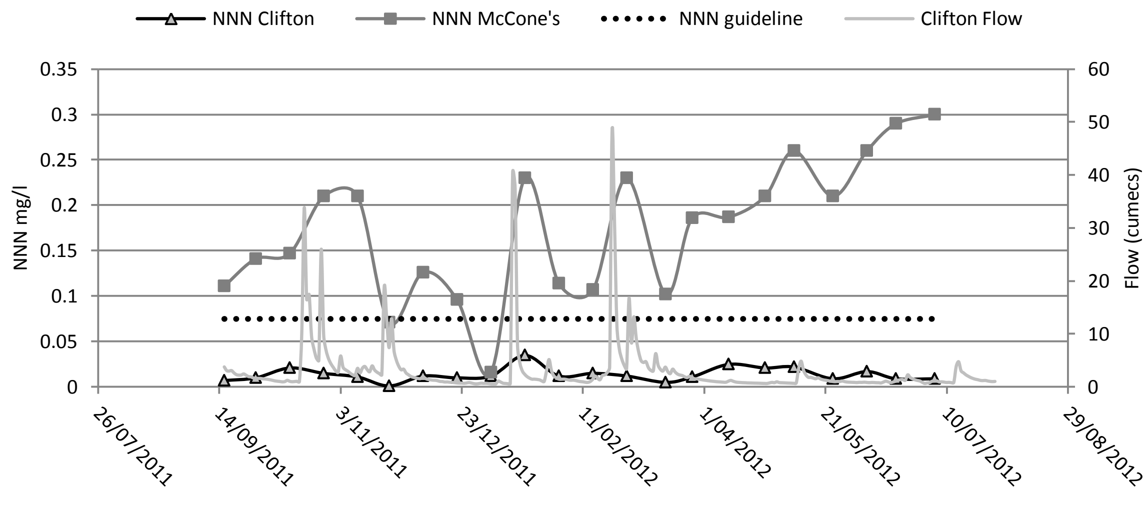

Figure 5.3 Nitrite-nitrate-nitrogen at Clifton Falls and McCone's, and flow at Clifton.

Figure 5.3 also shows the flow at Clifton Falls over the duration of this study. At higher flows (particularly the flow events of 19/10/11, 21/11/11, 13/1/12 and 23/2/12), NNN becomes elevated (compared to guidelines), which is a consequence of nutrient-rich groundwater input.

The seasonal effect of NNN can also be seen in Figure 5.3. During winter, plants take up less N, both on the land (pasture) and in the river (algae); consequently, the NNN concentration is higher during this period.

Figure 5.4 shows the concentration of NNN when chlorophyll *a* samples were taken. McCone's recorded concentrations of NNN in excess of 0.075 mg/l on four of five occasions. On two of these occasions, chlorophyll *a* exceeded 60 mg/m^2, and on another occasion, chlorophyll *a* exceeded 200 mg/m^2. Although Clifton Falls did not exceed the NNN guideline, on one occasion chlorophyll *a* exceeded 60 mg/m^2.

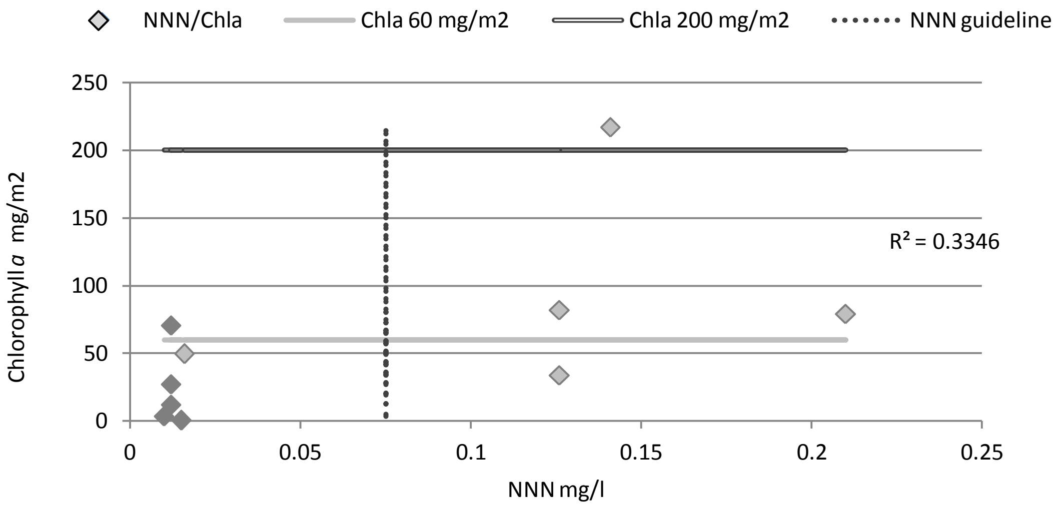

Figure 5.4 **NNN (mg/l) and chlorophyll a (mg/m2) at Clifton Falls (dark grey) and McCone's (light grey). The dark grey line denotes 200 mg/m2 chlorophyll a, and the light grey line denotes 60 mg/m2 chlorophyll a (Dodds et al., 1998).**

Figure 5.5 shows the concentration of DRP when chlorophyll *a* samples were taken. On these sampling occasions, the DRP guideline was not exceeded; the highest concentration of DRP recorded was 0.005 mg/l at McCone's. However, the chlorophyll *a* guideline of 60 mg/m^2 was exceeded on four occasions: once at Clifton Falls and three times at McCone's. On one of the occasions at McCone's, the chlorophyll *a* guideline of 200 mg/m^2 was breached.

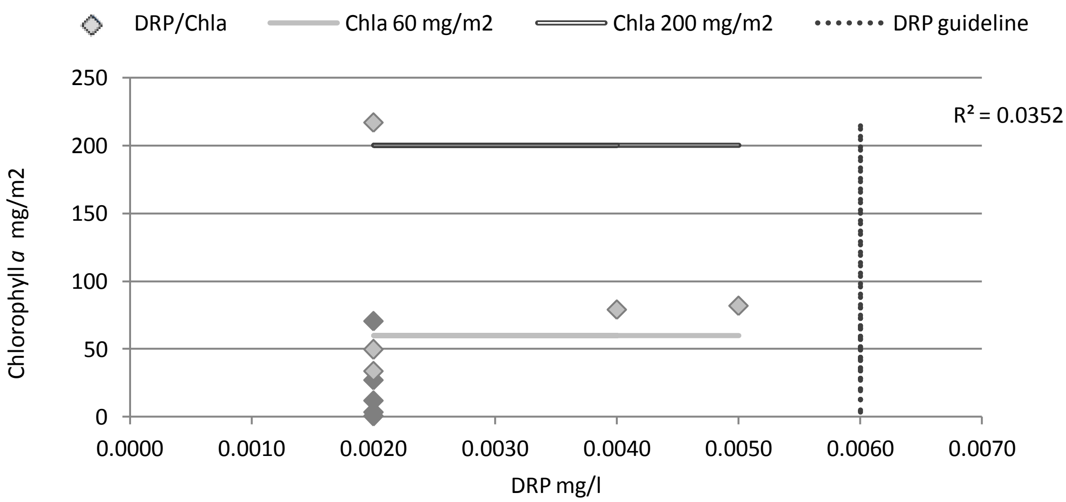

Figure 5.5 **DRP (mg/l) and chlorophyll *a* (mg/m²) at Clifton Falls (dark grey) and McCone's (light grey). The dark grey line denotes 200 mg/m² chlorophyll *a*, and the light grey line exceeds 60 mg/m² chlorophyll *a* (Dodds *et al.*, 1998).**

The concentrations of NNN, DRP and chlorophyll *a* were calculated as means over the summer period (September to March). The results are shown in Table 5.5. The mean concentration of NNN at McCone's is more than that recommended by Biggs (2000) to prevent biomass from exceeding 200 mg/m^2 chlorophyll *a.*

Table 5.5 Mean concentration of NNN and DRP at Clifton Falls and McCone's over the period September to March.

	Nitrite/nitrate nitrogen (mg/l)	Dissolved reactive phosphorus (mg/l)	Accrual 5d	Accrual 0d
Guideline concentration 30-days accrual	0.075	0.006		
Kakanui at Clifton Falls	0.0121	0.0023	35.4	26.0
Kakanui at McCone's	0.1374	0.0043	30.0	22.9

6. Kakanui catchment: Assessment of stream habitat and instream biology

This section provides an assessment of the influence of bed substrate on stream communities (macroinvertebrates and fish).

The influence of bed substrate on stream communities is compounded by the range of substrate size and its embeddedness and compactness. A stream bed with highly variable substrate size classes (e.g. Island Stream at Kuriheka) may provide abundant potential refugia for macroinvertebrates and fish, while a bed with a fine uniform substrate size (e.g. Waiareka Creek at Queen's Flat) provides little refuge. Embeddedness is an indication of how much of the dominant substrate is buried by finer sediment. Compactness is a measure of how tightly packed substrate is. Under certain conditions (e.g. frequent flash flows or sedimentation), substrate can become highly compacted. When this happens, bed substrate can become very stable, adversely affecting steam biological health by reducing or eliminating interstitial spaces, the habitat for macroinvertebrates and fish.

Aquatic macroinvertebrates are organisms that live on or within the bottom substrate (e.g. rocks, gravels, sands, silts and organic matter, such as macrophytes, or organic debris, such as logs and leaves), in rivers and streams. Examples include insect larvae (e.g. mayflies, stoneflies, caddisflies and beetles), aquatic oligochaetes (worms), snails and crustaceans (e.g. amphipods and crayfish). These macroinvertebrates are a useful means of assessing the biological health of a river because they are found everywhere and have different tolerances to temperature, dissolved oxygen, sediment and chemical pollution. They also have life-cycles ranging from a few months to a year or two; thus, the presence or absence and abundance of taxa can provide insight into long-term changes in water quality.

Each of the sites was electro-fished to determine the composition of fish species and how density varied between sites. Electric-fishing was completed at nine sites, and spotlighting at two sites.

6.1 Substrate

Substrate was assessed at the 11 sites (Figure 2.1) during baseline summer flows in January 2012. Substrate or particle size of the riverbed is important in determining which biological communities inhabit a river. Cobble and gravel stream beds provide a different habitat to sand or silt-laden streams because their interstices are larger and provide greater through flow and oxygenation.

All sites were assessed for substrate size in run and riffle reaches. For each site, two riffles and two runs were chosen for a cross-sectional survey. The substrate size of ten randomly selected particles was measured while wading across the stream's cross section. The second widest axis of each particle was measured. These measurements were assessed against the Wentworth scale (Table 6.1).

Table 6.1 Wentworth scale.

Score	Substrate type	Size
7	Bedrock	>400mm
6	Boulder	>256-4000mm
5	Cobble	>64 to 256mm
4	Pebble	>16 to 64mm
3	Gravel	>2 to 16mm
2	Sand	>0.063 to 2mm
1	Silt	<0.063mm

From the substrate measurements, the Substrate Index (SI) was calculated. This index, proposed by Harding *et al.* (2009), was based on the Wentworth scale, originally a modified form of the SI used by Jowett and Richardson (1990). The following formula was used to calculate SI.

Substrate index (SI) = SI = 0.08*%bedrock + 0.07*%boulder+0.06*%cobble +0.05*%pebble +0.04*%gravel +0.03*%sand and silt

A stream bed consisting entirely of bedrock will have an SI = 0.08*100% bedrock (i.e. 8), while a sandy bottom stream will have an SI = 0.03*100% sand (i.e. 3).

Table 6.2 and Figure 6.1 show that the Kakanui at Clifton Falls and Island Stream at Kuriheka had the largest substrate size. The dominant substrate at Clifton Falls is bedrock, while at Kuriheka, it is cobbles. The SI scores for the Kakanui at Mill Dam and McCone's, and the Kauru at Ewings and Rodger's Crossing, are very similar (between 5.5 and 5.9). Island Stream at Maheno, Kauru at Kakanui Valley Road Bridge and the two lower Waiareka sites are also very similar, with SI scores between 4.8 and 5.0. The outlier is Waiareka Creek at Queen's Flat, which has an SI of 3.0, indicating a substrate dominated by silt, mud and sand.

Table 6.2 Summary results of physical habitat assessment in the nine rivers.

Site	Median particle size based on the Wentworth scale	Substrate Index	Estimated gravel and fine sediment cover (%)	Compact-ness score	Embedd-edness score
Island Stm - Kuriheka	>64 to 256mm	6	10	2	1
Island Stm - Maheno	>2 to 16mm	5	50	2	1
Kakanui - Clifton Falls	>400mm	7.1	0	1	1
Kakanui - Mill Dam	>64 to 256mm	5.5	5	2	1
Kakanui - McCone's	>64 to 256mm	5.8	15	1	1
Kauru - Ewings	>64 to 256mm	5.9	10	1	1
Kauru – Rodger's Cr	>64 to 256mm	5.9	10	1	1
Kauru - Kakanui Vlly Rd	>2 to 16mm	4.8	60	1	1
Waiareka Ck - Queen's Flat	>0.063 to 2mm	3	100	1	0
Waiareka Ck - Kia Ora	>2 to 16mm	5	50	1	1
Waiareka Ck -Taipo Rd	>2 to 16mm	4.8	30	1	1

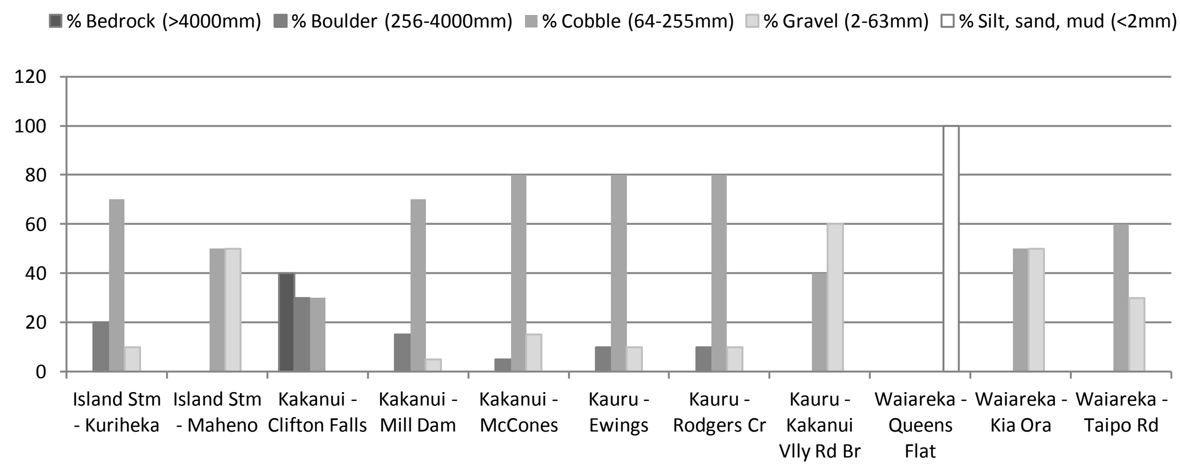

Figure 6.1 Bed substrate in runs at each monitoring site.

6.2 Embeddedness and compactness

For each of the ten randomly selected particles, the degree of substrate embeddedness and compactness was noted. The definitions of embeddedness and compactness are given in Table 6.3.

Table 6.3 Scores for the degree of embeddedness and compactness.

Score	Substrate embeddedness	Substrate compactness
1	Not embedded, the substrate on top of the bed	Loose, easily moved substrate
2	Slightly embedded, >25% of the particle is buried or attached to the surrounding substrate	Mostly loose, little compaction
3	Firmly embedded, about 50% of the substrate is embedded or attached to the surrounding substrate	Moderately packed
4	Heavily embedded, >66% of the substrate is buried	Tightly packed substrate

Table 6.2 show embeddedness and compactness scores at each site. The substrate was on top of the bed at each site (other than Waiareka Creek at Queen's Flat, which was 100% silt). Compactness was also low, with loose easily moved substrate at most sites, other than the two Island Stream sites and Kakanui at Mill Dam. These sites had mostly loose substrate with little compaction.

6.3 Instream organic matter and bank cover

Figure 6.2 shows organic matter and bank cover at each site. Organic matter can provide important habitat for stream invertebrates and fish undercut banks and overhanging vegetation also provide important habitat for fish.

Macrophytes were present at four sites - Island Stream at Maheno and the three Waiareka Stream sites - all of which scored highly for bank cover. Algae were dominant at the lower Kakanui sites (Mill Dam and McCone's). These sites also had a high percentage of bank cover. The Kauru had little organic matter present, other than a 20% cover of algae at Kakanui Valley Road Bridge. There was no bank cover at any of the Kauru sites.

The extent of woody debris and leaf packs was also minimal. The Kakanui at Clifton Falls and McCone's, and Waiareka Creek at Taipo Road all had 5%. This survery was undertaken in January. A greater percentage would probably occur during leaf fall in autumn.

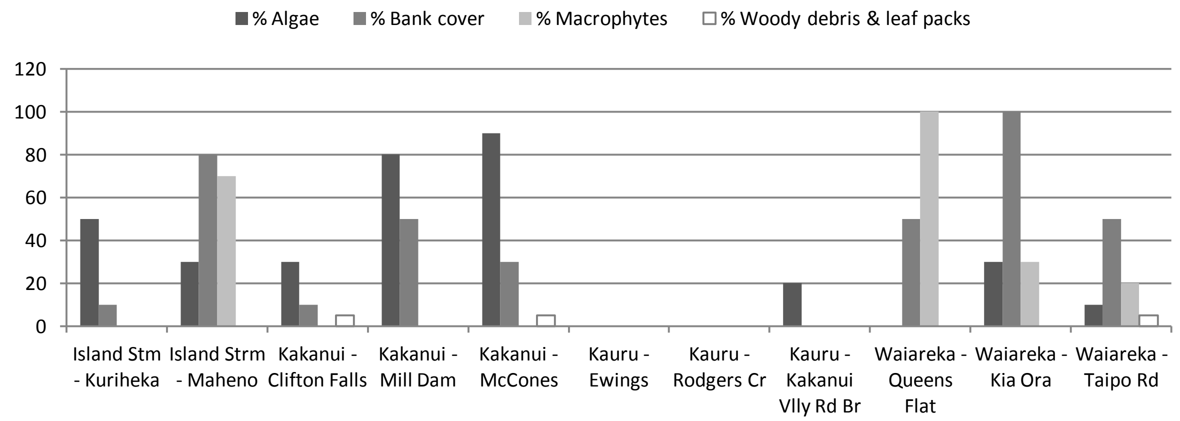

Figure 6.2 Organic matter and bank cover at each monitoring site.

6.4 Riparian cover

Riparian cover and vegetation was assessed at the 11 sites during baseline summer flows in January 2012. Riparian cover was assessed according to protocol 'P2d', as described in the Stream Habitat Assessment Protocols for wadeable rivers and streams of New Zealand (Harding *et al.,* 2009).

The protocol assesses the attributes that determine riparian zone influence on stream habitat and aims to allow inter-site comparisons. The P2d protocol allows scores to be derived for 12 key riparian attributes (Table 6.4). Each of the 12 key riparian attributes could be scored from one to five (five being good).The total score for each site is out of 125. All attributes (other than shading) are scored out of ten (five for the left bank and five for the right bank, then summed).

The scores were quite similar, within 23 points of each other, and ranging from 77 (Island Stream at Kuriheka) to 100 (Waiareka Creek at Queen's Flat). The noticeable differences were the upper catchment sites (Clifton Falls and Kuriheka), both of which have steep slopes from the stream bank. There was open livestock access at Island Stream (Maheno and Kuriheka) and Kakanui (McCone's). There was very low bank stability in the Kauru, especially at Kakanui Valley Road, with associated poor buffer width and intactness.

Table 6.4 Riparian cover assessment.

	Island Stream		Kakanui River			Kauru River			Waiareka Creek		
	Kuriheka	Maheno	Clifton Falls	Mill Dam	McCone's	Ewings	Rodgers Cr	Kakanui Vlly	Queen's Flat	Kia Ora	Taipo Rd
Shading of water	4	3	2	4	2	1	1	2	4	3	2
Buffer width	4	4	8	8	6	4	4	8	6	6	4
Buffer intactness	7	8	10	8	7	7	7	7	10	10	7
Vegetation composition of buffer	4	4	4	6	6	4	4	4	4	4	4
Vegetation composition of land adjacent to buffer	4	2	5	4	4	4	4	4	4	4	3
Bank stability	7	8	9	9	8	4	4	2	10	10	8
Livestock access	4	6	10	8	5	8	8	8	8	10	8
Riparian soil denitrification potential	6	6	7	6	6	6	6	6	10	6	6
Land slope 0-30 m from stream bank	5	9	5	8	8	10	10	10	8	7	6
Groundcover of buffer	8	10	9	9	8	7	7	8	10	10	10
Ground cover of land adjacent to buffer	8	8	9	6	6	8	8	8	10	10	5
Soil drainage	6	6	6	7	6	6	6	6	6	8	6
Rills/channels	10	10	10	10	10	10	10	10	10	10	10
TOTAL	77	84	94	93	82	79	79	83	100	98	79

6.5 Macroinvertebrates

Macroinvertebrate communities were sampled at the 12 sites in January 2012. One kicknet sample was collected from each site. Samples were collected according to collection protocol 'C1: hard-bottomed semi-quantitative', as described in the Ministry for the Environment's 'Protocols for sampling macroinvertebrates in wadeable streams' (Stark *et al.,* 2001). Each taxon present in the sample was assigned to one of five coded abundance categories (Table 6.5). Identification was carried out to the level at least equivalent to that recommended by the Ministry for the Environment (Stark *et al.,* 2001) protocol.

The indices often used to measure stream health are summarised below:

Taxonomic richness: The total number of taxa collected at a sampling site. In general, high taxonomic richness is considered 'good'; however, mildly impacted or polluted rivers with slight nutrient enrichment can have higher species richness than unaffected, pristine streams.

Ephemeroptera Plecoptera and Trichoptera (EPT) richness: The sum of the total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera[3] (caddisflies) taxa collected. These groups of insects are often the most sensitive to organic and mineral pollution; therefore, low numbers might indicate a polluted environment. The percentage of EPT taxa compared to the total number of taxa found at a site gives an indication of their importance in the overall community.

Macroinvertebrate Community Index (MCI): Assesses the organic enrichment of stony or hard-bottomed streams by sampling the riffle habitats of macroinvertebrates. Taxon scores are between 1 and 10, with 1 representing species highly tolerant to organic pollution (e.g. worms and some dipteran species) and 10 representing species highly sensitive to organic pollution (e.g. some mayflies and stoneflies). A site score is obtained by summing the scores of individual taxa and dividing this total by the number of taxa present at the site.

Semi-quantitative Macroinvertebrate Community Index (SQMCI): Uses the same approach as the MCI, but weights each taxon's score based on how abundant it is within the community. As with the MCI, SQMCI scores can be interpreted in the context of national standards (Table 6.6).

Table 6.5 Coded abundance scores used to summarise macroinvertebrate data (after Stark, 1998).

Abundance	Coded abundance	Weighting factor
1 to 4	Rare (R)	1
5 to 19	Common (C)	5
20 to 99	Abundant (A)	20
100 to 499	Very abundant (VA)	100
>500	Very very abundant (VVA)	500

Table 6.6 Interpretation of MCI values from Boothroyd and Stark (2000) (quality class A) and Stark and Maxted (2007) (quality class B).

Quality class A	Quality class B	MCI	SQMCI
Clean water	Excellent	>120	>6
Doubtful quality	Good	100 to 119	5 to 5.99
Probable moderate pollution	Fair	80 to 99	4 to 4.99
Probable severe pollution	Poor	<80	<4

Macroinvertebrate health indices show that the good MCI values were found at all Kauru River sites, the upper Island Stream site (Kuriheka) and the upper Kakanui site (Clifton Falls) (Figure 6.3). The most common macroinvertebrate found in the Kauru River and the upper Kakanui was the mayfly (*Deleatidium sp*). Caddises were more abundant in the Kauru than at the upper Kakanui site. Ewings had 'abundant' *Aoteapsyche* sp., *Olinga* sp. and *Pycnocentrodes* sp. Rodger's Crossing had 'abundant' *Olinga* sp. and *Pycnocentrodes sp*. The Kauru sites (Ewings, Rodger's Crossing) were the only sites where stoneflies (*Zelandobius* sp.) were found. In the upper Kakanui, *Aoteapsyche sp.* and *Pycnocentrodes sp.* were classified as 'common'.

Macroinvertebrate health indices show that the fair MCI values were found at the lower Island Stream site (Maheno) and the two lower Kakanui sites (Mill Dam, McCone's) (Figure 6.3). The only 'abundant' species at all three sites was the caddis, *Pycnocentrodes sp.*; however, other

[3] This includes Hydroptilidae (*Oxyethira & Paroxyethira*), which are very pollution tolerant.

caddis species were 'rare' or occasionally 'common'. No stoneflies were found and only a few mayflies. The mollusc *Potamopyrgus* was 'abundant' at all sites.

Macroinvertebrate health indices show that 'poor' MCI values were found at the three Waiareka Stream sites (Figure 6.3). The Waiareka Creek had no mayflies or stoneflies, and caddisflies were 'rare'. *Potamopyrgus* was 'abundant' at all Waiareka sites, and Orthocladiinae were 'abundant' at Kia Ora and Taipo Road.

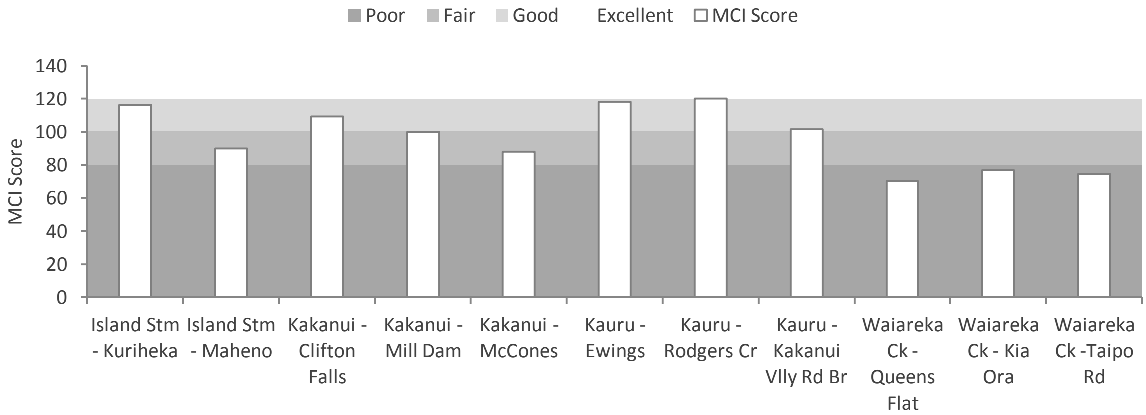

Figure 6.3 MCI values for all sites based on samples collected in January 2012.

The SQMCI scores shown in Figure 6.4 reflect the MCI scores. The Kauru obtained the highest scores, with two of the three sites in the 'excellent' category. 'Good' scores were obtained at the upper sites of the Kauru and the Kakanui main-stem. The lower Kakanui site (McCone's) and the two lower Waiareka Stream sites were categorised as 'fair', while the lower Island Stream site (Maheno), Kakanui at Mill Dam, and Waiareka Creek at Queen's Flat were 'poor'.

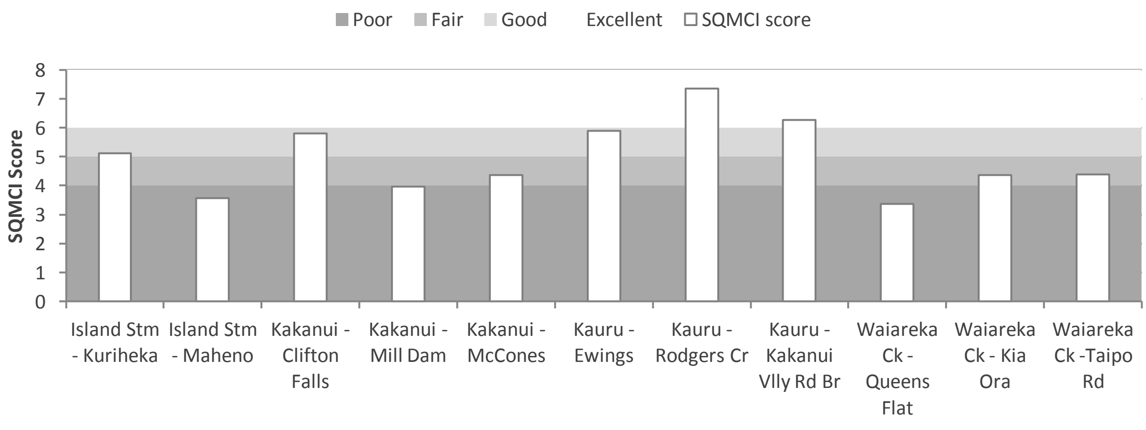

Figure 6.4 SQMCI for all sites based on samples collected in January 2012.

When the EPT data were expressed as a percentage of the total number of species (Figure 6.5), the Kakanui (all sites), the Kauru (all sites) and Island Stream (Kuriheka) had more than 40% EPT taxa. The highest proportion of EPT taxa were found at the upper sites in the Kakanui (Clifton) and Island Stream (Kuriheka). Waiareka Creek had a low percentage of EPT species, as the community was dominated by dipterans, worms, molluscs and crustaceans, rather than mayflies, stoneflies and caddisflies.

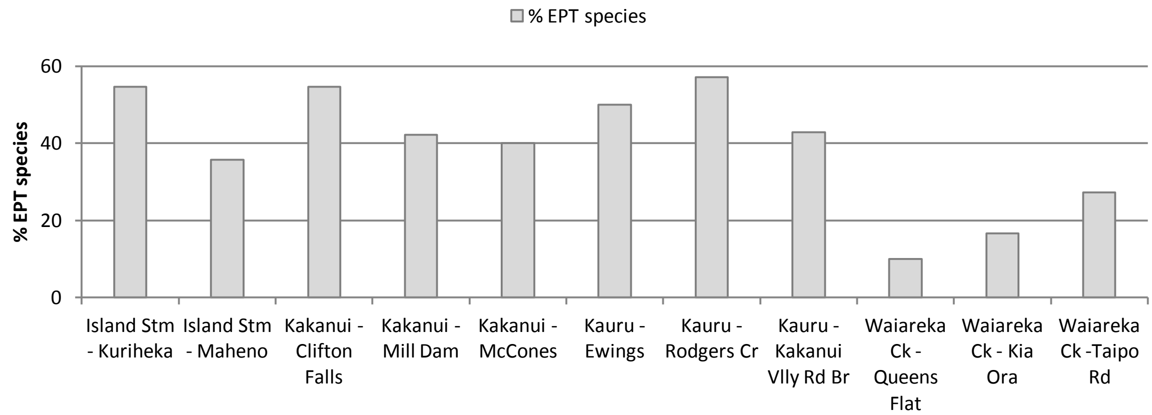

Figure 6.5 EPT data expressed as a percentage of the total number of species, based on samples collected in January 2012.

6.6 Fish communities

The 11 sites were electro-fished to see how the composition and density of fish species varied. By March 2012, electric-fishing was completed at nine sites and spotlighting at two.

The Kakanui River (Clifton Falls and McCone's) and Waiareka Creek at Taipo Road are fished annually as part of ORC's fish monitoring programme. At each of the Kakanui River sites, 150 m of river was fished in April 2012. (The area fished differing according to the width of river.) Waiareka Creek at Taipo Road and Kia Ora were surveyed by spotlighting because the substrate was too deep and silty to fish effectively.

The three sites on the Kauru River and the Kakanui at Gemmells Crossing were fished by the Department of Conservation (DOC) in October 2011. A three-run pass over 50 m was fished, and between four and seven species were present at each site. In December 2011, ORC fished both Island Stream sites (Kuriheka and Maheno) and the Waiareka Creek (Queen's Flat site) using the same method as DOC. However, the conductivity (1.8 mS/cm) at the Queen's Flat site was too high to fish effectively.

6.6.1 Fish species

Table 2.2 shows the 18 fish species listed in the NIWA New Zealand Freshwater fish database for the Kakanui River catchment (July 2012).

This survery found 12 native species in the main-stem of the river (Table 6.7). In the headwaters and middle reaches, the fish population was dominated by upland bullies, while nearer the sea, the diadromous species, mainly bluegill bullies and common bullies, dominated. In the Kauru, the fish population was dominated by Canterbury galaxias and upland bullies, although the lowland longaw galaxias was found in significant numbers at the lower two sites (Rodger's Crossing and Kakanui Valley Road Bridge). Island Stream was dominated by the common bully at Kuriheka, while longfin eel were dominant at Maheno. Waiareka Creek had few fish compared to the main-stem and other tributaries; the most common was the common bully at Queen's flat.

The Kakanui at McCone's had the highest number of native species (eight). The lowest number of species caught was in the Waiareka (Queen's Flat and Kia Ora).

Table 6.7 Fish species (and numbers) found in the Kakanui catchment during surveys conducted in March 2012 (EF= electric-fishing, SP= spotlighting).

Species name	Kakanui River			Kauru River			Island Stream		Waiareka Creek		
	Clifton Falls	Gemmells	McCone's	Ewings	Rodgers Cr	Kakanui Vlly Rd Br	Kuriheka	Maheno	Queen's Flat	Kia Ora	Taipo Rd
Method	EF	EF	EF	EF	EF	EF	EF	EF	EF	SP	SP
Area fished (m^2)	2091	559	1548	358	869	979	200	100	50		
Shortfin eel	1	3	15		1		7	7			
Longfin eel	3	3	19	3	2		11	41			
Unidentified eel										2	2
Torrentfish			6								
Koaro				3	2						
Lowland longjaw galaxias		9			57	30					
Banded kokopu											2
Inanga			6					18			7
Canterbury galaxias	19	41		59	105	102					
Lamprey	4		1				1				
Upland bully	110	245		61	74	108	2				
Common bully		3	395				109	4	27		
Giant bully											1
Bluegill bully			768								
Redfin bully			3								
Unidentified bully											3
Brown trout	28	275	4	5	24	248	78	7			1

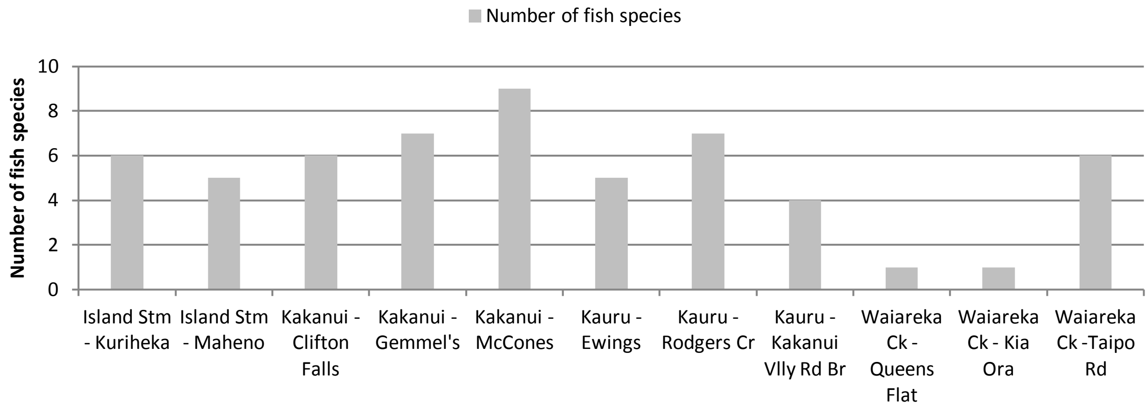

Figure 6.6 Number of fish species found at each sampling site during surveys conducted in March 2012.

6.6.2 Fish densities

At the sites where electro-fishing took place, a known area was sampled, and fish density could be calculated.

Total fish density was highly variable among sites (Figure 6.7). The Kakanui (Gemmells) and the Island Stream (Kuriheka) had the highest total densities of fish (both with 1.04 fish/m^2), while the Kakanui at Clifton Falls and the Kauru at Rodger's Crossing had the lowest fish densities (with 0.08 and 0.30 fish/m^2, respectively).

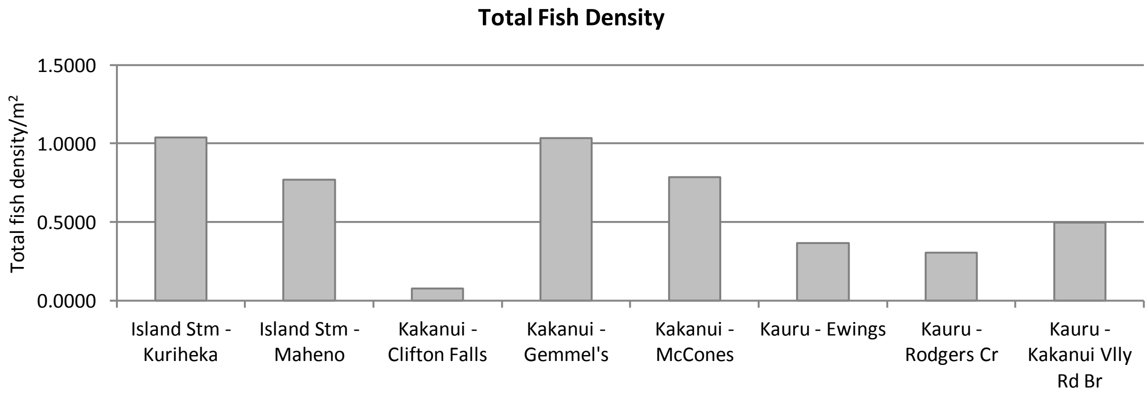

Figure 6.7 Total fish density (m^2) at each sampling site during surveys conducted in March 2012.

6.6.3 Native fish

The Kakanui at McCone's had the highest densities of torrentfish, bluegill bullies and redfin bullies. Island Stream at Kuriheka had the highest lamprey and common bully densities, and the highest densities of longfin eel, shortfin eel and inanga were collected from Island Stream at Maheno (Figure 6.8).

The Kakanui at Gemmells had high numbers of upland bully and brown trout.

The Kauru at Ewings had the highest density of koaro; the Kauru at Rodger's Crossing had the highest lowland longjaw galaxias and Canterbury galaxias density; and the Kauru at Kakanui Valley Road Bridge had the highest upland bully density. Upland bullies were the most common fish caught in the Kakanui River at Clifton Falls.

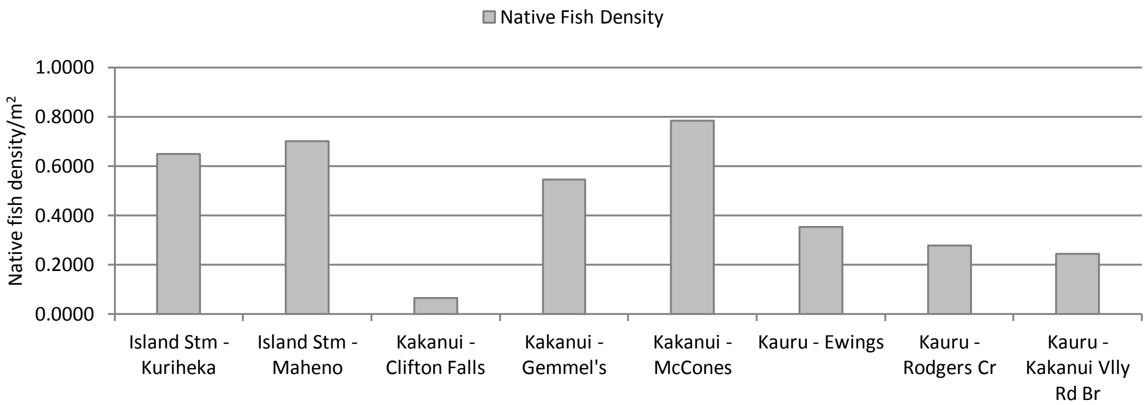

Figure 6.8 Native fish density (m^2) at each sampling site during surveys conducted in March 2012.

6.6.4 Brown trout

Brown trout were present at all sites. The highest density of trout was observed at the Kakanui at Gemmells Crossing, with high densities also observed at Island Stream at Kuriheka. The Kauru at Kakanui Valley Road Bridge also had high densities (Figure 6.9). Low densities were observed at all the other sites (Figure 6.9).

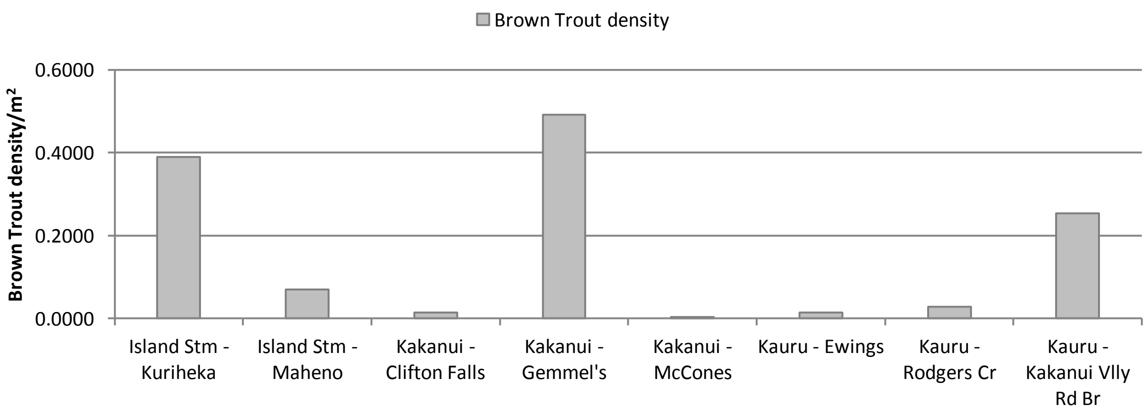

Figure 6.9 Brown trout density (m^2) at each sampling site during surveys conducted in March 2012.

7. Discussion

7.1 Historical water quality

Four sites in the Kakanui catchment are monitored bimonthly by ORC as part of its SOE water quality monitoring programme. The dates vary, from 1992 at Clifton Falls and McCone's, from 1992 at Ewings (no data 1995 to 2000) and from 1999 at Waiareka Creek. Summary statistics, including mean, median and range, for each of these ORC SOE sites are given in Table 4.2.

The difference in nutrient values between the upstream site (Clifton Falls) and the downstream site (McCone's) is significant, with NNN being nine times higher at McCone's than at Clifton Falls. Median N values for the lower Kakanui, although high, do not give a true reflection of the historical trend. Annual data (1991 to 2011) show a large increase in N at McCone's, from a median of 0.07 mg/l in 1991 to a median of 0.26 mg/l in 2010 (i.e. an increase of 5% per annum).

Waiareka Creek N and P data from 1999 to June 2006 and July 2006 to 2012 were analysed. The two time periods correspond to 'before and after' the placement of a minimum flow of 100 l/s in Waiareka Creek (near its confluence with the Kakanui River). Due to the increased flow in the creek, a significant decrease in contaminant concentrations might have been expected if an intensification of land use had not occurred. DRP showed a significant increase between 2001 and 2012, but no trend showed if the period 2006 to 2012 was considered on its own. However, the median concentration of DRP still exceeded ANZECC guideline values. This was not the case with NNN, which showed a significant increase over the entire time period (1999 to 2012as well as between 2006 and 2012. The continuing upward trend for NNN is a consequence of land-use intensification.

Although there was a significant decrease in NH_4 concentrations over the entire time period, there was no significant decrease between 2006 and 2012. The lack of trends in NH_4 and DRP concentrations (2006 to 2011) are probably due to the increased flows caused by augmentation (NOIC), not to a change in contaminants entering the watercourse.

7.2 Nutrients and algae

Nuisance algae growths can be common in rivers affected by excessive nutrient contamination. Instream values, such as swimming and angling, can be affected adversely by nuisance algae growths.

The dissolved nutrients (NNN and DRP) were generally low in the Kauru River, unlike Waiareka Creek, where nutrients were generally above guideline levels. The most interesting result was the large increase in NNN between the upper and lower Kakanui sites. The Kakanui at Mill Dam and McCone's had median NNN concentrations above guideline values (Figure 4.5), but at Clifton Falls, the NNN concentration was well below the guideline.

Figure 7.1 shows the relationship between flow (at Mill Dam) and nitrate values at McCone's (2003 to 2012). This relationship is aligned to the groundwater-surface-water interaction, with a general trend of increasing nitrate as flow increases. There is a slight increase in N at very low flows, which represents the higher relative contribution of groundwater to base flow.

Groundwater in the Kakanui-Kauru alluvium becomes a significant contributor to the system when the river flow at McCone's falls below the median. The main reason is the shift in balance between inflow at the top of the catchment and the contribution from storage in riparian gravels. The drying up of the Kauru River, which increases the proportion of groundwater contribution to flow at McCone's, is another possible reason.

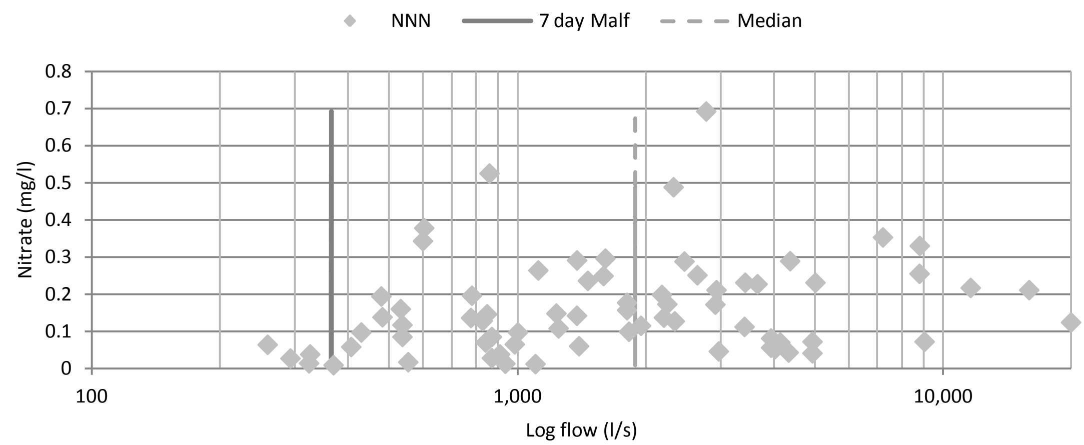

Figure 7.1 Relationship between flow and NNN at McCone's.

Between July and September 2012, ORC took groundwater samples at bores in Maheno and Five Forks. The results were fairly consistent. NNN recorded between 2.2 and 3.6 mg/l at Five Forks and between 12.8 and 15.3 mg/l at Maheno. It is clear that a very small groundwater contribution to the river would result in an increase in NNN values in the river below Gemmells.

The excessive growth of algae or macrophytes is only possible if nutrients are available, particularly NNN and DRP, which are biologically available for plant uptake. Using an N:P ratio of <7:1 to indicate N-limitation and >15:1 to indicate P-limitation (mass basis), Kakanui (Clifton Falls), Kauru (Ewings) and Waiareka Creek (all sites) were N-limited, but Figure 4.7 shows that the lower Kakanui is generally P-limited (i.e. there is an excess of N).

The ratio of N:P should be put into the context of the concentrations observed. In Waiareka Creek, both N and P are high, and algal periphyton blooms are likely to occur, even though the >7:1 ratio suggests the presence of N-limitation. The lower Kakanui also shows P-limitation, but algal blooms are known to occur regularly at McCone's.

Many of the lower nitrate values in Figure 7.1 will reflect some nitrogen uptake due to periphyton growth, and temporal changes in the supply and assimilation of nutrients are reflected in the chemistry of stream water. An annual cycle can be seen in the McCone's data, with lower nitrate values recorded each summer (Figure 7.2). This cycle seems to occur regardless of flow, so there appears to be significant nitrate removal by periphyton during warmer months. To gauge the true extent of nutrients instream, it is worth considering an additional SOE monitoring site at Mill Dam or slightly upstream at Riverside (located upstream of the nutrient-rich groundwater input).

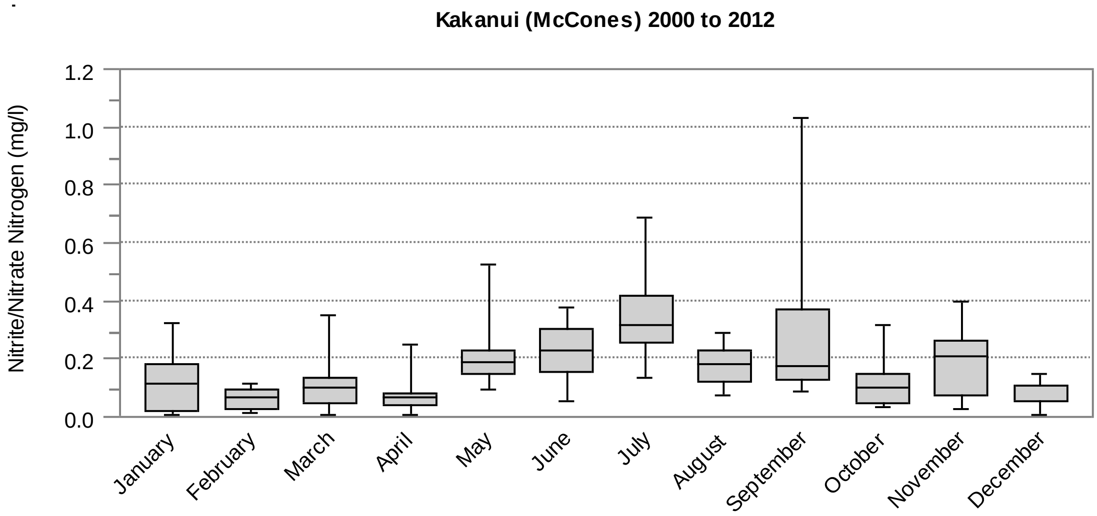

Figure 7.2 Seasonal NNN at McCone's based on ORC monitoring between 2000 and 2012.

Biggs (1998) undertook a study in the Kakanui River to determine whether the intensification of land use influenced periphyton proliferations. The study came about because some community groups considered that there was an over-allocation of water in the Kakanui catchment. These groups suggested that abstraction in summer was reducing flows to such an extent that it was compromising the 'life-supporting capacity' of the river. In particular, trout-fishing opportunities were considered to have decreased significantly in the lower river possibly because low flows were causing periphyton proliferations.

Figure 7.3 shows that, before 1998, there were very few days when the river at Mill Dam was below the 7-day MALF (433 l/s); however, since 1997, the number of days below 433 l/s has generally been much higher. In other words, lower rainfall in the years before 1998 does not seem to have generated as many days below the 7-day MALF as in subsequent years.

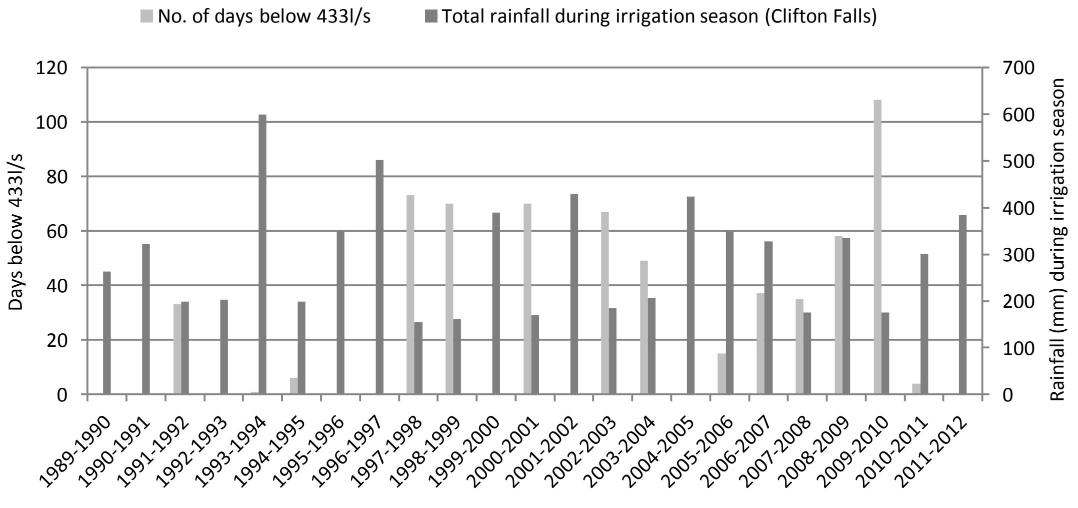

Figure 7.3 Number of days below the 7-day MALF at Mill Dam.

Biggs and Close (1989) found that nutrients influence the accrual of algae in streams when there is an extended period of low flow. Before Biggs conducted his work in the Kakanui in 1998, the flows in the Kakanui River were generally well above 433 l/s. Results from the Biggs' (1998) periphyton investigation concluded that:

- there was a statistically significant difference in mean chlorophyll *a* in the riffles (Clifton Falls, Gemmells and McCone's)
- maximum chlorophyll *a* concentrations in the riffles did not increase downstream. Only the values at Clifton Falls exceeded the levels deemed to be a proliferation, which could impact on values such as trout (200mg/m^2 chlorophyll *a)*.

The results of investigations in 2011/12 showed that:

- there was a statistically significant difference in mean chlorophyll *a* in the riffles (same sites), with higher periphyton biomass at McCone's than at sites upstream
- unlike the 1998 results, the values at the downstream site (McCone's) exceeded the proliferation criteria for chlorophyll *a*.

Biggs (2000) found that algal proliferations decrease greatly in hydrologically stable streams as nutrient levels are reduced. The Kakanui River does not have enough flushing flows to scour algae, and therefore any mitigation measures that reduce nutrient supply rates to groundwater would be valuable.

As groundwater in the Kakanui-Kauru alluvium is a significant contributor to the river (particularly below Gemmells), nutrient concentrations in the lower Kakanui may not be able to reach dissolved nutrient levels low enough to prevent benthic algae from exceeding specific target values.

As groundwater concentrations of nutrients in the lower Kakanui are so high, the surface-water target values are likely to be exceeded, even when the volume of groundwater contribution to surface water is low, thereby causing nuisance algae growths (Figure 7.4).

Figure 7.4 Proliferation of benthic algae in the Kakanui at McCone's.

To study the influence of the irrigation scheme on water quality in the Kakanui estuary, NNN and DRP at Taipo Road and McCone's were investigated. Flow data from Springhill Road (measured in 2005/2006) and Taipo Road (ongoing since 2007) was used to generate load data.

Figure 7.5 shows that the P load from Waiareka Creek has increased from 1.8 kg/day in 2005/2006 to over 5 kg/day in 2011/2012, whereas the P load from the Kakanui has remained stable. Figure 7.6 shows that the Kakanui had a much higher N load than Waiareka Creek before 2009, but since that time, it has started to increase.

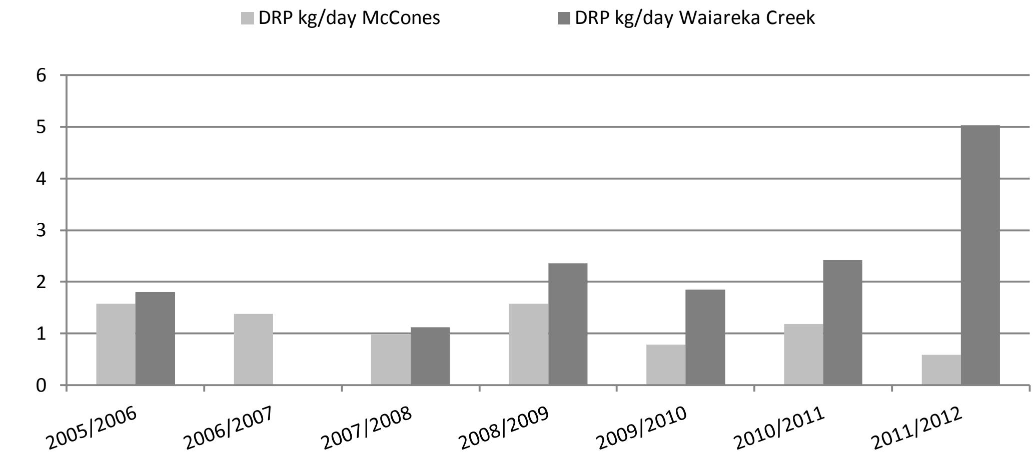

Figure 7.5 Kakanui at McCone's and Waiareka Creek, DRP kg/day.

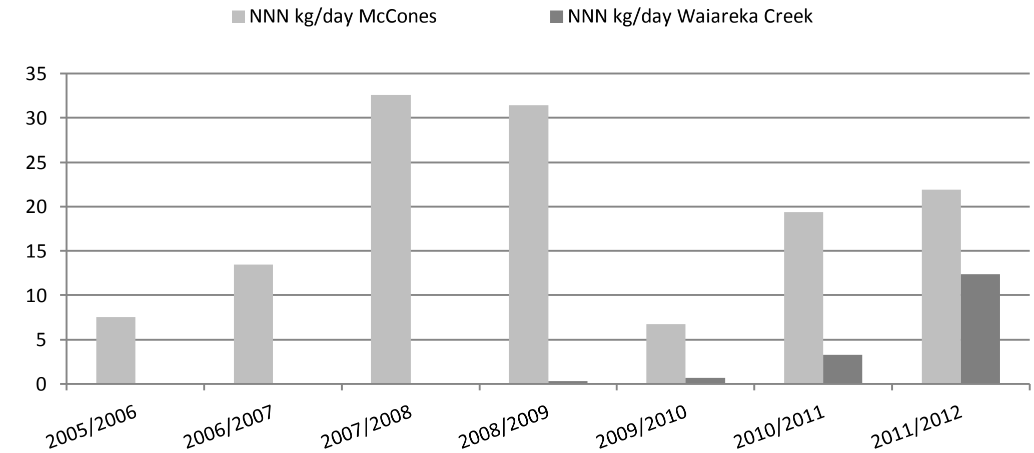

Figure 7.6 Kakanui at McCone's and Waiareka Creek, NNN kg/day.

The percentage contribution of nutrient loads from Waiareka Creek to the Kakanui estuary since 2005 is shown in Figure 7.7. The percentage contribution of N and P to the estuary from Waiareka Creek has increased by about 35% during that period. In 2011/12 (a wet year), Waiareka Creek contributed about 80% P and 40% N to the estuary.

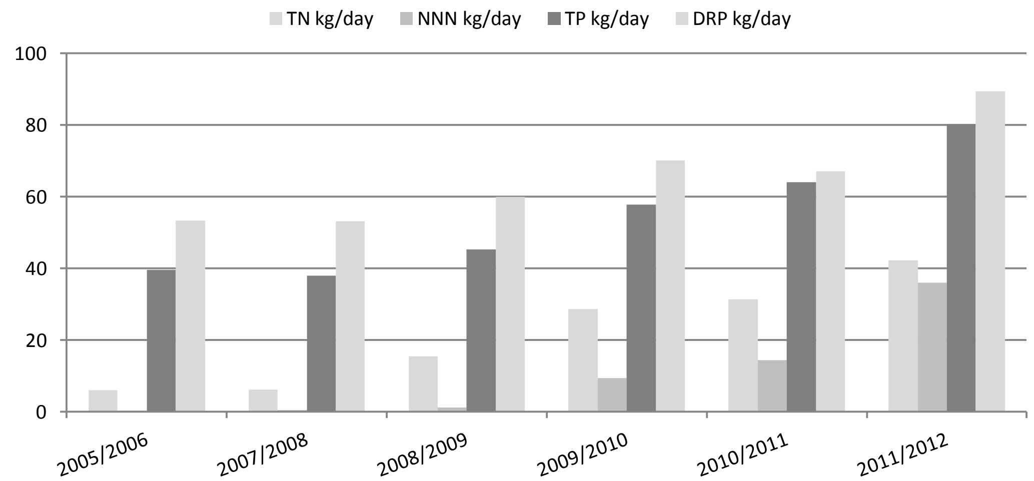

Figure 7.7 Nutrient contribution from Waiareka Creek to the Kakanui estuary (%).

The proliferation of benthic algae in the Kakanui estuary (Figure 7.8) is likely to be stimulated by the high nutrient concentrations provided by the lower Kakanui (NNN) and Waiareka Creek (DRP).

Figure 7.8 Algae in the Kakanui Estuary (ORC, February 2012).

7.3 Toxicants

Ammonia is a common agricultural pollutant from animal-waste products. It exists in two forms in water: non-toxic ionised ammonium (NH_4) and unionised ammonia (NH_3), which is very toxic to many aquatic species, even at low concentrations. The ratio of NH_3 to NH_4 increases with pH, such that both are approximately equal at 20°C and pH 9.4. However, when concentrations of NH_4 reach about 1–2 mg/l (Wilcock *et al.*, 2007), concentrations of unionised NH_3 can become toxic to stream life, especially to invertebrates (Hickey and Vickers, 1994).

Although such concentrations can occur in streams of pasture catchment (MfE, 2009), the highest concentration found was 0.27 mg/l in the Waiareka Creek at Kia Ora Road. Historical temperature and pH results mean that toxic concentrations of NH_3 are unlikely to be present.

AgResearch (2011) developed a test to detect the contamination of surface waters by drainage associated with the application of effluent to land under bad practice. An equation based on concentrations of *E. coli*, P and NH_4 was run on all samples taken at all sites. Six samples were found to be contaminated with effluent: the Kauru at Ewings (7/12/11), Waiareka Creek at Kia-Ora (27/10/11 and 23/11/11), Waiareka Creek at Queen's Flat (23/11/11 and 7/12/11) and Waiareka Creek at Taipo Road (23/11/11). All of these dates coincided with high flows, and therefore runoff was likely to have occurred.

7.4 Faecal contaminants

The presence of bacteria in the water indicates the presence of faecal material and, with it, the possibility that other disease-causing organisms may be also present. These organisms are able to enter water through a number of routes. In the Kakanui catchment, this is most likely to occur through runoff from pastoral farm land, although wild life living in and around water bodies may also contribute.

Faecal loadings have been assessed by Wilcock (2006). He showed that the highest source of *E. coli* (ha-pasture/yr) was wintering pads/pasture (150 cows), which contributed 7 x 10^{13} *E. coli*/ha-pasture/yr, closely followed by dairy (3 x 10^{13} *E. coli*/ha-pasture/yr), irrigation to land (1 x 10^{12} *E. coli*/ha-pasture/yr), surface runoff (1 x 10^{11} *E. coli*/ha-pasture/yr) from dairy and sheep/beef, dairy drains (3 x 10^{10} *E. coli*/ha-pasture/yr) and runoff from laneways (9 x 10^{9} *E. coli*/ha-pasture/yr). In the Kakanui catchment, bacterial contamination of rivers is likely to be a combination of all these sources

One of the major contributors to bacterial contamination is probably effluent irrigation when soils are at or near saturation. As a rule of thumb, irrigation should not exceed the water-storage capacity of the soil. To prevent nutrient loss to waterways in wet weather, adequate storage is needed to allow for deferred irrigation (Houlbrooke *et al*., 2004). Deferred irrigation is also likely to be successful with respect to bacteria loss.

In the Kakanui catchment, which has 31 dairy farms, nine had between three weeks' and two months' dairy effluent storage, and 13 had two months' or more dairy effluent storage. The other nine farms had between 0-10 days' storage. On these farms, deferred irrigation is probably not possible all the time.

In South Otago, sub-surface artificial drains commonly underlie pasture. In the Kakanui catchment, only one of the 31 dairy farms stated that tile drains were present on their property. In the Kakanui, it is more common to see open drains, which collect runoff, be it rainfall or irrigation. It is known that the levels of bacteria in open drains in the Kakanui can have extremely high levels of bacteria, with sampling of open farm drains by ORC during 2012 recording bacteria concentrations of up to 120,000 cfu/100 ml.

Faecal contamination of streams can be very high during floods due to the disturbance and mobilisation of sediments and the introduction of agricultural runoff. Bacteria concentrations at base flow are more important when considering the health risk to downstream water users (such as swimmers) and stock drinking water. (MfE, 2009). When looking at base flow alone, only Island Stream (Maheno), Kakanui (McCone's) and the Kauru (Kakanui Valley Rd) had bacteria concentrations below the MfE 'alert' level of 260 *E. coli*/100 ml on every occasion.

To consider the health risk to downstream users, the 11 *E. coli* samples taken between November and March (summer bathing season) at each site were analysed for non-compliance with the MfE 2003 guidelines. The Kakanui (Mill Dam) and the Kauru (Kakanui Valley Road) were compliant at all times. At Taipo Road, the Waiareka Creek exceeded 550 *E. coli*/100 ml on three of the 11 occasions, and the 'alert' level of 260 cfu/100 ml was exceeded six times. Island Stream (Maheno, Kuriheka) and the Kakanui (Clifton) exceeded 550 cfu/100 ml on five of the 11 occasions. Kakanui at Clifton Falls is a popular swimming hole, and the 'alert' level of 260 cfu/100 ml was exceeded eight times at this site, which has been attributed to upstream nesting colonies of gulls.

7.5 Sediments and visual quality

Sediment consists of particles of all sizes, including fine clay particles, silt, sand and gravel. Nutrients, in particular, may attach to sediment and then be transported into surface waters; they can then settle with the sediment or detach and become soluble in the water column. There are many sources for instream sediment. The most common source is erosion, exacerbated by stock access to water, which causes banks to be destabilised and slump into rivers. Riparian vegetation is very good at stabilising banks and reducing contaminant inputs. Larger trees and shrubs provide better riparian cover than pasture, as sediment can only be stored temporarily by pasture, as it is released during flood events (MfE, 2009).

Agricultural practices also influence the amount of suspended sediment in rivers. Streams surrounded by pasture grazed by dairy cattle or deer have significantly more fine sediment than streambeds surrounded by tussock (Matthaei *et al*., 2006).

The loss of sediment to rivers can lead to alterations to the physical, chemical and biological state of the river. The physical changes include the water becoming more turbid (reduced penetration of light) or the smothering of the streambed by fine sediments, which decreases available habitat for invertebrates and fish and spawning success in native and introduced fish. Sediment can also cause chemical alterations, as it can become a store for contaminants such as heavy metals, pesticides, bacteria and nutrients, especially phosphorus, which can later be released. Sediment can also cause biological alterations, such as a reduction in the rate of photosynthesis (due to a reduction in light) for periphyton and macrophytes.

The median concentration of SS at all of the sites fell below the guideline concentration of 7.0 mg/l. The highest median (3.0 mg/l) was found in Waiareka Creek at Kia Ora, which reflects the high P concentration also found in the creek.

7.6 Substrate and riparian cover

In the main-stem Kakanui, the substrate became finer in the downstream reaches, with 30% boulders (>264 mm diameter) at Clifton, 20% at Mill Dam and 10% in the lower reaches. There was less change in the finer substrates, but the proportion of cobbles (64-264 mm) and gravel (8-64 mm) increased with distance downstream.

The upper catchment sites (Kakanui at Clifton Falls and Island Stream at Kuriheka) had the coarsest substrate. Those with finer substrate included Waiareka Creek (Queen's Flat), Island Stream (Maheno) and the Kauru (Kakanui Valley Road).

The substrate in the tributaries was generally dominated by cobble and gravel. This similarity in substrate-size was probably due to flushing flows reducing fine sediment build up. However, the headwater site in Waiareka Creek (Queen's Flat) had fine sediment accounting for 100% of the substrate. Such excessive sedimentation can cause degraded macroinvertebrate and fishery values because of a loss of habitat availability (as fine sediment fills in interstitial spaces between larger substrate). It is not only the finer substrate that inhibits habitat availability, large amounts of stable substrate, such as bedrock, restrict the habitat available to macroinvertebrates and provide more surface area for algal growths to settle and grow on. Bedrock was only present at the Kakanui (Clifton Falls) site (Figure 7.9).


Figure 7.9 Kakanui at Clifton Falls (showing bedrock) and the Kakanui at McCone's (showing cobbles).

Appropriate riparian management is vital to maintaining water and habitat quality and the ecological values of rivers and streams. Healthy riparian zones act as buffers against the impact of land-based processes by reducing erosion (as they slow down the speed of overland water flow before it reaches the river) and by filtering inputs of sediment, nutrients and bacteria in overland flow. Riparian zones also protect banks from erosion and lessen the impact of floods. If stock were able to access the river, then these riparian zones would be damaged.

Fencing, to exclude livestock from rivers, means that the dense vegetation associated with riparian buffer strip (inside the fence) is able to reduce the momentum and magnitude of surface runoff, thereby stopping sediment and faecal contamination of streams. The Dairying and Clean Steams Accord (2003) required that 90% of dairy cattle were excluded from streams, rivers and lakes and their banks by 2012. This exclusion applied to dairy properties on the Kakanui, and the level of compliance in the Kakanui appears to be high. In the Waiareka Creek catchment, an environmental farm plan is required as a condition of the resource consent granted to NOIC for supply of water to properties on the North Otago downlands. The farm plan contains elements such as irrigation, soils, nutrients and riparian and dairy effluent management. The irrigation company expects farmers to comply and audits every farm every three years. The ORC Regional Plan: Water also has rules to protect damage to rivers from stock access.


Figure 7.10 Examples of riparian vegetation in the Kakanui catchment.

Most of the sites scored '2' for vegetation composition, translating to 'exotic weedy shrubs, gorse, blackberry, broom, or mainly high grasses or low native shrubs of 0.3 to 2 m'. Mill Dam and Clifton Falls (Kakanui) scored highly for the width of the vegetation buffer (5-15 m), and Kakanui (Clifton) and Waiareka Creek (Kia Ora) had completely intact (100%) vegetation buffers. The vegetation at Clifton Falls is dense, but still allows stock access to the river. Figure 7.10 gives examples of vegetation composition.

7.7 Macroinvertebrates and fish

Agricultural-chemical water quality degradation generally does not have toxicological effects and is often correlated with other factors, such as sedimentation, changes in ecosystem function and structure, and the loss of riparian vegetation, all of which can affect instream ecology. Other factors, such as the shallowness of the river in the reach monitored, the condition of the riparian zone and the velocity of the water during periods of high flow may also affect ecological values.

Sedimentation reduces habitat availability and can cause degraded macroinvertebrate and fishery values. Habitat availability is an important resource requirement for macroinvertebrates. Bank instability, because of the loss of riparian vegetation, and bank collapse, due to stock access and natural erosion, provide fine sediment that smothers substrate, thereby reducing substrate size and habitat availability for macroinvertebrates. On the whole, there was little sedimentation in the Kakanui catchment, with the exception of Waiareka Creek.

MCI values were 'good' at all Kauru River sites, the upper Island Stream site (Kuriheka) and the upper Kakanui site (Clifton Falls). Otherwise, Kakanui and Island Stream had values that fell into the 'fair' category. Waiareka Creek was classified as 'poor', which, according to Stark *et al.* (2001), suggests probable moderate pollution. No mayflies or stoneflies were found at any of the Waiareka sites, and caddisflies were rare, but the Waiareka Creek is slow flowing, with few riffles or exposed substrate, which is not the preferred habitat for EPT taxa. The low scores observed in Waiareka Creek, therefore, probably reflect, at least in part, the habitat conditions (dominated by fine sediments) in this stream.

The other sites in Kakanui and Island Stream were dominated by caddisflies, *Pycnocentrodes* sp., which is the most common stony-cased caddis, and also the mollusc *Potamopyrgus* sp., which is a widespread snail that can tolerate a wide range of water quality.

Small rivers and streams, particularly those close to the coast such as the Kakanui, are prime habitat for many native fish species. Usually, fish tend to be most abundant where the habitat quality is best (water velocity, depth, substrate, cover), and fewer in number where the habitat is poor or absent.

Eels were found in a wide variety of water depths and velocities. Their main habitat requirement is suitable cover, usually substrate or vegetation, and adequate food. Habitat and food availability in Waiareka Creek is poor; hence, there are few eels. However, these numbers are probably artificially low because of the method of fishing and the presence of deep pools. The Kakanui at McCone's had by far the most suitable habitat and a plentiful food supply. Further inland, the number of shortfin eels tends to decrease, as was the case in the Kakanui main-stem and Island Stream.

Coarse substrate and intersistitial space (the spaces between stones) are particuarly important for native NZ fish species because they are benthic dwelling and use the stream bed for shelter, foraging and nesting. In this study, the highest densities of native fish were found in streams dominated by large substrate. The Kakanui (McCone's) had high numbers of native fish, as did Island Stream. (Maheno is dominated by eels.)

Jowett (1994) found that bluegill bullies and torrentfish were present in very swift, deep water in the Kakanui River; whereas upland bullies, common bullies and Canterbury galaxias were edge dwelling and so were found to be most abundant along the margins of riffles. This study found the same results.

The fishery at the Kakanui (Clifton) site was not as good as the other sites, probably because of high water velocities or perhaps the influence of bedrock, which reduces refuge habitat. The highest numbers of brown trout were caught in the Kakanui (Gemmells Crossing), the Kauru

(Kakanui Valley Bridge) and Island Stream (Kuriheka). At all the other sites, few trout were caught.

Although the Kauru is ephemeral, which adversely affects the brown trout population, it does create a refuge for lowland longjaw galaxias and other native species. At Island Stream (Kuriheka), trout and native fish co-exist probably because of good habitat, such as coarse substrate and good intersistitial spaces, which are important for native fish species as they use the riverbed for shelter, foraging and spawning.

8. Conclusions

- The Kakanui-Kauru riparian aquifer is largely driven by surface-water flows.
    - Groundwater recharge occurs in the alluvial gravels in the Kauru River and the main-stem Kakanui River, particularly downstream of Gemmells crossing. Land-surface recharge occurs in Waiareka Creek.
    - There is a significant input of N between Clifton Falls and McCone's, which changes the main-stem Kakanui from N-limited at Clifton to P-limited at Mill Dam. The change in river chemistry is a result of the addition of N via groundwater-surface-water interaction.
    - The drying of the Kauru River increases the proportion of groundwater base flow to the Kakanui River during the summer.

- Nutrient concentrations in the lower Kakanui may not achieve dissolved nutrient levels low enough to prevent benthic algae from exceeding specific target values.
    - The high turnover of groundwater storage in response to high-flow events has implications for nitrate accrual in the aquifer. The aquifer is able to accumulate nitrate to moderate concentrations. If this occurs, the water released as base flow following a high-flow event will have sufficient nitrate to exceed the surface-water threshold of 0.075 mg/l (Biggs, 2000, 30 days accrual). Target values in the lower Kakanui are likely to be exceeded even with low groundwater-nutrient concentrations.
    - During this study, the median N concentration at McCone's was more than 15 times higher than at Clifton Falls (0.012 mg/l at Clifton Falls and 0.186 mg/l at McCone's).
    - The number of days where mean flows fall below 433 l/s (7-day MALF) appear to have increased since 2005.
    - The mean concentration of NNN at McCone's is more than that recommended by Biggs (2000) to prevent biomass from exceeding 200 mg/m^2 chlorophyll *a*. Biggs (1998) found that the values at Clifton Falls, not McCone's, exceeded the levels deemed to be a proliferation.
    - The Waiareka Creek enters the Kakanui River just upstream of the Kakanui Estuary. The combination of nutrient-rich water from both the Kakanui (NNN) and Waiareka Creek (DRP and NNN) probably stimulates algae growth in the estuary.
    - In 2011/2012, the DRP load from Waiareka Creek was 5 kg/day, whereas the DRP load from the Kakanui River was 0.4 kg/day. In contrast, the Kakanui River has a much higher N load than Waiareka Creek. In 2011/12, the NNN load from the Kakanui River was 24 kg/day, compared to 10 kg/day from the Waiareka Creek.
    - In 2012, the percentage contribution of nutrients from Waiareka Creek to the Kakanui Estuary was about 80% DRP and 40% NNN.

- Bacteria concentrations were significantly elevated in Waiareka Creek, but were above guideline concentrations at all sites, except the site in the Kauru at Kakanui Valley Road Bridge.
    - The Kakanui at Clifton Falls site is a popular swimming hole, but there was a large percentage (48%) of instances of non-compliance with the microbiological guidelines for contact recreation (above 260 cfu/100 ml) at this site, which is attributed to upstream nesting colonies of gulls.

  - There was also a high degree of non-compliance (39%) at the upper Island Stream site. This site is upstream of intensive agriculture.

- Substrate and riparian cover was reasonably good at all sites:
  - As expected, the substrate became finer in the downstream reaches of the Kakanui River, with 30% consisting of boulders (>264 mm diameter) at Clifton, 20% at Mill Dam and 10% in the lower reaches. The Kauru River had poor riparian cover, due to the wide, braided river channels and the instability of the bed.

- Ecological values were as expected:
  - MCI values show that 'good' MCI values were found at all Kauru River sites, the upper Island Stream site (Kuriheka) and two Kakanui sites (Clifton and Mill Dam). The other Kakanui site (McCone's) was classified as 'fair'. Waiareka Creek was classified as 'poor', which can be attributed to instream habitat conditions, with few riffles or exposed substrate.
  - The highest number of brown trout were caught in the Kakanui (Gemmells Crossing), the Kauru (Kakanui Valley Bridge) and Island Stream (Kuriheka). Few trout were caught at the other sites.
  - The Kakanui (McCone's) and Island Stream (Maheno) had large numbers of native fish. The Kauru River supported a large number of lowland longjaw galaxiids.

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Appendices

Appendix 1. Water quality results

	Island Stream at Kuriheka estate							
	Total nitrogen	Nitrite/ nitrate nitrogen	Ammoniacal nitrogen	Total phosphorus	Dissolved reactive phosphorus	*E. coli*	Suspended solids	Flow
	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	mg/l	l/s
16/09/2011	0.21	0.039	0.005	0.007	0.002	250	1.5	121
29/09/2011	0.2	0.014	0.005	0.006	0.002	80	1.5	36
13/10/2011	0.22	0.033	0.005	0.008	0.002	200	1.5	39
27/10/2011	0.65	0.33	0.015	0.016	0.004	800	1.5	1028
10/11/2011	0.34	0.061	0.005	0.017	0.002	1300	1.5	500
23/11/2011	0.39	0.096	0.005	0.012	0.012	2400	1.5	717
7/12/2011	0.22	0.031	0.005	0.009	0.002	3800	1.5	224
21/12/2011	0.27	0.022	0.005	0.008	0.002	120	1.5	30
4/01/2012	0.42	0.018	0.005	0.021	0.002	300	11	17
18/01/2012	0.37	0.055	0.018	0.01	0.002	290	1.5	126
1/02/2012	0.26	0.033	0.016	0.01	0.005	1100	1.5	129
15/02/2012	0.24	0.049	0.005	0.012	0.005	3300	1.5	344
29/02/2012	0.6	0.34	0.005	0.011	0.005	170	1.5	592
16/03/2012	0.24	0.065	0.005	0.006	0.002	80	1.5	311
27/03/2012	0.7	0.31	0.005	0.02	0.005	420	1.5	306
11/04/2012	0.34	0.159	0.005	0.009	0.006	50	1.5	203
26/04/2012	0.2	0.104	0.005	0.012	0.002	28	1.5	40
8/05/2012	0.25	0.098	0.005	0.009	0.005	16	1.5	39
24/05/2012	0.27	0.153	0.005	0.007	0.002	25	1.5	84
7/06/2012	0.2	0.11	0.005	0.006	0.002	16	1.5	74
19/06/2012	0.22	0.113	0.005	0.007	0.002	6	1.5	110
5/07/2012	0.2	0.078	0.005	0.005	0.002	4	1.5	60
19/07/2012	0.28	0.117	0.005	0.011	0.007	8	1.5	151
median	0.26	0.078	0.005	0.009	0.002	170	1.5	

	Island Stream at Maheno							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.37	0.057	0.005	0.019	0.005	48	1.5	211
29/09/2011	0.59	0.12	0.017	0.027	0.005	50	3	84
13/10/2011	0.61	0.155	0.014	0.037	0.009	220	1.5	103
27/10/2011	2.1	0.94	0.101	0.115	0.049	3500	8	1871
10/11/2011	0.67	0.171	0.026	0.044	0.022	1000	1.5	468
23/11/2011	0.9	0.14	0.005	0.068	0.016	2100	4	1308
7/12/2011	0.56	0.094	0.005	0.055	0.03	1600	1.5	313
21/12/2011	0.45	0.023	0.005	0.04	0.016	230	1.5	96
4/01/2012	1.2	0.006	0.005	0.09	0.015	13	9	1
18/01/2012	0.7	0.121	0.024	0.06	0.029	300	1.5	238
1/02/2012	0.59	0.111	0.043	0.071	0.041	590	1.5	207
15/02/2012	0.5	0.067	0.011	0.079	0.059	230	1.5	136
29/02/2012	0.89	0.38	0.018	0.047	0.028	370	1.5	853
16/03/2012	0.5	0.084	0.005	0.066	0.021	250	3	358
27/03/2012	1.29	0.43	0.011	0.139	0.064	6000	16	513
11/04/2012	0.41	0.097	0.005	0.039	0.032	5	1.5	190
26/04/2012	0.3	0.073	0.005	0.028	0.018	90	1.5	103
8/05/2012	0.33	0.081	0.005	0.018	0.015	59	1.5	97
24/05/2012	0.37	0.128	0.005	0.04	0.011	100	6	194
7/06/2012	0.34	0.149	0.005	0.016	0.01	34	1.5	179
19/06/2012	0.34	0.151	0.005	0.021	0.011	16	1.5	145
5/07/2012	0.3	0.135	0.005	0.015	0.007	49	1.5	99
19/07/2012	0.22	0.082	0.005	0.012	0.006	20	1.5	137
median	0.5	0.12	0.005	0.04	0.016	220	1.5	

	Kakanui at Clifton Falls Bridge							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.055	0.007	0.005	0.01	0.002	160	1.5	3506
29/09/2011	0.055	0.01	0.005	0.002	0.002	300	1.5	1613
13/10/2011	0.055	0.021	0.005	0.002	0.002	130	1.5	1058
27/10/2011	0.18	0.015	0.005	0.014	0.002	400	1.5	9260
10/11/2011	0.055	0.011	0.005	0.005	0.002	1500	1.5	3232
23/11/2011	0.17	0.001	0.005	0.012	0.002	1200	1.5	6929
7/12/2011	0.055	0.012	0.005	0.002	0.002	1300	1.5	1789
21/12/2011	0.055	0.01	0.005	0.002	0.002	440	1.5	709
4/01/2012	0.055	0.012	0.005	0.002	0.002	300	1.5	548
18/01/2012	0.13	0.035	0.005	0.006	0.002	300	1.5	2224
1/02/2012	0.11	0.012	0.01	0.007	0.007	700	1.5	1521
15/02/2012	0.055	0.015	0.005	0.002	0.002	1500	1.5	1470
29/02/2012	0.11	0.012	0.005	0.004	0.002	180	1.5	3517
16/03/2012	0.055	0.005	0.005	0.002	0.002	90	1.5	3814
27/03/2012	0.14	0.011	0.005	0.002	0.002	80	1.5	1792
11/04/2012	0.055	0.025	0.005	0.002	0.002	400	1.5	1101
26/04/2012	0.055	0.021	0.005	0.002	0.002	90	1.5	675
8/05/2012	0.055	0.022	0.005	0.002	0.002	80	3	700
24/05/2012	0.055	0.009	0.005	0.004	0.002	19	1.5	1050
7/06/2012	0.055	0.017	0.005	0.002	0.002	22	1.5	872
19/06/2012	0.055	0.009	0.005	0.002	0.002	9	1.5	1092
5/07/2012	0.055	0.009	0.005	0.002	0.002	2	1.5	1125
19/07/2012	0.055	0.006	0.005	0.002	0.002	21	1.5	1985
median	0.055	0.012	0.005	0.002	0.002	180	1.5	

	Kakanui at McCone's							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.23	0.111	0.005	0.002	0.002	35	1.5	3447
29/09/2011	0.23	0.141	0.005	0.002	0.002	30	1.5	1590
13/10/2011	0.27	0.147	0.012	0.002	0.002	33	1.5	1224
27/10/2011	0.61	0.21	0.03	0.083	0.011	900	5	17965
10/11/2011	0.32	0.21	0.005	0.007	0.004	90	1.5	4605
23/11/2011	0.32	0.071	0.005	0.017	0.006	500	1.5	10908
7/12/2011	0.25	0.126	0.005	0.004	0.002	220	1.5	2376
21/12/2011	0.21	0.096	0.005	0.002	0.002	200	1.5	835
4/01/2012	0.16	0.016	0.005	0.009	0.002	55	1.5	426
18/01/2012	0.45	0.23	0.005	0.01	0.002	270	1.5	3528
1/02/2012	0.34	0.114	0.071	0.01	0.008	540	1.5	2354
15/02/2012	0.18	0.107	0.005	0.007	0.005	140	1.5	1520
29/02/2012	0.43	0.23	0.005	0.012	0.007	260	1.5	5723
16/03/2012	0.21	0.102	0.005	0.006	0.002	230	1.5	4907
27/03/2012	0.4	0.186	0.005	0.023	0.009	4100	4	3374
11/04/2012	0.31	0.187	0.005	0.007	0.007	240	1.5	1469
26/04/2012	0.27	0.21	0.005	0.006	0.002	36	1.5	854
8/05/2012	0.35	0.26	0.005	0.004	0.002	80	1.5	1008
24/05/2012	0.29	0.21	0.005	0.004	0.002	10	1.5	1685
7/06/2012	0.37	0.26	0.005	0.004	0.002	24	1.5	1416
19/06/2012	0.61	0.29	0.005	0.004	0.002	11	3	1494
5/07/2012	0.37	0.3	0.005	0.004	0.002	23	1.5	1450
19/07/2012	0.25	0.101	0.005	0.004	0.002	30	1.5	2494
median	0.31	0.186	0.005	0.006	0.002	90	1.5	

	Kakanui at Mill Dam							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.21	0.102	0.005	0.002	0.002	16	1.5	4068
29/09/2011	0.23	0.157	0.005	0.002	0.002	80	1.5	1659
13/10/2011	0.28	0.181	0.005	0.002	0.002	48	1.5	1261
27/10/2011	0.39	0.094	0.005	0.017	0.002	270	6	14478
10/11/2011	0.24	0.159	0.005	0.006	0.002	200	1.5	4627
23/11/2011	0.24	0.059	0.005	0.01	0.002	380	1.5	10538
7/12/2011	0.24	0.154	0.005	0.009	0.002	140	1.5	2292
21/12/2011	0.29	0.21	0.005	0.002	0.002	200	4	911
4/01/2012	0.26	0.13	0.005	0.013	0.002	71	34	547
18/01/2012	0.43	0.24	0.005	0.007	0.002	260	1.5	3347
1/02/2012	0.26	0.141	0.058	0.002	0.005	130	1.5	2102
15/02/2012	0.2	0.132	0.005	0.002	0.002	380	1.5	1704
29/02/2012	0.32	0.198	0.005	0.007	0.002	280	1.5	6124
16/03/2012	0.16	0.083	0.005	0.002	0.002	200	1.5	5710
27/03/2012	0.24	0.144	0.005	0.002	0.002	360	1.5	3146
11/04/2012	0.35	0.25	0.005	0.002	0.002	2100	1.5	1477
26/04/2012	0.34	0.28	0.005	0.002	0.002	220	1.5	957
8/05/2012	0.41	0.33	0.005	0.002	0.002	160	1.5	1067
24/05/2012	0.29	0.23	0.005	0.002	0.002	100	1.5	1589
7/06/2012	0.36	0.28	0.005	0.002	0.002	96	1.5	1358
19/06/2012	0.36	0.31	0.005	0.002	0.002	100	1.5	1482
5/07/2012	0.32	0.26	0.005	0.002	0.002	25	1.5	1491
19/07/2012	0.23	0.115	0.005	0.002	0.002	100	1.5	2646
median	0.28	0.159	0.005	0.002	0.002	160	1.5	

	Kauru at Ewings							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.19	0.01	0.005	0.002	0.002	170	1.5	849
29/09/2011	0.15	0.015	0.005	0.002	0.002	120	1.5	379
13/10/2011	0.19	0.027	0.005	0.008	0.002	60	1.5	299
27/10/2011	0.21	0.041	0.013	0.012	0.004	240	1.5	3652
10/11/2011	0.1	0.011	0.005	0.005	0.002	330	1.5	1751
23/11/2011	0.14	0.001	0.005	0.008	0.002	600	4	2658
7/12/2011	0.1	0.018	0.005	0.73	0.002	1200	1.5	704
21/12/2011	0.14	0.009	0.005	0.002	0.002	390	1.5	203
4/01/2012	0.17	0.018	0.005	0.03	0.002	97	1.5	138
18/01/2012	0.17	0.014	0.005	0.004	0.002	190	1.5	824
1/02/2012	0.17	0.01	0.018	0.002	0.002	360	1.5	667
15/02/2012	0.11	0.004	0.005	0.006	0.002	460	1.5	1250
29/02/2012	0.17	0.021	0.005	0.005	0.002	41	1.5	1568
16/03/2012	0.055	0.001	0.005	0.002	0.002	50	1.5	1538
27/03/2012	0.15	0.01	0.005	0.004	0.002	30	1.5	962
11/04/2012	0.055	0.015	0.005	0.002	0.002	240	1.5	422
26/04/2012	0.055	0.009	0.005	0.002	0.002	26	1.5	171
8/05/2012	0.055	0.009	0.005	0.002	0.002	3	1.5	169
24/05/2012	0.055	0.01	0.005	0.002	0.002	130	4	331
7/06/2012	0.055	0.013	0.005	0.01	0.002	4	1.5	294
19/06/2012	0.055	0.004	0.005	0.002	0.002	6	1.5	368
5/07/2012	0.055	0.005	0.005	0.002	0.002	1	1.5	228
19/07/2012	0.055	0.01	0.005	0.002	0.002	5	1.5	519
median	0.11	0.01	0.005	0.002	0.002	120	1.5	

	Kauru at Kakanui Valley Road 400m d/s							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.055	0.036	0.005	0.004	0.002	130	1.5	598
29/09/2011	0.11	0.025	0.005	0.002	0.002	6	1.5	79
13/10/2011	0.14	0.081	0.017	0.007	0.002	4	1.5	71
27/10/2011	0.25	0.055	0.005	0.01	0.002	300	1.5	3078
10/11/2011	0.055	0.03	0.005	0.02	0.002	260	1.5	1860
23/11/2011	0.17	0.028	0.005	0.005	0.002	150	1.5	3116
7/12/2011	0.16	0.072	0.005	0.002	0.002	40	1.5	0
21/12/2011	0.16	0.128	0.005	0.002	0.002	3	1.5	0
4/01/2012	0.13	0.077	0.005	0.007	0.002	3	1.5	0
18/01/2012	0.28	0.13	0.005	0.005	0.002	33	1.5	258
1/02/2012	0.13	0.029	0.014	0.002	0.004	17	1.5	258
15/02/2012	0.15	0.045	0.005	0.005	0.002	35	1.5	258
29/02/2012	0.34	0.115	0.005	0.002	0.002	44	1.5	258
16/03/2012	0.15	0.024	0.005	0.002	0.002	31	1.5	1423
27/03/2012	0.055	0.018	0.005	0.002	0.002	160	1.5	566
11/04/2012	0.11	0.045	0.005	0.002	0.002	50	1.5	293
26/04/2012	0.055	0.045	0.005	0.002	0.002	42	1.5	245
8/05/2012	0.18	0.11	0.005	0.002	0.002	16	1.5	251
24/05/2012	0.23	0.049	0.005	0.007	0.002	13	1.5	129
7/06/2012	0.1	0.051	0.005	0.006	0.002	18	1.5	0
19/06/2012	0.1	0.055	0.005	0.002	0.002	35	1.5	0
5/07/2012	0.14	0.068	0.005	0.002	0.002	11	1.5	0
19/07/2012	0.28	0.041	0.005	0.005	0.002	9	1.5	0
median	0.14	0.049	0.005	0.002	0.002	33	1.5	

	Kauru at Rodger's Road Crossing							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.12	0.019	0.005	0.004	0.002	9	1.5	794
29/09/2011	0.14	0.047	0.005	0.002	0.002	1	1.5	113
13/10/2011	0.19	0.09	0.005	0.002	0.002	9	1.5	98
27/10/2011	0.23	0.05	0.005	0.013	0.002	180	1.5	3405
10/11/2011	0.11	0.018	0.005	0.004	0.002	800	1.5	1602
23/11/2011	0.16	0.017	0.005	0.006	0.002	490	1.5	1951
7/12/2011	0.14	0.078	0.005	0.002	0.002	290	1.5	550
21/12/2011	0.24	0.163	0.005	0.002	0.002	10	1.5	58
4/01/2012	0.41	0.3	0.005	0.013	0.005	1	1.5	9
18/01/2012	0.22	0.039	0.005	0.006	0.002	120	1.5	964
1/02/2012	0.16	0.023	0.011	0.002	0.01	60	1.5	512
15/02/2012	0.16	0.032	0.005	0.012	0.002	3000	1.5	n/a
29/02/2012	0.2	0.047	0.005	0.006	0.002	100	1.5	n/a
16/03/2012	0.055	0.011	0.005	0.002	0.002	180	1.5	n/a
27/03/2012	0.13	0.01	0.005	0.006	0.002	280	1.5	n/a
11/04/2012	0.25	0.03	0.005	0.002	0.002	1200	1.5	n/a
26/04/2012	0.055	0.013	0.005	0.002	0.002	130	1.5	n/a
8/05/2012	0.055	0.032	0.005	0.005	0.002	28	1.5	n/a
24/05/2012	0.055	0.009	0.005	0.002	0.002	20	1.5	n/a
7/06/2012	0.055	0.015	0.005	0.002	0.002	7	1.5	n/a
19/06/2012	0.055	0.012	0.017	0.002	0.002	15	1.5	n/a
5/07/2012	0.055	0.016	0.005	0.002	0.002	18	1.5	n/a
19/07/2012	0.055	0.011	0.005	0.002	0.002	3	1.5	n/a
median	0.14	0.023	0.005	0.002	0.002	60	1.5	n/a

	Waiareka Creek at Kia Ora Road							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	mg/l	mg/l	mg/l	mg/l	cfu/100ml	mg/l	l/s
16/09/2011	1.08	0.004	0.005	0.078	0.002	93	13	n/a
29/09/2011	1.43	0.22	0.188	0.051	0.004	60	4	n/a
13/10/2011	0.47	0.155	0.019	0.051	0.049	30	1.5	n/a
27/10/2011	2.6	1.42	0.192	0.191	0.099	2700	7	n/a
10/11/2011	2	0.88	0.026	0.108	0.066	300	1.5	n/a
23/11/2011	3.7	0.91	0.27	0.62	0.31	36000	17	n/a
7/12/2011	1.49	0.34	0.005	0.147	0.107	600	1.5	n/a
21/12/2011	0.49	0.111	0.005	0.115	0.091	340	8	n/a
4/01/2012	0.38	0.069	0.005	0.132	0.101	100	1.5	n/a
18/01/2012	3	1.24	0.121	0.38	0.25	110	7	n/a
31/01/2012	0.78	0.24	0.005	0.185	0.151	240	1.5	n/a
14/02/2012	0.73	0.21	0.021	0.141	0.122	230	1.5	n/a
28/02/2012	2.9	1.28	0.149	0.38	0.24	360	9	n/a
16/03/2012	1.86	0.77	0.015	0.135	0.1	110	1.5	n/a
29/03/2012	1.37	0.49	0.01	0.113	0.082	70	1.5	n/a
11/04/2012	1.26	0.49	0.005	0.108	0.09	60	1.5	n/a
26/04/2012	0.92	0.46	0.005	0.07	0.055	46	1.5	n/a
8/05/2012	1.35	0.31	0.005	0.119	0.036	13	12	n/a
24/05/2012	1.2	0.67	0.005	0.075	0.034	26	3	n/a
7/06/2012	1.51	0.94	0.005	0.054	0.047	5	3	n/a
20/06/2012	1.67	0.4	0.005	0.117	0.029	4	9	n/a
5/07/2012	1.62	0.34	0.005	0.1	0.018	3	11	n/a
19/07/2012	1.55	0.57	0.005	0.091	0.015	2	10	n/a
median	1.43	0.46	0.005	0.115	0.082	93	3	n/a

	Waiareka Creek at Queen's Flat							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.71	0.007	0.005	0.051	0.027	110	1.5	n/a
29/09/2011	0.76	0.004	0.005	0.06	0.036	31	1.5	n/a
13/10/2011	0.55	0.009	0.005	0.057	0.044	200	1.5	n/a
27/10/2011	2.2	0.76	0.005	0.166	0.056	6000	9	n/a
10/11/2011	0.84	0.006	0.005	0.083	0.066	200	1.5	n/a
23/11/2011	1.42	0.04	0.005	0.23	0.102	13000	7	n/a
7/12/2011	2.6	0.55	0.005	0.29	0.141	33000	10	n/a
21/12/2011	1.2	0.001	0.005	0.199	0.155	1200	1.5	n/a
4/01/2012	1.12	0.001	0.005	0.173	0.134	2100	1.5	n/a
18/01/2012	1.57	0.109	0.045	0.31	0.22	140	1.5	n/a
31/01/2012	1.16	0.013	0.019	0.28	0.23	90	1.5	n/a
14/02/2012	1.05	0.014	0.032	0.28	0.23	32	1.5	n/a
28/02/2012	1.51	0.125	0.044	0.43	0.3	60	4	n/a
16/03/2012	1.03	0.012	0.005	0.199	0.152	170	1.5	n/a
29/03/2012	0.83	0.018	0.005	0.2	0.17	120	1.5	n/a
11/04/2012	0.8	0.016	0.021	0.171	0.153	90	1.5	n/a
26/04/2012	0.61	0.01	0.005	0.13	0.094	90	1.5	n/a
8/05/2012	0.68	0.017	0.014	0.123	0.103	100	1.5	n/a
24/05/2012	0.56	0.031	0.01	0.093	0.075	61	1.5	n/a
7/06/2012	0.67	0.04	0.005	0.076	0.07	110	1.5	n/a
20/06/2012	0.72	0.029	0.01	0.059	0.064	31	1.5	n/a
5/07/2012	0.52	0.065	0.018	0.057	0.036	21	1.5	n/a
19/07/2012	0.56	0.042	0.015	0.054	0.05	14	1.5	n/a
median	0.83	0.017	0.005	0.166	0.102	110	1.5	n/a

	Waiareka Creek at Taipo Road							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	1.32	0.001	0.005	0.136	0.008	30	18	199
29/09/2011	1.02	0.001	0.005	0.133	0.012	90	12	210
13/10/2011	0.9	0.39	0.053	0.125	0.104	1700	1.5	209
27/10/2011	3.2	1.67	0.07	0.22	0.157	400	5	1478
10/11/2011	2.1	0.96	0.033	0.169	0.138	1900	1.5	178
23/11/2011	3.3	1.66	0.025	0.31	0.18	18000	8	2040
7/12/2011	1.5	0.52	0.005	0.23	0.184	2900	1.5	880
21/12/2011	0.88	0.196	0.005	0.184	0.156	300	1.5	141
4/01/2012	0.53	0.131	0.005	0.24	0.21	100	1.5	540
18/01/2012	2.9	0.85	0.04	0.56	0.4	150	5	363
31/01/2012	1.5	0.38	0.013	0.24	0.2	260	1.5	281
14/02/2012	0.6	0.118	0.005	0.196	0.182	180	1.5	339
28/02/2012	3.3	1.3	0.1	0.56	0.38	330	10	287
16/03/2012	1.77	0.43	0.005	0.21	0.182	340	1.5	228
29/03/2012	1.03	0.32	0.005	0.183	0.163	120	1.5	168
11/04/2012	1.03	0.24	0.005	0.156	0.139	90	1.5	153
26/04/2012	0.76	0.184	0.005	0.124	0.112	150	1.5	163
8/05/2012	0.87	0.34	0.005	0.099	0.091	70	1.5	114
24/05/2012	0.82	0.47	0.005	0.169	0.16	50	1.5	94
7/06/2012	0.95	0.51	0.005	0.084	0.079	25	1.5	103
20/06/2012	1.48	0.76	0.005	0.08	0.079	35	1.5	91
5/07/2012	0.85	0.51	0.005	0.072	0.053	14	1.5	80
19/07/2012	1.08	0.04	0.005	0.123	0.045	30	9	152
median	1.03	0.39	0.005	0.169	0.156	150	1.5	

	Fuchsia Creek at Balruddery							
	Total nitrogen	**Nitrite/ nitrate nitrogen**	**Ammoniacal nitrogen**	**Total phosphorus**	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**	**Flow**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**cfu/100ml**	**mg/l**	**l/s**
16/09/2011	0.37	0.001	0.005	0.021	0.01	14	5	9
29/09/2011	1.61	0.001	0.005	0.56	0.006	20	1.5	5
13/10/2011	3.4	0.006	0.005	0.37	0.002	100	4	4
27/10/2011	0.68	0.039	0.005	0.067	0.025	700	4	387
10/11/2011	0.5	0.001	0.005	0.037	0.023	80	3	101
23/11/2011	0.84	0.007	0.005	0.074	0.022	1400	1.5	250
7/12/2011	0.59	0.005	0.005	0.058	0.035	120	1.5	29
21/12/2011	0.58	0.001	0.005	0.062	0.029	4	1.5	6
4/01/2012	1.99	0.001	0.005	0.23	0.012	1500	57	4
18/01/2012	0.67	0.003	0.005	0.067	0.039	100	1.5	12
1/02/2012	0.98	0.003	0.01	0.14	0.022	300	20	2
15/02/2012	3.5	0.001	0.005	1.35	0.019	3300	200	1
29/02/2012	0.6	0.003	0.005	0.065	0.04	110	1.5	55
16/03/2012	0.51	0.002	0.005	0.052	0.03	28	1.5	26
27/03/2012	0.42	0.004	0.005	0.045	0.03	200	1.5	35
11/04/2012	0.4	0.005	0.005	0.039	0.02	900	1.5	9
26/04/2012	0.3	0.004	0.005	0.02	0.015	120	1.5	5
8/05/2012	0.29	0.002	0.005	0.018	0.01	18	1.5	3
24/05/2012	0.23	0.001	0.005	0.011	0.01	130	1.5	21
7/06/2012	0.26	0.004	0.005	0.082	0.01	46	1.5	9
19/06/2012	3.9	0.001	0.005	0.026	0.008	6	1.5	6
5/07/2012	0.27	0.003	0.005	0.01	0.002	1	1.5	4
19/07/2012	0.18	0.011	0.005	0.009	0.006	5	1.5	5
median	0.58	0.003	0.005	0.058	0.019	100	1.5	

Appendix 2. Algal community composition

Algal community composition at Clifton Falls over five sampling dates.

	Clifton Falls	29/09/2011	3/11/2011	9/12/2011	11/01/2011	9/02/2011
Filamentous green algae	*Microspora*					3
	Mougeotia					4
	Ulothrix		1			4
Filamentous red algae	*Audouinella*	6				
Diatoms	*Cocconeis*				2	1
	Cymbella			2		
	Didymosphenia	6		8	8	
	Epithemia	2		2	3	
	Frustulia					
	Gomphoneis	3		2	2	5
	Gomphonema			1		2
	Nitzschia					3
	Surirella				2	2
	Synedra	2	2	1	4	4

Algal community composition at Gemmells Crossing over five sampling dates.

	Gemmells	29/09/2011	3/11/2011	9/12/2011	11/01/2011	9/02/2011
Filamentous green algae	*Microspora*		1			
	Mougeotia		1	2		3
	Stigeoclonium		3			
Filamentous diatoms	*Fragilaria*				2	
Diatoms	*Cymbella*			1	1	1
	Didymosphenia	8	6	7	7	7
	Gomphoneis					2
	Naviculoid diatoms			1		
	Nitzschia	1				
	Synedra	1	1	3	5	4
Colonial green algae	*Scenedesmus*				1	

Algal community composition at McCone's over five sampling dates.

	McCone's	29/09/2011	3/11/2011	9/12/2011	11/01/2011	9/02/2011
Filamentous green algae	*Microspora*		2	2		2
	Mougeotia	2		3	2	
	Stigeoclonium	4				5
	Ulothrix	4				3
Filamentous red algae	*Audouinella*		2			
Filamentous diatoms	*Melosira*			2	3	
	Tabellaria				1	
Diatoms	*Cocconeis*		1			1
	Cymbella			1		5
	Didymosphenia	7		7	6	3
	Epithemia				2	
	Frustulia			1		
	Gomphoneis	2	2	1		5
	Gomphonema					1
	Naviculoid diatoms	1		2		
	Nitzschia	5	1			4
	Surirella				1	
	Synedra	3	3	3	3	6

Appendix 3. Macroinvertebrate results

Macroinvertebrate data (Ryder Consulting, May 2012).

TAXON	MCI score	Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui River at Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
						R						
COLEOPTERA												
Berosus species	5											
Elmidae	6	A			C	C	A	C	VA			
CRUSTACEA												
Isopoda	5											
Ostracoda	3		C			R				R		
Paracalliope fluviatilis	5		A		R	C					VVA	VVA
Paranephrops zealandicus	5											
DIPTERA												
Aphrophila species	5			C			A	R	C			
Austrosimulium species	3						C				C	
Ceratopogonidae	3		R									
Chironomus species	1					R						R
Empididae	3					R	R					
Culicidae	3									R		
Eriopterini	9						R		R			
Ephydridae	4											
Maoridiamesa species	3	R					R					R
Muscidae	3	R		C		C	R		C			
Orthocladiinae	2	C	C	C	A	VA	A	R	A	R	A	A
Podonominae	8	R			C				R		R	
Polypedilum species	3											

Appendix 3 continued

TAXON	MCI score	Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui River st Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
DIPTERA												
Stratiomyidae	5										R	
Tanypodinae	5	R			A	R	R					
Tanytarsini	3	R			A	A					R	
EPHEMEROPTERA												
Coloburiscus humeralis	9	R										
Deleatidium species	8	C	R	VA	C		VA	VA	VA			
Nesameletus species	9			R		R	A	R				
Oniscigaster species	10	R										
MEGALOPTERA												
Archichauliodes diversus	7	C		C	R		C	C				
MOLLUSCA												
Gyraulus species	3		A		R	A				VA		
Physa / Physella species	3		C		R	A				A	C	A
Potamopyrgus antipodarum	4	VA	VVA	VA	VA	VA	VA	C	C	A	VVA	VVA
Sphaeriidae	3		A							C		A
OLIGOCHAETA	1	C	VA		C	R		R	R		A	C
ODONATA												
Austrolestes colensonis	6										R	
Xanthocnemis zealandica	5									A		
NEMATODA	3					R						
OLIGOCHAETA	1	C	VA		C	R		R	R		A	C
PLATYHELMINTHES	3									R		
Temnocephala novaezealandiae	3											
PLECOPTERA												
Stenoperla species	10	R					R	R				

Appendix 3 continued

TAXON	MCI score	Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui River at Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
PLECOPTERA												
Zelandobius species	5											
Zelandoperla species	10											
TRICHOPTERA												
Aoteapsyche species	4			C	R	A	A	C			R	
Costachorema xanthopterum	7	R					R					
Helicopsyche species	10						R					
Hudsonema alienum	6											
Hudsonema amabile	6	C	R		R	C		R		R		
Hydrobiosidae early instar	5											
Hydrobiosis clavigera group	5						R		C			
Hydrobiosis umbripennis group	5	R		R		C	C		R			
Neurochorema species	6				R	R						R
Olinga species	9	A	R		R		A	A				
Oxyethira albiceps	2	R			A	C			C		R	
Paroxyethira species	2											
Plectrocnemia maclachlani	8											
Polyplectropus species	8					C						
Psilochorema species	8	C	R	R	R	R	C	C	C			R
Pycnocentria species	7	R				C						
Pycnocentrodes species	5	A	A	C	A	VVA	A	A	C			R
Number of taxa		22	14	11	19	25	22	14	14	10	12	11
Number of EPT taxa		12	5	6	8	10	11	8	6	1	2	3
MCI score		116	90	109	100	88	118	120	101	70	77	75
SQMCI score		5.1	3.6	5.8	4.0	4.4	5.9	7.4	6.3	3.4	4.4	4.4

Appendix 4. Habitat data

Habitat data P2b (Ryder Consulting, January 2012).

Site name		**Island Stream at Kuriheka**	**Island Stream at Maheno**	**Kakanui River at Clifton Falls**	**Kakanui River at Mill Dam**	**Kakanui River at McCone's**	**Kauru River at Ewings**	**Kauru River at Rodger's Crossing**	**Kauru River at Kakanui Valley Road Bridge**	**Waiareka Creek at Queen's Flat**	**Waiareka Creek at Kia Ora**	**Waiareka Creek at Taipo Road**
Sampling date	**9 January 2012**											
Pool 1	Max depth (m)	0.55	0.5	4.5	1		0.35			0.6	0.73	1.2
	Sediment depth (m)	0.05	0.05	0	0.03		0			0.25	0.04	0
	Crest depth (m)	0.3	0.2	0.5	0.5		0.2			0.45	0.35	0.3
Pool 2	Max depth (m)				0.9		0.5				0.68	
	Sediment depth (m)				0.03		0				0	
	Crest depth (m)				0.4		0.2				0.22	
Pool 3	Max depth (m)						0.55					
	Sediment depth (m)						0					
	Crest depth (m)						0.15					

Appendix 4. continued

Habitat data P2c (Ryder Consulting, January 2012).

	Sampling date 9 January 12	Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui River at Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
Riffle												
Bed Substrate	% Concrete/artificial	0	0	0		0	0	0			0	
	% Bedrock (>4000mm)	0	0	30		0	0	0			0	
	% Boulder (256– 4000mm)	20	10	35		5	10	10			60	
	% Cobble (64 - 255 mm)	70	70	35		80	80	80			30	
	% Gravel (2 – 63 mm)	10	20	0		15	10	10			10	
	% Silt, sand, mud (< 2 mm)	0	0	0		0	0	0			0	
	% embeddedness	5	0	0		5	0	0			10	
	Substrate compactness	2	0	1		1	1	1			2	
	% Deposition & scouring	0	0	0		0	0	0			0	
Organic Matter	% Macrophytes	0	0	0		0	0	0			20	
	% Moss	0	0	5		0	0	0			0	
	% Algae	50	30	30		90	0	0			50	
	% Woody debris & leaf packs	0	0	0		5	0	0			0	
Fish Habitat	% Obstructions to flow	0	0	10		0	0	0			0	
	% Bank cover	10	80	10		0	0	0			10	

Appendix 4. continued

Habitat data P2c (Ryder Consulting, January 2012).

	Sampling date 9 January 12	Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui River at Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
Run												
Bed Substrate	% Concrete/artificial	0	0	0	10	0	0	0	0	0	0	10
	% Bedrock (>4000mm)	0	0	40	0	0	0	0	0	0	0	0
	% Boulder (256– 4000mm)	20	0	30	15	5	10	10	0	0	0	0
	% Cobble (64 - 255 mm)	70	50	30	70	80	80	80	40	0	50	60
	% Gravel (2 – 63 mm)	10	50	0	5	15	10	10	60	0	50	30
	% Silt, sand, mud (< 2 mm)	0	0	0	0	0	0	0	0	100	0	0
	% embeddedness	10	10	0	10	5	0	0	0	0	0	0
	Substrate compactness	2	2	1	2	1	1	1	0	1	1	1
	% Deposition & scouring	0	10	0	0	0	0	0	0	100	0	0
Organic Matter	% Macrophytes	0	70	0	0	0	0	0	0	100	30	20
	% Moss	0	0	5	0	0	0	0	0	0	0	0
	% Algae	50	30	30	80	90	0	0	20	0	30	10
	% Woody debris & leaf packs	0	0	5	0	5	0	0	0	0	0	5
Fish Habitat	% Obstructions to flow	0	0	10	0	0	0	0	0	0	0	0
	% Bank cover	10	80	10	50	30	0	0	0	50	100	50

Appendix 4. continued

Habitat data P2c (Ryder Consulting, January 2012).

	Sampling Date 9 January 12	Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui River at Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
Pool												
Bed Substrate	% Concrete/artificial	0	0	0	10					0	5	0
	% Bedrock (>4000 mm)	0	0	5	0					0	0	0
	% Boulder (256-4000 mm)	10	0	5	10					0	0	0
	% Cobble (64-255 mm)	40	80	40	65					0	65	70
	% Gravel (2-63 mm)	50	20	50	10					0	20	30
	% Silt, sand, mud (< 2 mm)	0	0	0	5					10	10	0
	% embeddedness	20	30	0	50					0	30	0
	Substrate compactness	3	2	1	2					1	3	1
	% Deposition & scouring	10	10	0	0					100	10	0
Organic Matter	% Macrophytes	0	90	0	50					100	60	35
	% Moss	0	0	0	0					0	0	0
	% Algae	10	0	0	50					0	10	10
	% Woody debris & leaf packs	10	0	0	0					0	0	10
Fish Habitat	% Obstructions to flow	0	0	0	0					0	0	0
	% Bank cover	30	30	60	50					50	80	70

Appendix 4. continued

Habitat data P2d (Ryder Consulting, January 2012).

Site name		Island Stream at Kuriheka	Island Stream at Maheno	Kakanui River at Clifton Falls	Kakanui Rive atr Mill Dam	Kakanui River at McCone's	Kauru River at Ewings	Kauru River at Rodger's Crossing	Kauru River at Kakanui Valley Road Bridge	Waiareka Creek at Queen's Flat	Waiareka Creek at Kia Ora	Waiareka Creek at Taipo Road
Buffer width	Left	1	1	4	4	3	2	2	4	4	3	2
	Right	3	3	4	4	3	2	2	4	2	3	2
Buffer intactness	Left	3	4	5	4	4	4	4	4	5	5	3
	Right	4	4	5	4	3	3	3	3	5	5	4
Vegetation composition of buffer	Left	1	2	2	3	3	2	2	2	2	2	2
	Right	3	2	2	3	3	2	2	2	2	2	2
Vegetation composition of land adjacent to buffer	Left	2	1	2	2	2	2	2	2	3	2	1
	Right	2	1	3	2	2	2	2	2	1	2	2
Bank stability	Left	3	4	4	5	4	3	3	1	5	5	3
	Right	4	4	5	4	4	1	1	1	5	5	5
Livestock access	Left	2	3	5	4	3	4	4	4	4	5	4
	Right	2	3	5	4	2	4	4	4	4	5	4
Riparian soil denitrification potential	Left	3	3	4	3	3	3	3	3	5	3	3
	Right	3	3	3	3	3	3	3	3	5	3	3
Land slope 0-30 m from stream bank	Left	3	5	3	4	4	5	5	5	4	4	3
	Right	2	4	2	4	4	5	5	5	4	3	3
Groundcover of buffer	Left	4	5	5	4	4	4	4	4	5	5	5
	Right	4	5	4	5	4	3	3	4	5	5	5
Ground cover of land adjacent to buffer	Left	4	4	5	3	3	4	4	4	5	5	1
	Right	4	4	4	3	3	4	4	4	5	5	4
Soil drainage	Left	3	3	4	3	3	3	3	3	4	3	2
	Right	3	3	3	3	3	3	3	3	4	3	3
Rills/channels	Left	5	5	5	5	5	5	5	5	5	5	5
	Right	5	5	5	5	5	5	5	5	5	5	5