Surface water quality

The Water of Leith and Lindsay's Creek

Kaikorai Stream

Waitati River and Carey's Creek

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Foreword

To help protect water quality, the Otago Regional Council (ORC) carries out long-term water quality monitoring as part of a State of the Environment programme. To supplement this information, targeted and detailed short-term monitoring programmes are also implemented in some catchments. This report provides the results from more detailed investigations carried out in three catchments:

- Water of Leith
- Kaikorai Stream
- Waitati River and Carey's Creek

The Water of Leith and Kaikorai Stream are both located in Dunedin and drain typical residential and industrial areas. Both watercourses have many stormwater outfalls which compromise water quality.

The Waitati River and Carey's Creek have little development in their catchments. The upper catchments are forested while lower in the catchment, pasture dominates. Water quality is generally very good.

This report forms a baseline study from which ORC and local community programmes can work together to address various issues in the catchments. It is hoped that these catchment programmes will promote environmentally sound practices which will sustain and improve water quality.

Executive summary

Between July 2007 and March 2008, the Otago Regional Council (ORC) carried out intensive water quality monitoring programmes in the following catchments:

- Water of Leith
- Kaikorai Stream
- Waitati River and Carey's Creek

The aim of this monitoring was to establish a baseline water quality. These rivers are considered important for various reasons and as such are listed in Schedule 1A, Schedule 9, Schedule 1D, Policy 7.6.1 and Policy 7.6.2 of the Water Plan (Water Plan).

The two urban catchments (Water of Leith and Kaikorai Stream) flow through residential and industrial areas and water quality is compromised by the many stormwater outfalls that discharge into the streams.

Results from this monitoring programme show that water quality in the Water of Leith and Lindsay's Creek is poor and it clearly deteriorates with distance from the head waters. Bacteria concentrations are extremely high at the downstream sites in both the Water of Leith and Lindsay's Creek, and Lindsay's Creek in particular shows a clear increase in nutrient concentrations with distance downstream. The macroinvertebrate health in both catchments is fair.

The Kaikorai Stream has a more complicated water quality pattern, as good quality water is introduced to Fraser's Stream from the Deep Stream and Deep Creek Catchments. The upper Kaikorai Stream has extremely poor water quality with elevated nutrient and bacteria concentrations, and while there is a slight improvement in water quality downstream of the Fraser's Creek confluence, relevant water quality guideline values are generally exceeded. The macroinvertebrate health in the Kaikorai Stream is extremely poor and this reflects the poor water quality.

The Waitati River and Carey's Creek have forested upper catchments (indigenous forest, deciduous hardwoods and pine forests), while lower in the catchment, pasture dominates. There is little development in either catchment. The water quality results from this monitoring programme show that the Waitati River and Carey's Creek have good water quality with few individual samples exceeding relevant guideline levels.

Table of contents

List of tables

List of figures

1. Introduction

The Otago Regional Council (ORC) is responsible for promoting the sustainable management of Otago's rivers and undertakes a surface water quality monitoring programme to fulfil its responsibilities under the Resource Management Act (1991), the Regional Policy Statement and the Regional Plan: Water (Water Plan).

The State of the Environment (SOE) monitoring programme involves regular monitoring of physico-chemical and microbiological water quality in selected lakes, rivers and streams. To complement the SOE monitoring programme, more intensive water quality surveys are undertaken, involving more regular monitoring, particularly over the summer period.

The more intensive monitoring is important because it helps ORC gauge the state of the region's rivers and streams; it also provides feedback on the effectiveness of policies in the Water Plan and it enables informed decision making on how water resources are managed.

This report summarises results from three intensive monitoring programmes:

1. The Water of Leith and Lindsay's Creek which flow through Dunedin City. This densely populated urban catchment presents a number of inherent problems to water quality, including stormwater overflows and degraded habitat.
2. The Kaikorai Stream is another water course situated in a densely populated catchment. It has a wide range of land use activities and consequently a wide array of potential contaminants to water.
3. Carey's Creek and the Waitati River flow through generally undeveloped catchments with forestry and native vegetation being the dominant land use. Both rivers generally enjoy high quality water which provides opportunities for varied use, including domestic and public water supply and irrigation.

The primary objective in each of the three programmes was to assess the state of water quality to establish a baseline water quality. This was done by looking at individual analytes and also by linking the water quality results to the Water Quality Index.

The reporting period for the three surveys was between July 2007 and March 2008.

1.1 Water quality guidelines

Most of the guidelines used in this report are the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) default trigger values for aquatic ecosystems (referenced as ANZECC 2000).

These trigger values are intended to be compared with the *median* values over a period of time. They are not statutory standards and exceedances do not necessarily mean an adverse environmental effect would result, but act as an early warning mechanism of potential problem or a change in water quality that may warrant investigation.

The best reference conditions or guideline values are set by locally appropriate data. The ANZECC (2000) guidelines therefore recommend deriving site-specific trigger values for different catchments where possible, using a minimum of two years of water quality results from continuous monthly sampling (24 samples) from appropriate reference sites.

Table 1.1 Summary of physico-chemical and microbiological analytes and guideline values

Analyte	Abbreviation	Guideline Value	Reference
Ammoniacal nitrogen	NH4	≤0.9	ANZECC & ARMCANZ (2000)
Nitrite/nitrate nitrogen	NNN	≤0.444	ANZECC & ARMCANZ (2000)
Total nitrogen	TN	≤0.614	ANZECC & ARMCANZ (2000)
Dissolved reactive phosphorus	DRP	≤0.01	ANZECC & ARMCANZ (2000)
Total phosphorus	TP	≤0.033	ANZECC & ARMCANZ (2000)
Water temperature	Deg C	<20	-
Dissolved oxygen	DO	≥80	RMA 1991 Third Schedule
Escherichia coli	Ec	126	Department of Health 1992
pH	pH	6.5-9.0	ANZECC (1992)
Conductivity	Cond	-	-
Turbidity	Turb	≤5.6	ANZECC & ARMCANZ (2000)

1.1.1 Water Quality Index Classification

The Water Quality Index (WQI) was used to allow inter-site comparisons about the state of water quality in the three surveys undertaken.

The WQI for each site was derived from the median values for the following six variables: turbidity, DO (% saturation), DRP, NH4, NNN and *E. coli* bacteria. The median values were then assessed against national water quality guidelines. This approach has been used elsewhere at both a regional level (e.g. Stark and Maxted 2004, Milne and Perrie 2006) and a national level (e.g. Larned *et al*. 2005).

The application of the WQI enables water quality at each site to be classified into one of four categories (Table 1.2) to provide a snapshot of water quality. The categories only indicate how many variables meet guideline standards. Table A2.1 in Appendix 2 goes into more detail by indicating which guidelines were exceeded.

Table 1.2 Water Quality Index Classification

Classification	Definition
Very Good	Median values for all six variables comply with guideline values
Good	Median values for five of the six variables comply with guideline values (DO is one variable which must comply)
Fair	Median values for three or four of the six variables comply with guideline values.(DO is one variable which must comply)
Poor	Median values for two or less of the six variables comply with guideline values
WQI variables	
Turbidity	Caused by suspended matter and interferes with the passage of light through water
DO	Important indicator of the ability of water to support aquatic life
DRP	Growth-limiting nutrient affected by e.g. wastewater effluent, fertilisers and animal waste
NH_4	Can be toxic to fish depending on temperature and pH conditions. Affected by runoff of animal wastes, dairy shed effluent and fertiliser
NNN	Nutrient essential for growth. Affected by e.g. wastewater effluent, agricultural runoff and animal wastes
E.coli	Indicator of faecal contamination (affected by e.g. wastewater effluent, animal waste, sediment load)

1.2 Macroinvertebrate monitoring

Macroinvertebrates include insect larvae (e.g. caddisflies, mayflies and stoneflies), aquatic worms (oligochaetes), aquatic snails, and crustaceans (e.g. amphipods, isopods and freshwater crayfish). Because different macroinvertebrate species have different tolerances to environmental factors such as dissolved oxygen, chemical pollutants and fine sediment, the presence or absence of different species can also indicate changes in water quality. The following biotic indices are widely used as a tool to help interpret the health of a waterway:

Species richness is the total number of species (or taxa) collected at a sampling site. In general terms, high species richness may be considered good, though often mildly impacted or polluted rivers with slight nutrient enrichment can have higher species richness than naturally healthy streams and rivers.

The *EPT species* is an index which is a sum of the total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) species collected. These groups of insects are often the most sensitive to organic and mineral pollution therefore low numbers of these species might indicate a polluted environment. In some cases, the percentage of EPT species compared to the total number of species found at a site can give an indication of the importance of these species in the overall community.

The *Macroinvertebrate Community Index* (MCI) was developed by Stark (1985, 1993, 1998) to assess organic enrichment of stony or hard-bottomed streams based on sampling macroinvertebrates from riffle habitats. It is an index based on adding the pollution tolerance scores of all species found at a site. Species that are very sensitive to pollution score highly, whereas more pollution tolerant species receive a low score.

The *Semi-quantitative Macroinvertebrate Community Index* (SQMCI) is a variation of the MCI that accounts for the abundance of pollution sensitive and tolerant species. The SQMCI is calculated from coded count data (individual taxa counts are assigned to one of Rare (R), Common (C), Abundant (A), Very Abundant (VA) or Very Very Abundant (VVA) abundance classes).

Table 1.3 Criteria for macroinvertebrate health according to different macroinvertebrate indices

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

2. Water of Leith and Lindsay's Creek

Routine physico-chemical water quality monitoring has been undertaken in the Water of Leith Catchment since 1995. More intensive monitoring was undertaken in the Water of Leith and its principal tributary, Lindsay's Creek, between July 2007 and March 2008.

The Water of Leith has a catchment area of 42.1km^2 and flows into the Pacific Ocean at Otago Harbour, Dunedin.

Figure 2.1 Aerial photograph showing the confluence of the Water of Leith and Otago Harbour

The main stem of the Water of Leith has a significant number of natural values, including significant trout spawning and a significant presence of salmon and trout. For this reason, it is listed in Schedule 1A of the Water Plan.

Cultural values associated with food gathering and processing (mahika kai) and the protection of nursery and breeding areas for native fish and birds (kohanga) have been identified as important in the Water of Leith. These and other cultural values are listed in Schedule 1D of the Water Plan.

Historical water quality monitoring of the Water of Leith has shown that water quality is degraded, particularly in its lower reaches. Policy 7.6.1 of the Water Plan acknowledges that water quality needs enhancing so that it becomes suitable to support primary contact recreation.

The Water of Leith has numerous values listed in the Water Plan and poor water quality has a major impact on these values. There are no large consented discharges into the Water of Leith; it is the urban nature of the catchment with numerous stormwater outfalls discharging into the river that compromises its water quality.

2.1 Background information

2.1.1 Water of Leith and Lindsay's Creek Catchment

The Water of Leith rises at the saddle between Mount Cargill and Swampy Hill and flows into Otago Harbour, Dunedin. It has a course of slightly over 11.6km with a catchment area of 42.1km^2. The total fall in the river is approximately 365m and, for a considerable distance, the Leith flows in a narrow valley with steep slopes rising to the hills, Mount Cargill (680m) to the east, Flagstaff Hill (668m) and Swampy Spur (665m) to the west. There are numerous tributary streams, the principal of which are West Branch, Morrison's Creek, Cedar Creek, Nichol's Creek and Ross Creek on the right bank and Cargill Creek, Pine Hill Creek and Lindsay's Creek on the left bank.

Lindsay's Creek is the main tributary of the Water of Leith, rising on the upper slopes of Mount Cargill at an elevation of approximately 518m and has a course of about 6.8km to its junction with the Water of Leith at the Botanical Gardens, roughly 2km upstream from Otago Harbour.

Both the Water of Leith and Lindsay's Creek are very liable, from the character of their catchment areas, to sudden extreme floods.

2.1.2 Land use

The Land Cover Data Base gives a breakdown of land use in the area. Figure 2.2 shows that in the upper catchments indigenous hardwoods, harvested forest, manuka, kanuka, grassland and pine forest dominate, while in the lower catchment the bottom and side slopes of the valley are occupied to a large degree by streets and buildings, parks and open spaces and a large surface mine.

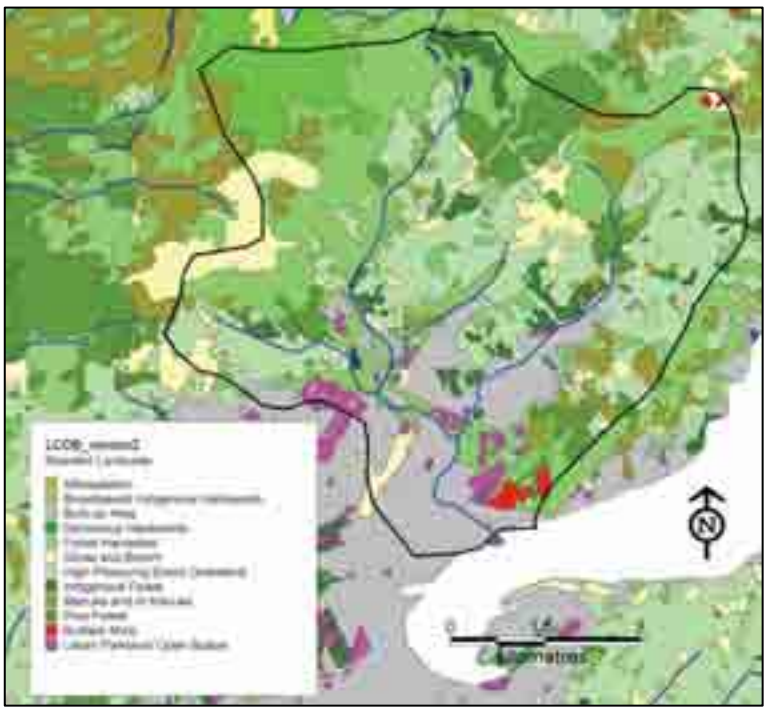

Figure 2.2 Map of land use in the Water of Leith Catchment

2.2 Surface water quality monitoring

2.2.1 Water quality monitoring sites

Water quality monitoring has been undertaken at various sites on the Water of Leith since 1995. The sites still monitored are the main stem Water of Leith at Dundas Street and the main tributary, Lindsay's Creek, at North Road Bridge.

In addition to these two sites, between July 2007 and March 2008, monthly monitoring was undertaken at an additional four sites. All monitoring sites are listed in Table 2.1 and the location of these sites is shown in Figure 2.3.

Figure 2.3 Location of Otago Regional Council monitoring sites on the Water of Leith

Table 2.1 Water quality monitoring sites on the Water of Leith Catchment, July 2007 to March 2008

River	Site	Northing	Easting
Lindsay's Creek	Bethune's Gully	2319700	5483000
Lindsay's Creek	North Road Bridge	2317550	5481090
Lindsay's Creek	15 m u/s Leith confluence	2317300	5480500
Water of Leith	Sullivan's Dam*	2317320	5485890
Water of Leith	Malvern Street*	2316130	5481880
Water of Leith	Dundas St bridge	2317200	5480000
Water of Leith	u/s Lindsay's confluence	2317154	5480387
* The Sullivan's Dam site was monitored in July and August only. Access difficulties meant the site was moved to Malvern Street for the September to March samples. In this report the site is referred to as Malvern Street.			

2.2.2 Rainfall

The amount of rainfall 72 hours prior to each sampling period was determined at Sullivan's Dam rain-gauge and Mooyman homestead rain-gauge (shown in Figure 2.3). Limited rainfall fell in this period and amounts are detailed in Table 2.2.

Table 2.2 Total daily rainfall recorded at Sullivan's Dam rain-gauge and Mooyman's homestead rain-gauge 24 hrs, 48 hrs and 72 hrs prior to each sampling run

	Jul 2007	Aug 2007	Sep 2007	Oct 2007	Nov 2007	Dec 2007	Jan 2008	Feb 2008	Mar 2008
Sullivan's									
24 hrs	0.3	3.5	1.4	0.5	6.3	7.6	-	-	0
24 to 48 hrs	0.6	18.8	1.4	3.2	6.3	8.9	-	-	1.1
48 to 72 hrs	2.1	23.1	3	10.1	8	12.5	-	-	1.1
Mooyman's									
24 hrs	0	0.5	0.5	0	20	0.5	0.5	-	0
24 to 48 hrs	-	5.5	1	0.5	20.5	4.5	0.5	-	0
48 to 72 hrs	2	16.5	3	5.5	21	5	0.5	-	0

2.2.3 Flow

The ORC has continuous flow records for the Water of Leith catchment. Recording stations are located on the main stem at the University footbridge and Lindsay's Creek at North Road (shown in Table 2.3).

Table 2.3 shows mean flow on the day of sampling, as well as the monthly mean flows.

Table 2.3 Mean flow on day of sampling and monthly mean flows recorded at West Branch Bridge (cumecs)

	Mean flow on sampling date		Monthly mean flow	
	University	**North Road**	**University**	**North Road**
July 2007	0.615	0.67	1.3	0.425
August 2007	0.934	1.307	0.269	0.142
September 2007	0.469	0.453	0.184	0.095
October 2007	0.344	0.398	0.482	0.216
November 2007	0.652	0.39	0.128	0.039
December 2007	0.353	0.726	0.177	0.081
January 2008	0.525	0.449	0.12	0.069
February 2008	0.248	0.269	0.241	0.103
March 2008	0.184	0.230	0.314	0.257

2.2.4 Historical results

A summary of the water quality results for the Water of Leith at Dundas Street and Lindsay's Creek upstream of the Water of Leith are given in Table 2.4.

Key water analytes were compared with the ANZECC 2000 default trigger values for slightly disturbed lowland river ecosystems in New Zealand.

Table 2.4 Median water quality results for the Water of Leith at Dundas Street (February 1995 to January 2008) and Lindsay's Creek upstream of the Water of Leith (January 1998 to January 2008) with exceedances of guideline values indicated in bold type

Site	Turbidity (NTU)	*E. coli* (n/100ml)	Ammoniacal N (mg/l)	Nitrite/nitrate N (mg/l)	Total N (mg/l)	Dissolved reactive P (mg/l)	Total P (mg/l)
ANZECC 2000	5.6	260*	0.9	0.444	0.614	0.010	0.033
Water of Leith	3.2	**445**	0.02	0.362	**0.65**	**0.017**	**0.041**
Lindsay's Ck	3.8	**1100**	0.02	**0.666**	**1.095**	**0.019**	**0.046**

*Acceptable/Green Mode of the Ministry for Environment/Ministry of Health (2003) Recreational Water Quality Guidelines

Table 2.4 indicates that nutrient and bacteria concentrations at both sites are above the recommended guidelines for DRP, TP, TN and *E. coli*; however, the NH_4 results were below 0.9 mg/l and the free ammonia component (after considering temperature and pH) was less than the guideline value of 0.021 mg/l. The median *E. coli* bacteria concentration is also extremely high and a high percentage (59% in the Water of Leith and 93% in Lindsay's Creek) of all results recorded exceeded the Ministry for the Environment/Ministry of Health's (2003) Microbiological Water Quality Guidelines for Recreational Areas, indicating it would be unwise to undertake contact recreation activities such as swimming at these sites.

2.3 Surface water quality monitoring 2007-2008

Table 2.5 summarises the results of the more intensive monitoring undertaken between July 2007 and March 2008. Full results are detailed in Appendix 1.

Table 2.5 Median water quality results for the Water of Leith (July 2007 to March 2008) with exceedances of guideline values indicated in bold type

Site	Turbidity (NTU)	E. coli** (cfu/ 100ml)	Ammoniacal N (mg/l)	Nitrite/ Nitrate N (mg/l)	Total N mg/l	Dissolved reactive P (mg/l)	Total P (mg/l)
Guideline*	**5.6**	**260**	**0.9**	**0.444**	**0.614**	**0.01**	**0.033**
Water of Leith							
Malvern Street	4.69	110	0.01	**0.667**	**0.99**	**0.017**	**0.041**
u/s Lindsay's Ck	4.09	**2000**	0.01	0.368	**0.62**	**0.029**	**0.045**
Dundas St Br	3.61	**1800**	0.01	0.383	**0.72**	**0.028**	**0.043**
Lindsay's Creek							
Bethune's Gully	2.42	74	0.005	**0.584**	**0.69**	**0.015**	0.031
North Road Br	3.24	**640**	0.02	**0.632**	**0.85**	**0.015**	0.033
u/s Leith	4	**1100**	0.02	**0.874**	**1.1**	**0.022**	**0.052**
*ANZECC 2000 Default Trigger Value for lowland rivers **Acceptable/Green Mode of the Ministry for Environment/Ministry of Health (2003) Recreational Water Quality Guidelines							

Table 2.5 indicates that water quality can be compromised throughout the catchment. None of the sites had water quality that was of better quality than all the relevant guideline values.

In the following section results from water quality monitoring were compared against guideline values (refer to Table 2.2). Rainfall (mm) and flow (cumecs) were also plotted on relevant graphs.

2.3.1 *E. coli*

Table 2.5 shows that the median *E. coli* bacteria concentrations are elevated at all sites other than at the upper two sites, Bethune's Gully in Lindsay's Creek and Malvern Street in the Water of Leith.

As bacteria are not normally distributed, it is usual to back-transform the logged mean data (see Appendix 3). When this was performed on the Water of Leith, it was clear that the only sites without elevated *E. coli* levels were in the upper catchment.

Figure 2.4 clearly shows the four sites where recommended recreational water quality guidelines are not met, indicating it would be unwise to undertake contact recreation activities at these sites.

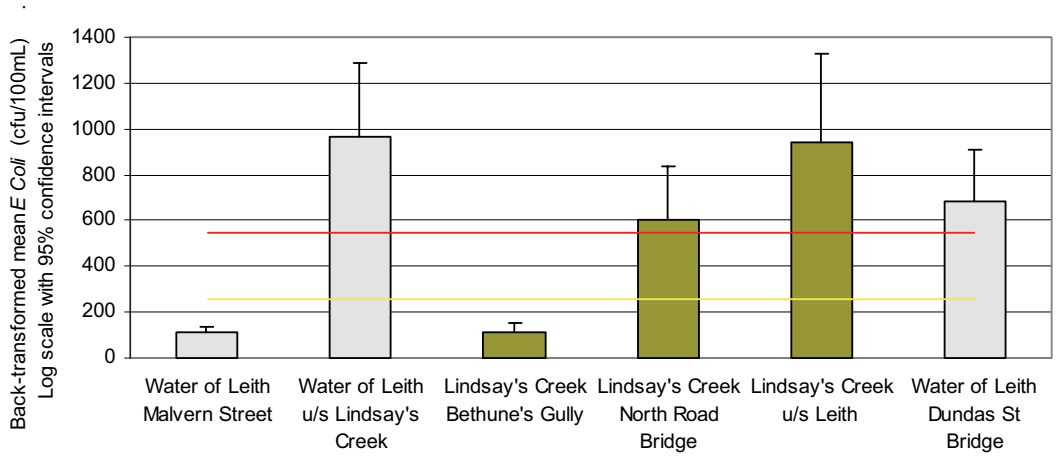

Figure 2.4 Back-transformed mean *E. coli* concentrations with 95% confidence intervals. The red line depicts the MfE/MoH 2003 Action/Red Mode (above 550 Ec/100ml) and the yellow line depicts the MfE/MoH 2003 Acceptable/Green Mode (below 260 Ec/100ml)

Individual *E. coli* values were plotted against rainfall and flow to see whether there was any correlation between high bacteria counts and heavy rainfall (using the 48 hr rainfall recorded at Sullivan's Dam). Figure 2.5 shows that the high rainfall just prior to the water quality sampling in August, November and December does not appear to have a great influence on bacteria numbers. There may be some seasonal response to bacteria levels with lower levels in July to September and higher levels corresponding to the warmer months. There was not much variation in flow during the sampling period; the higher flows seen did not correspond to sampling events, other than in March, when sampling coincided with a flow of 0.953 cumecs. This elevated bacteria levels at all sites to exceed the MfE/MoH alert level. Dundas Street had the lowest count at 1800 cfu/100ml and Malvern Street had the highest count at 4400 cfu/100ml.

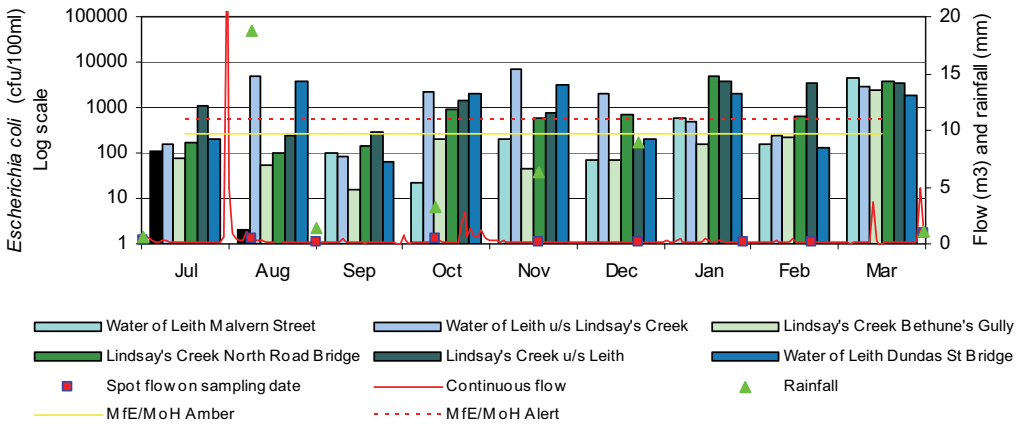

Figure 2.5 *E. coli* (cfu/100ml) levels plotted against the total 48 hr rainfall (mm) recorded at Sullivan's Dam and mean daily flow (cumecs) recorded at the University Footbridge. The sites shown in black were taken at Sullivan's Dam

2.4 Ammoniacal nitrogen

Ammoniacal nitrogen is the combination of ammonium ions and ammonia (NH_3). The ANZECC 2000 high reliability (95%) trigger value for freshwater is 0.9 mg/l. NH_3 is the main toxic component for aquatic organisms, the prevalence of which is dependent on the pH, temperature and salinity of the water. The ANZECC 2000 guideline for NH_3 is 0.021 mg/l. Table 2.5 gives the median values for ammoniacal nitrogen and these are shown graphically in Figure 2.6.

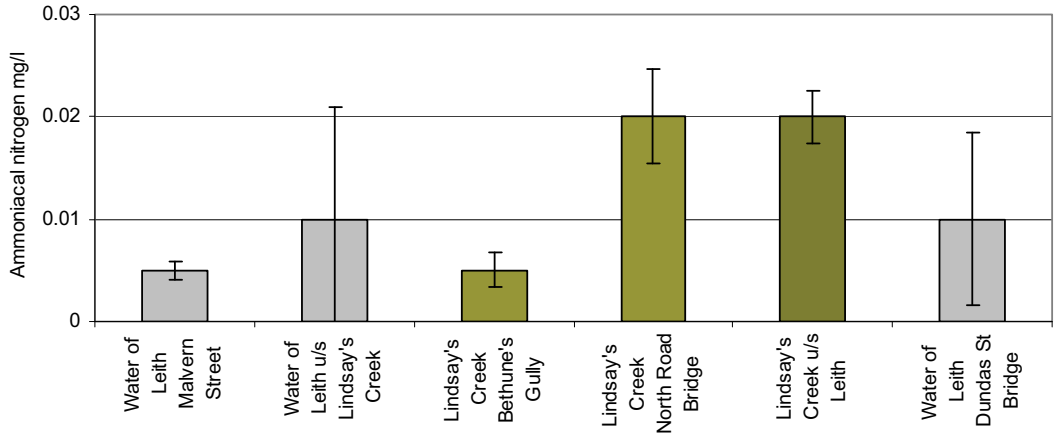

Figure 2.6 Median ammoniacal nitrogen concentrations at each monitoring site (July 2007 to March 2008)

Median NH_4 concentrations are not elevated at any of the sites monitored. The highest concentration recorded was 0.08mg/l, taken at Dundas St on 5 November 2007; however, this did not exceed the NH4 guideline level. In addition, after taking pH and temperature into consideration, the NH_3 guideline value of 0.021 mg/l was not exceeded at any site.

2.5 Nitrite/nitrate nitrogen

Figure 2.7 shows that median NNN results were elevated above the ANZECC 2000 default trigger guideline of 0.444 mg/l at all sites in Lindsay's Creek and at the Malvern Street site in the Water of Leith.

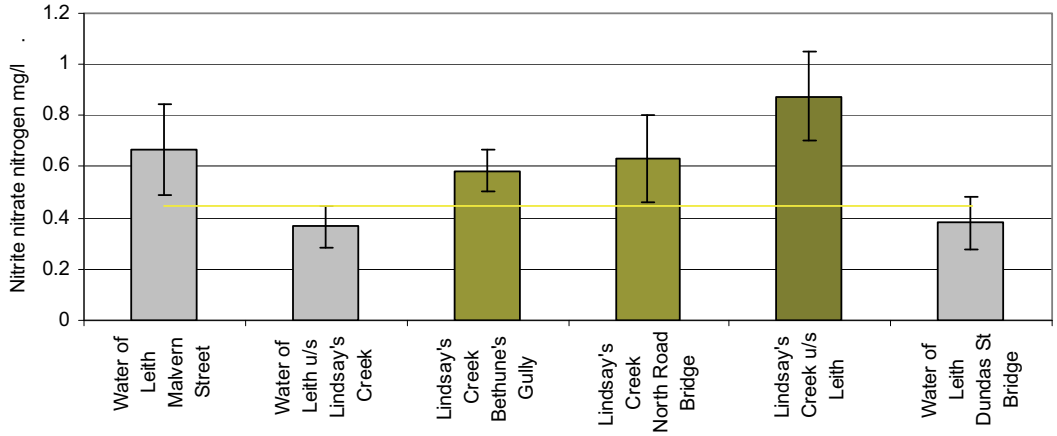

Figure 2.7 Median nitrite/nitrate nitrogen concentrations at each monitoring site (July 2007 to March 2008). The yellow line depicts the ANZECC 2000 default trigger guideline value for NNN (0.444 mg/l)

Figure 2.8 shows NNN concentrations for individual sites plotted against flow, rainfall and the ANZECC default trigger value (0.444 mg/l). The highest concentration of NNN recorded was at Malvern Street in March when sampling coincided with a flow of 0.953 cumecs. The concentration of NNN in winter is higher than during the summer months. Rainfall in August may account for the highest concentrations of NNN found; every site, except Sullivan's Dam, exceeded the ANZECC default trigger guideline of 0.444 mg/l.

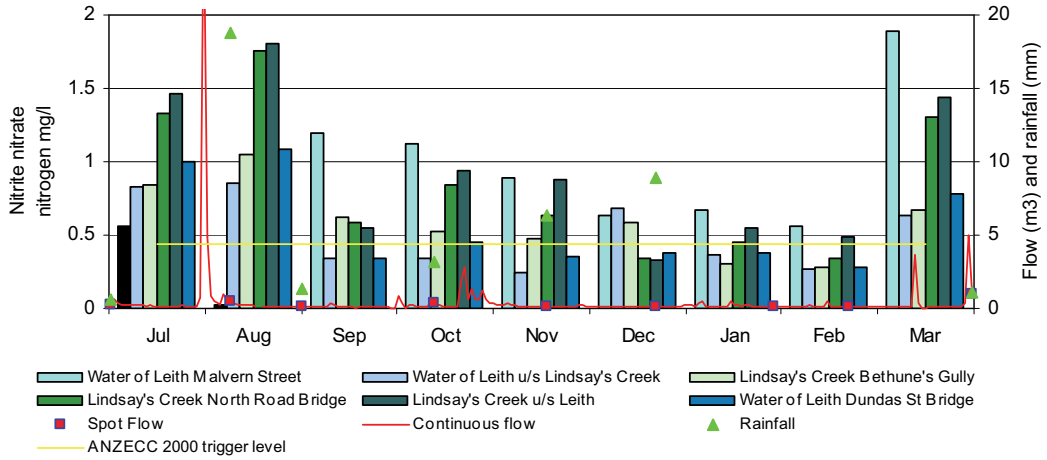

Figure 2.8 Nitrite/nitrate nitrogen (mg/l) concentrations plotted against the total 48 hr rainfall (mm) recorded at Sullivan's Dam and mean daily flow (cumecs) recorded at the University Footbridge. The sites shown in black were taken at Sullivan's Dam

2.6 Total nitrogen

Figure 2.9 shows median TN concentrations at each site. In Lindsay's Creek, the same pattern as nitrite/nitrate nitrogen is observed with concentrations increasing downstream.

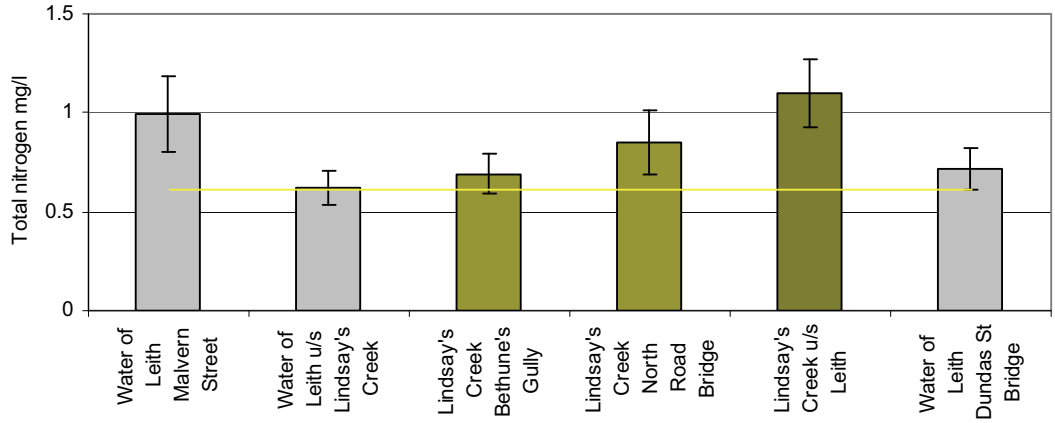

Figure 2.9 Median total nitrogen concentrations at each monitoring site (July 2007 to March 2008). The yellow line depicts the ANZECC 2000 default trigger guideline value for TN (0.614 mg/l)

The highest concentration of TN in the Water of Leith was found at Malvern Street; however, at all sites the median TN exceeded the ANZECC default trigger value of 0.614 mg/l.

When all individual results are plotted on a monthly basis against flow (Figure 2.10), it can be seen that the higher concentrations of TN are recorded in July, August and March, and lower results occur during the summer. The August sampling round

coincided with heavy rainfall recorded at the Sullivan's Dam rain-gauge, but flows were not affected.

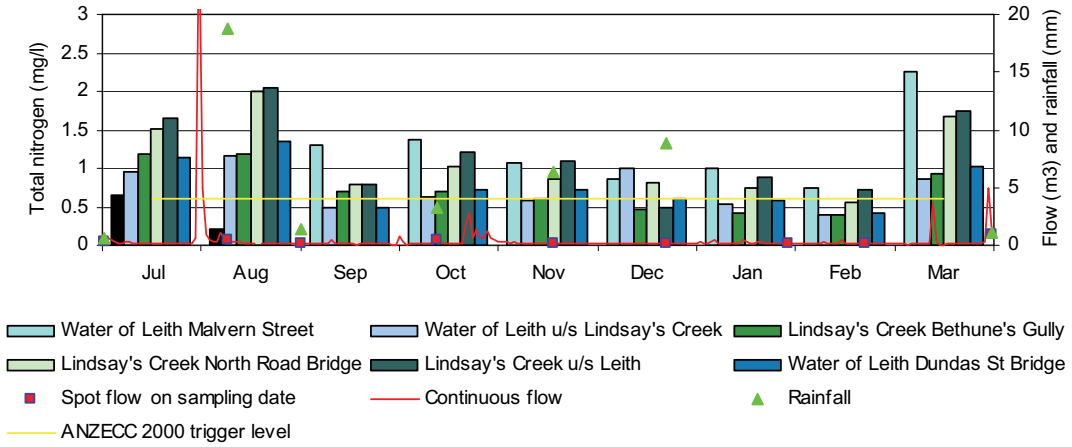

Figure 2.10 Total nitrogen (mg/l) concentrations plotted against the total 48 hr rainfall (mm) recorded at Sullivan's Dam and mean daily flow (cumecs) recorded at the University Footbridge. The sites shown in black were taken at Sullivan's Dam

2.7 Dissolved reactive phosphorus

Median DRP concentrations are shown in Figure 2.11. The median results from all sites exceed the ANZECC default trigger value.

The New Zealand Periphyton Guidelines give a value for DRP concentrations (0.026 mg/l) which has been predicted as the maximum to prevent excess periphyton biomass. There is a large increase in DRP concentrations in the two downstream Water of Leith sites, where both median values exceed this guideline.

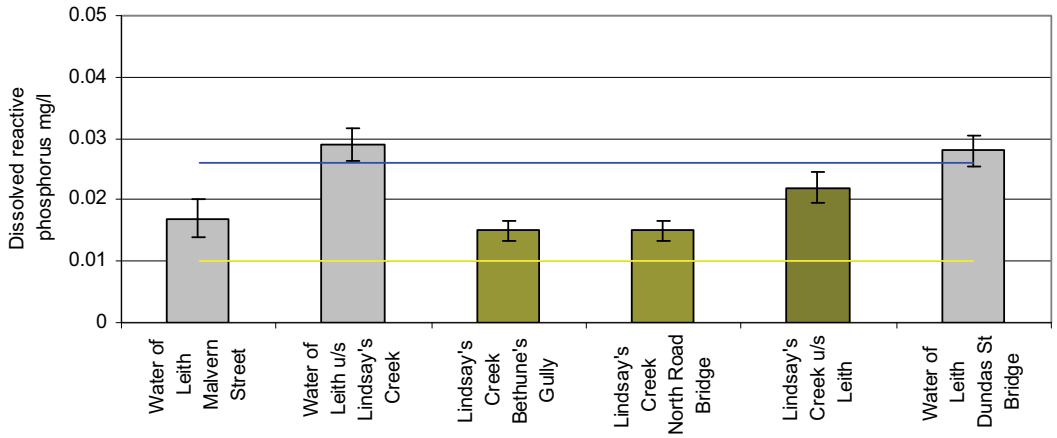

Figure 2.11 Median dissolved reactive phosphorus concentrations at each monitoring site (July 2007 to March 2008). The yellow line depicts the ANZECC 2000 default trigger guideline value for DRP (0.010 mg/l); the blue line depicts the NZ periphyton guideline (0.026 mg/l)

When individual sites are plotted against month of sampling (Figure 2.12), it shows that the higher concentrations of DRP occur in the summer months. It is only in December, January and February that at least half the sites exceed the NZ Periphyton Guideline value (0.026 mg/l).

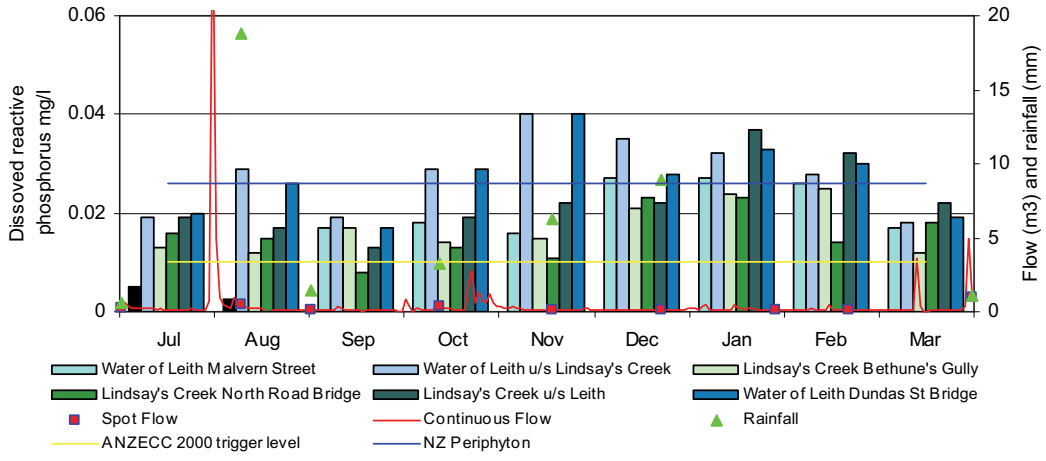

Figure 2.12 Dissolved reactive phosphorus (mg/l) concentrations plotted against the total 48 hr rainfall (mm) recorded at Sullivan's Dam and mean daily flow (cumecs) recorded at the University Footbridge. The sites shown in black were taken at Sullivan's Dam

2.8 Total phosphorus

Figure 2.13 shows median results for TP. The Water of Leith exceeds the ANZECC 2000 guideline values at all sites, but Lindsay's Creek only exceeds 0.33 mg/l at the lower site just upstream of the Leith.

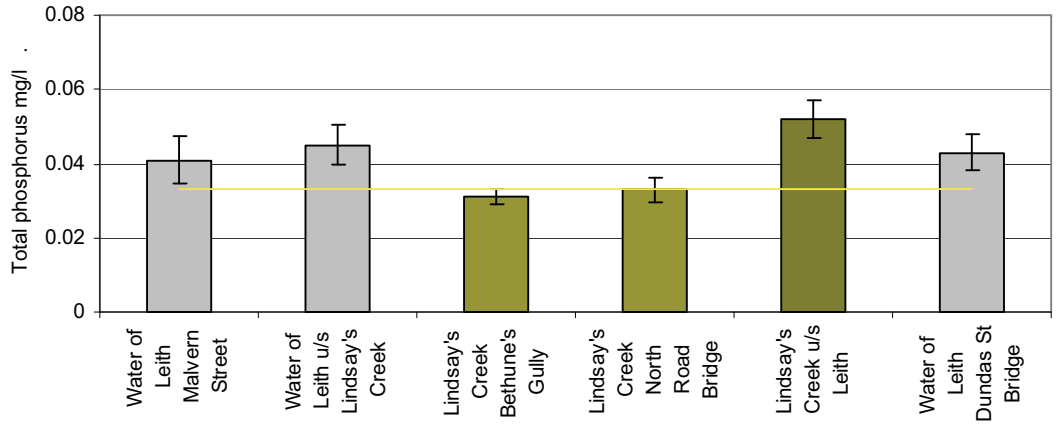

Figure 2.13 Median total phosphorus concentrations at each monitoring site (July 2006 to March 2007). The yellow line depicts the ANZECC 2000 default trigger guideline value for TP (0.033 mg/l)

When individual sites are plotted against month of sampling (Figure 2.14), it can be seen that the results in July, August and September are lower than the remainder of the sampling period. In September, none of the sites had concentrations of TP that exceeded the ANZECC 2000 default trigger value, while this value was met or exceeded at all sites in December and January.

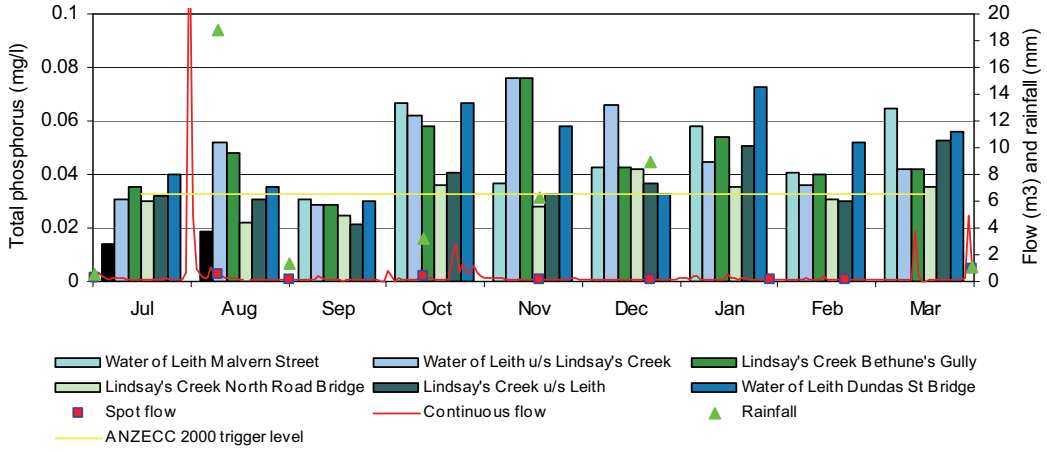

Figure 2.14 Total phosphorus (mg/l) concentrations plotted against the total 48 hr rainfall (mm) recorded at Sullivan's Dam and mean daily flow (cumecs) recorded at the University Footbridge. The sites shown in black were taken at Sullivan's Dam

2.9 Dissolved oxygen

Dissolved oxygen usually follows a different pattern to other analytes monitored with higher oxygen concentrations in the upper catchments which then decrease downstream. However, Figure 2.15 shows that in the Water of Leith, DO is high at all sites (exceeding the guideline level of 80%) with the lower sites recording some of the highest median concentrations. These higher concentrations downstream are likely to be primarily due to gradient morphology.

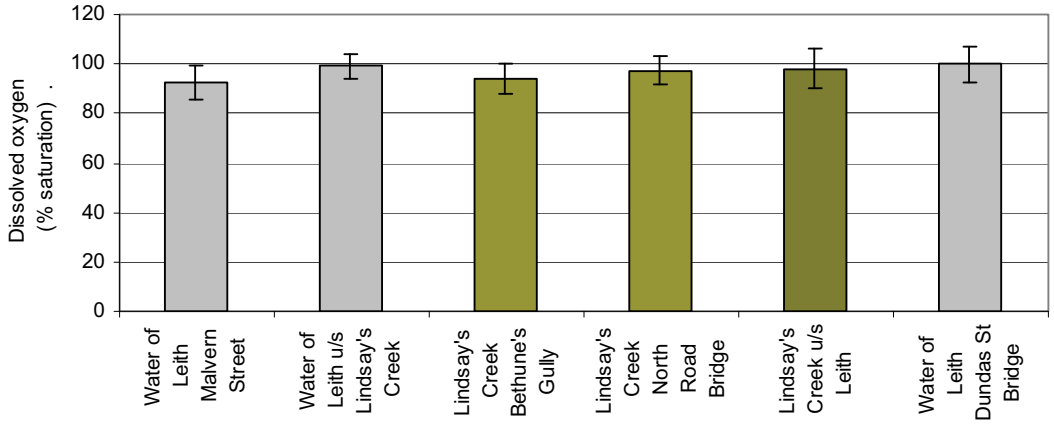

Figure 2.15 Median dissolved oxygen concentrations at each monitoring site (July 2007 to February 2008)

2.10 Turbidity

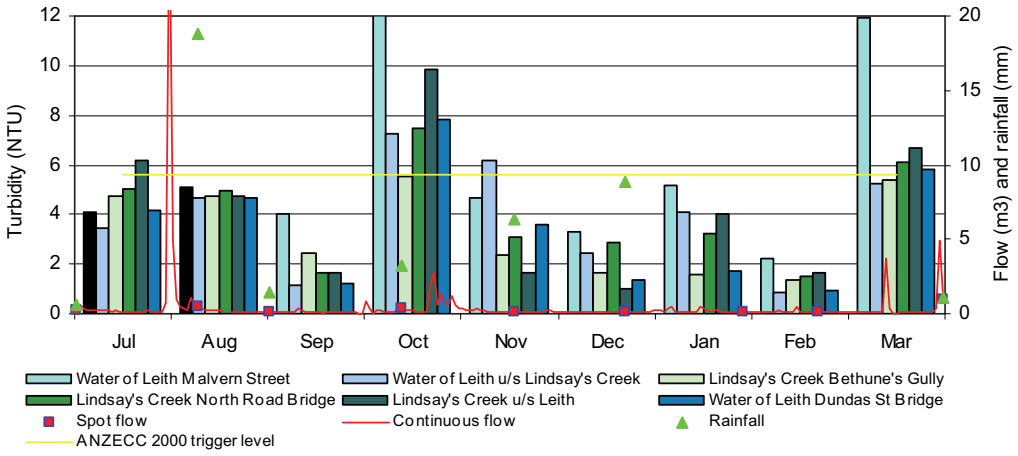

Figure 2.16 Turbidity (NTU) plotted against the total 48 hr rainfall (mm) recorded at Sullivan's Dam and mean daily flow (cumecs) recorded at the University Footbridge. The sites shown in black were taken at Sullivan's Dam

Figure 2.16 shows turbidity for individual sites plotted against rainfall. October and March show elevated levels of turbidity with the majority of sites exceeding the ANZECC default trigger guideline of 5.6 NTU; both these sampling rounds coincided with small amounts of rainfall. Between November and February, turbidity remains low at all sites.

2.11 Biological monitoring

Biological monitoring information is also available for the Water of Leith at Dundas Street and Lindsay's Creek upstream of the Water of Leith. The two sites are shown in Figure 2.17.

Figure 2.17 Macroinvertebrate monitoring site at Dundas Street, Water of Leith and Lindsay's Creek upstream of the Water of Leith

Table 2.6 gives the results for macroinvertebrate monitoring. The results for the water of Leith are generally poor to fair over all categories (refer to Table 2.1). In 2006, there was an improvement in both the MCI and SQMCI scores, although this was not seen in the 2007 results. The results for Lindsay's Creek are also poor or fair in all categories; the SQMCI scores are consistently poor. There has been no obvious improvement or deterioration in macroinvertebrate health/water quality over time.

Table 2.6 Species richness, EPT species, macroinvertebrate community index (MCI) values and semi-quantitative macroinvertebrate community index (SQMCI) values for macroinvertebrate samples collected from the Water of Leith at Dundas Street and Lindsay's Creek upstream of the Water of Leith between 2001 and 2007

	Water of Leith at Dundas Street			
	No Taxa	**EPT**	**MCI**	**SQMCI**
2001	23	8	92	2.06
2003	14	4	78	1.85
2004	17	8	89	2.9
2006	19	11	112	6.7
2007	18	9	99	5.1
	Lindsay's Creek upstream of Water of Leith			
	No Taxa	**EPT**	**MCI**	**SQMCI**
2001	19	7	87.4	3.76
2003	9	2	64	2.58
2004	12	4	82	2.7
2006	21	9	94	2.7

MCI and QMCI scores may be affected by a number of factors other than pollution (e.g. bed stability, recent flow conditions and regimes, water temperature, habitat type). A key component of the MCI index is the availability of suitable habitat. The MCI index is designed specifically for stony riffle substrates in flowing water. Both sites have good substrate, but the stones are generally smothered in fine sediment. By comparing changes in MCI values at the same site over a period of time, it can be seen whether there has been an improvement or deterioration in macroinvertebrate health (which may reflect on water quality).

Table 2.7 shows that the results for the MCI and SQMCI can be assessed using Stark's (1998) protocol (MCI). If the average MCI and SQMCI results are used, both the Water of Leith and Lindsay's Creek are categorised as having probable severe pollution (SQMCI) to probable moderate pollution (MCI).

Table 2.7 Interpretation of macroinvertebrate community index values from stony riffles (after Stark 1998)

Interpretation	MCI	SQMCI
Clean water	>120	>6
Doubtful quality	100 - 119	5 – 5.99
Probable moderate pollution	80 – 99	4 – 4.99
Probable severe pollution	<80	<4.00

2.12 Discussion

2.12.1 Water quality

The survey was based on nine samples taken monthly between July 2007 and March 2008. Although this is quite a limited dataset, it is clear that water quality deteriorates with distance from the head waters of the catchment, nutrient and bacteria concentrations increase, while dissolved oxygen levels decrease. This is a typical trend in river systems that flow through developed catchments and reflects the number of point and non-point source inputs that enter the Water of Leith.

In the Water of Leith, water quality is generally highest at Malvern Street, then decreases with distance downstream with the poorest quality found at Dundas Street. Lindsay's Creek has the highest water quality at Bethune's Gully, which then deteriorates downstream as it flows past North Road Bridge towards the Water of Leith.

This reflects the findings of the SOE Report (2007) in which a WQI was used to classify rivers. The WQI was derived from water quality results taken between 2000 and 2006 and used the median values for six variables: turbidity, dissolved oxygen (% saturation), dissolved reactive phosphorus, ammoniacal nitrogen, nitrite/nitrate nitrogen and *Escherichia coli* bacteria. In the SOE report (2007), the Water of Leith at Dundas Street received a WQI of 'fair', with the failing parameters being *E. coli* and DRP, while Lindsay's Creek at North Road Bridge also received a WQI of 'fair', with its failing parameters being *E. coli*, DRP and NNN.

If the WQI is applied to this survey, then the classification for each site is shown in Table 2.8, along with the % exceedances of relevant guideline values (n = 54).

Table 2.8 WQI classification (DRP, NH_4, DO % saturation, NNN, turbidity and *E. coli*) and exceedances of guideline values expressed as a percentage

Site	% Exceedances of guideline values (n = 54)	Water Quality Index
Water of Leith at Malvern Street	39%	Fair
Water of Leith upstream of Lindsay's Creek	44%	Fair
Water of Leith at Dundas Street	39%	Fair
Lindsay's Creek at Bethunes Gully	35%	Fair
Lindsay's Creek at North Road Bridge	46%	Fair
Lindsay's Creek upstream of the Water of Leith	48%	Fair

All sites had WQI classifications of 'fair'; however, Table 2.8 shows that Lindsay's Creek at Bethune's Gully had the lowest number of exceedances of the relevant guideline levels, while Lindsay's Creek upstream of the Water of Leith had the most failures.

Policy 7.6.1 of the Water Plan has an objective to enhance the water quality in the Water of Leith so that it becomes suitable to support primary contact recreation. High bacteria levels were recorded at all sites. Of the 54 samples taken, the contact recreation guideline (MfE/MoH 2003) was exceeded 25 times (46%) with six failures each (out of nine) in Lindsay's Creek at North Road bridge and upstream of the Water of Leith. In the upper catchment, the number of exceedances was much lower with Lindsay's Creek at Bethune's Gully only recording one exceedance and the Water of Leith at Malvern Street only recording two exceedances. The higher level of bacterial contamination in the lower catchment is likely to be due to stormwater issues because of the urban nature of the catchment.

In the SOE Report (2007), water quality trends for the Water of Leith and Lindsay's Creek were analysed (all data up to June 2006). The trends are shown in Table 2.9. It was found that there was a declining trend in NH4 in Lindsay's Creek, but all other trends were either improving or were not changing.

Table 2.9 Water quality trends in the Water of Leith (1997 to 2006)
Statistically significant trends are depicted in blue for improving water quality and red for declining water quality (▲=p <0.2, ▲▲=p <0.1, ▲▲▲=p <0.05, ● = no change)

	Water of Leith at Dundas Street	Lindsay's Creek at North Road Bridge
WQI	Fair	Fair
Ammoniacal nitrogen	▲▲	▼
Conductivity	●	▲▲▲
Escherichia coli	●	●
Nitrite/nitrate nitrogen	▲	▲
Suspended solids	▲	●
Total nitrogen	▲	●
Total phosphorus	▲	●
Turbidity	▲▲	●

E. coli in both the Water of Leith and Lindsay's Creek is high. Table 2.9 shows that there has been no improvement in bacteria concentrations, and this survey highlights that both these sites still exhibit elevated *E. coli* levels which far exceed the contact recreation guidelines (MfE/MoH 2003). However, the improvement in water quality in both streams is attributed to a decrease in sewage entering the water courses through foul sewer overflows or cross connections (foul and stormwater).

Most of the nutrients (NNN, TN, DRP, TP) in the Water of Leith are also elevated with the downstream sites (Lindsay's Creek upstream of the Water of Leith and the Water of Leith at Dundas Street) generally having the most elevated concentrations of nutrients. However, there were seasonal differences. For example, winter concentrations of TN were higher; this is clearly seen in Figure 2.10 where TN concentrations in July and August are much higher than during the rest of the sampling period. This is not related to rainfall events and is probably due to organic matter being decomposed relatively slowly during the winter. The Water of Leith at Malvern Street exhibited higher levels of TN and NNN than the other monitoring sites in the Water of Leith. This is unexplained and needs further investigation.

2.12.2 Catchment management

The Water Plan (Policy 7.6.1) specifically identifies the Water of Leith as a water body in need of enhancement so that it becomes suitable for contact recreational activities. This objective is being sought through both point and non-point source contamination.

The main point source discharges which influence water quality in the Water of Leith are the multitude of stormwater outfalls that discharge along the length of the Water of Leith and Lindsay's Creek; some of these flow even in dry weather. Urban stormwater contains a wide array of contaminants that, in sufficient concentration and quantity, can cause significant pollution of receiving waters by degrading water quality and altering stream habitat and ecology. Urban stormwater enters the watercourse as a point source, but the material carried in it can be derived from non-point sources, such as runoff from open land, or from spills. The outfalls are managed by the Dunedin City Council and there is no formal monitoring. However, the Dunedin City Council, as a condition of the consent to discharge stormwater into Otago Harbour, is in the process of developing catchment management plans, specifically to address stormwater in Dunedin.

As well as this initiative, ORC often uses the Water of Leith as a focus for environmental education, particularly with groups of schoolchildren. The hope is that the message of 'clean water = healthy wildlife' will be carried to the wider community.

3. Kaikorai Stream

Routine physico-chemical water quality monitoring has been undertaken at various sites in the Kaikorai Stream since 1997. More intensive monitoring was undertaken between July 2007 and March 2008 at an additional six sites.

The Kaikorai Stream flows into the Pacific Ocean near Waldronville, approximately 10km south of Dunedin city centre. This is shown in Figure 3.1.

Figure 3.1 Kaikorai Stream Estuary

The main stem of the Kaikorai Stream has no significant natural values listed in Schedule 1A of the Water Plan; however, just upstream of its confluence with the Pacific Ocean, it has a large brackish water lagoon and extensive saltmarsh and *Leptocarpus* (rush) marsh with a high diversity of indigenous flora and fauna. This wetland links with the downstream estuarine area providing extensive habitat for waterfowl and, as a result, is acknowledged in Schedule 9 of the Water Plan.

Cultural values, including those associated with food gathering and processing (mahika kai) and the protection of nursery and breeding areas for native fish and birds (kohanga), have been identified as important in the Kaikorai Stream. These and other cultural values are listed in Schedule 1D of the Water Plan.

Historical water quality monitoring of the Kaikorai Stream has shown that water quality is degraded, particularly in its lower reaches. Policy 7.6.1 and Policy 7.6.2 of the Water Plan acknowledges that water quality needs enhancing so that it becomes suitable to support primary contact recreation and that the Macroinvertebrate Community Index score is increased.

The Kaikorai Stream has numerous values listed in the Water Plan and poor water quality has a major impact on these values. The main discharge in the Kaikorai Catchment is from the Mt Grand Water Treatment Plant; however, this flow significantly increases the water quality and instream values of the Kaikorai Stream. It is the urban nature of the catchment, with numerous stormwater outfalls discharging into the stream, that compromises the water quality.

3.1 Background information

3.1.1 Kaikorai Catchment

The Kaikorai Stream has a total catchment area of 55.4km^2 and flows in a south westerly direction for approximately 14.5km down the Kaikorai Valley into the Pacific Ocean near Waldronville. The catchment is contained by Kaikorai Hill to the north and to the west lie Abbot's Hill, the Chain Hills and Saddle Hill. The catchment includes the western flanks of Dunedin city and all of Green Island. The remaining area includes the communities of Fairfield and Waldronville.

Fraser's Stream is a major tributary of the Kaikorai Stream and the Dunedin City Council discharges up to 560 litres per second from the Mt Grand Water Treatment Plant to MacLeod's Creek (a tributary of Fraser's Stream). This flow significantly increases the water quality and instream values contained in the Kaikorai Stream.

3.1.2 Land use in the Kaikorai Catchment

The Land Cover Data Base gives a breakdown of land use in the area. Figure 3.2 shows the urban area as grey and the Kaikorai Lagoon is shown as blue. The landfill is shown as black and is located adjacent to the lagoon. The remainder of the catchment is mainly high producing exotic grassland with some manuka and kanuka.

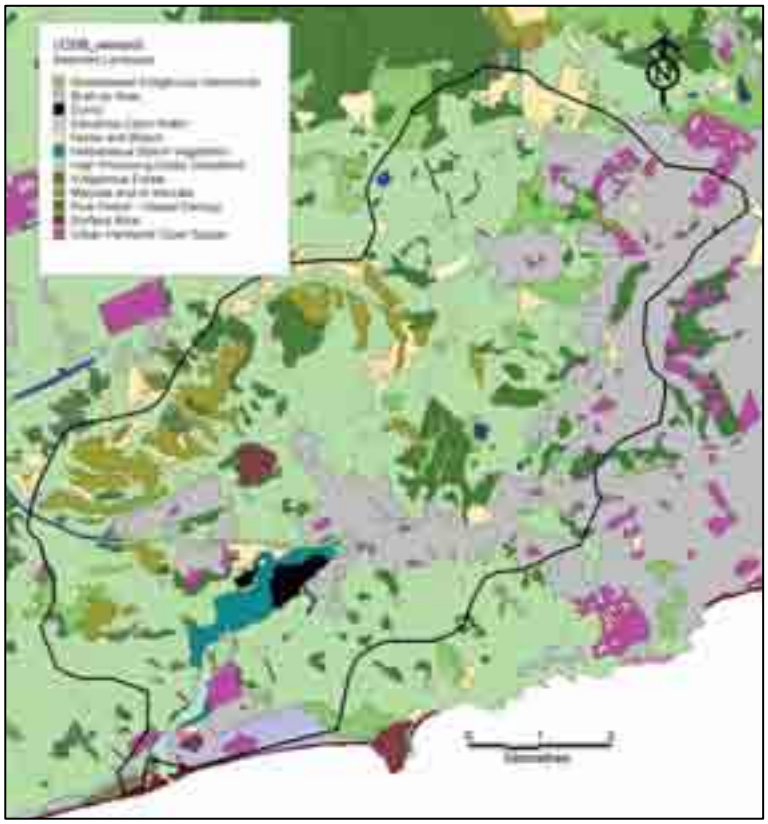

Figure 3.2 Map of land use in the Kaikorai Catchment

3.2 Surface water quality monitoring

3.2.1 Water quality monitoring sites

Water quality monitoring has been undertaken at various sites on the Kaikorai Stream since 1997. The only site monitored as part of the SOE monitoring programme is the main stem Kaikorai Stream at Brighton Road, Green Island.

In addition to this site, between July 2007 and March 2008 monthly monitoring was undertaken at an additional six sites. The location of these sites is shown in Figure 3.3 and the monitoring sites are listed in Table 3.1.

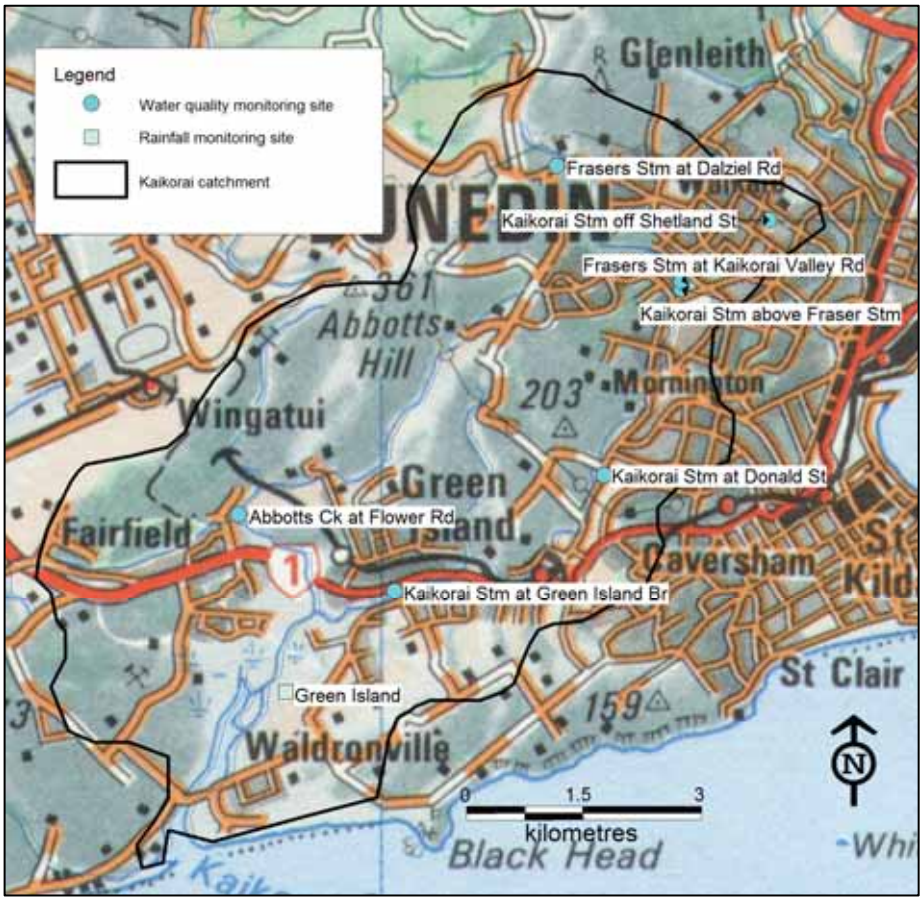

Figure 3.3 Location of water quality monitoring sites, flow stations and rainfall stations in the Kaikorai Catchment

Table 3.1 Water quality monitoring sites in the Kaikorai Catchment July 2007 to March 2008

River	Site	Northing	Easting
Kaikorai Stream	Marae off Shetland St	2314930	5479990
Kaikorai Stream (culverted)	Confluence with Fraser's Stm	2313800	5479100
Kaikorai Stream	Donald Street	2312800	5476700
Kaikorai Stream	Green Island bridge	2310100	5475200
Fraser's Stream	Dalziel Road	2312200	5480700
Fraser's Stream	Kaikorai Valley Rd	2313800	5479200
Abbott's Ck	Flower Rd	2308100	5476200

3.2.2 Rainfall

The amount of rainfall 24, 48 and 72 hours prior to each sampling period was determined at the Green Island rain-gauge (network number 15094A), shown in Table 3.2. Other than in March, limited rainfall fell during this period.

Table 3.2 Total daily rainfall recorded at the Green Island rain-gauge 24 hrs, 48 hrs and 72 hrs prior to each sampling run

	Jul 2007	Aug 2007	Sep 2007	Oct 2007	Nov 2007	Dec 2007	Jan 2008	Feb 2008	Mar 2008
Green Island									
24 hrs	0.2	1.1	0	0	2.0	0	0	0	13.9
24 to 48 hrs	8.0	5.8	0	2.0	0.4	0	1.4	0	31.0
48 to 72 hrs	0.6	0	0	1.2	0	0	0	0	15.3

3.2.3 Flow

ORC has no continuous flow records for the Kaikorai Catchment; however, the flow is recorded at the water quality monitoring site run by Kaikorai Valley College. Information about the sensors and set-up of the monitoring site can be found at http://www.kvc.school.nz/Kaikoraistream/Intro_Folder/SensorInfo.htm. It is these flow data that have been used in this report. Table 3.3 shows mean flow on the day of sampling as well as monthly mean flows.

Table 3.3 Mean flow on day of sampling and monthly mean flows (cumecs)

	Mean flow on sampling date	Monthly mean flow
July 2007	11.09	7.73
August 2007	0.23	0.32
September 2007	0.22	0.41
October 2007	0.27	1.02
November 2007	0.36	0.46
December 2007	n/a	0.32 (limited dataset)
January 2008	0.17	0.39
February 2008	0.13	0.51
March 2008	0.41	n/a

3.2.4 Historical results

A summary of the water quality results for the Kaikorai Stream at Brighton Road Bridge are given in Table 3.4. Key water analytes are compared with the ANZECC 2000 default trigger values for slightly disturbed lowland river ecosystems in New Zealand.

Table 3.4 Median water quality results for the Kaikorai Stream at Brighton Road Bridge (August 1997 to January 2008) with exceedances of guideline values indicated in bold type

Site	Turbidity (NTU)	*E. coli* (n/100ml)	Ammoniacal N (mg/l)	Nitrite/nitrate N (mg/l)	Total N (mg/l)	Dissolved reactive P (mg/l)	Total P (mg/l)
ANZECC 2000	5.6	260*	0.9	0.444	0.614	0.010	0.033
Brighton Road	3.87	**710**	0.02	0.317	**0.625**	0.0085	0.032
*Acceptable/Green Mode of the Ministry for Environment/Ministry of Health (2003) Recreational Water Quality Guidelines							

Table 3.4 indicates that nutrient and bacteria concentrations are above the recommended guidelines for TN and *E. coli*. When looking at the NH_4 results, all were below 0.9 mg/l and the ammonia component (after considering temperature and pH) was less than the guideline value of 0.021 mg/l. The bacteria results were particularly high, and looking at individual results, 72% of *E. coli* samples exceeded the Ministry for the Environment/Ministry of Health's (2003) Microbiological Water Quality Guidelines for Recreational Areas, indicating it would be unwise to undertake contact recreation activities such as swimming at this site.

3.3 Surface water quality monitoring 2007-2008

Table 3.5 summarises the results of the more intensive monitoring undertaken between July 2007 and March 2008. Full results can be found in Appendix 1.

Table 3.5 Median water quality results for the Kaikorai Stream (July 2006 to March 2007) with exceedances of guideline values indicated in bold type

Site	Turbidity (NTU)	E. coli* (cfu/ 100ml)	Ammoniacal N (mg/l)	Nitrite/ nitrate N (mg/l)	Total N mg/l	Dissolved reactive P (mg/l)	Total P (mg/l)
Guideline**	**5.6**	**260**	**0.9**	**0.444**	**0.614**	**0.01**	**0.033**
Kaikorai Stream							
Shetland St	**9.86**	**900**	0.11	**1.59**	**2.26**	**0.011**	**0.098**
us Fraser's Stm	**9.54**	**900**	0.07	**2.36**	**2.73**	**0.023**	**0.103**
Donald St	2.87	190	0.005	**0.624**	**0.86**	**0.013**	**0.034**
Brighton Rd	2.78	**670**	0.02	0.328	**0.71**	**0.016**	**0.04**
Fraser's Stream							
Dalziel R	3.93	**550**	0.03	**1.6**	**1.69**	**0.022**	**0.058**
us Kaikorai	2.25	150	0.005	0.322	**0.83**	**0.011**	0.025
Abbot's Creek							
Flower Road	**15.6**	140	0.03	0.137	**0.81**	**0.011**	**0.079**
**ANZECC 2000 Default Trigger Value for lowland rivers *Acceptable/Green Mode of the Ministry for Environment/Ministry of Health (2003) Recreational Water Quality Guidelines							

Water quality is clearly poorest in the upper Kaikorai at Shetland Street and in the culvert upstream of Fraser's Stream, but Table 3.5 indicates that water quality can be compromised throughout the catchment. None of the sites had water quality that was of better quality than all the relevant guideline values.

In the following section, results from water quality monitoring were compared against guideline values (refer to Table 1.1). Rainfall (mm) and flow (cumecs) were also plotted on relevant graphs.

3.3.1 *E. coli*

Table 3.5 shows that the median *E. coli* bacteria concentrations are elevated at all sites other than the main stem Kaikorai at Donald Street, Fraser's Stream upstream of the Kaikorai Stream and Abbot's Creek.

As bacteria are not normally distributed it is usual to back-transform the logged mean data (see Appendix 3). When this was performed on the Kaikorai Stream dataset, it was clear that other than at Donald Steet, the other sites on the Kaikorai Stream had elevated *E. coli* levels, as did the tributary of the Fraser's Stream at Dalziel Road.

Figure 3.4 clearly shows the four sites where recommended recreational water quality guidelines are not met, indicating it would be unwise to undertake contact recreation activities at these sites.

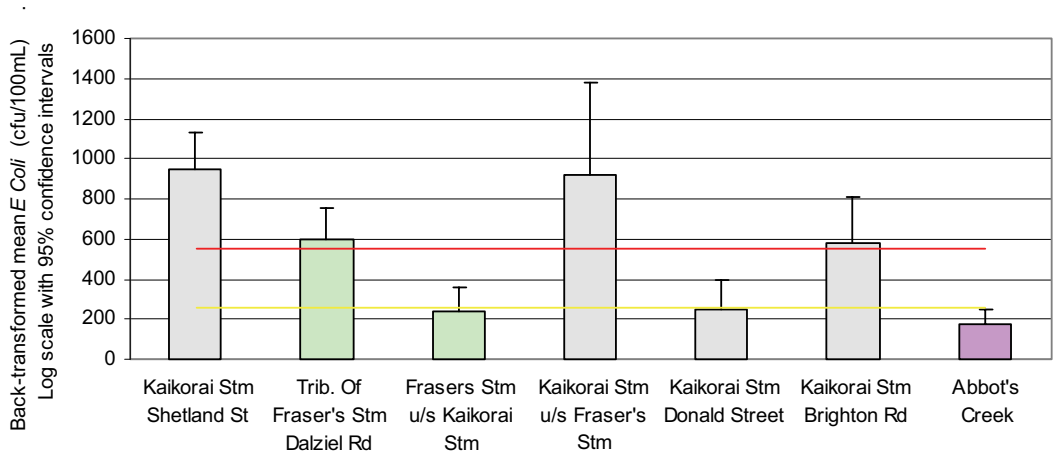

Figure 3.4 Back-transformed mean *E. coli* concentrations with 95% confidence intervals. The red line depicts the MfE/MoH 2003 Action/Red Mode (above 550 Ec/100ml) and the yellow line depicts the MfE/MoH 2003 Acceptable/Green Mode (below 260 Ec/100ml)

Individual *E. coli* values were plotted against rainfall to see whether there was any correlation between high bacteria counts and heavy rainfall (using the 48 hr rainfall recorded at Green Island rain-gauge).

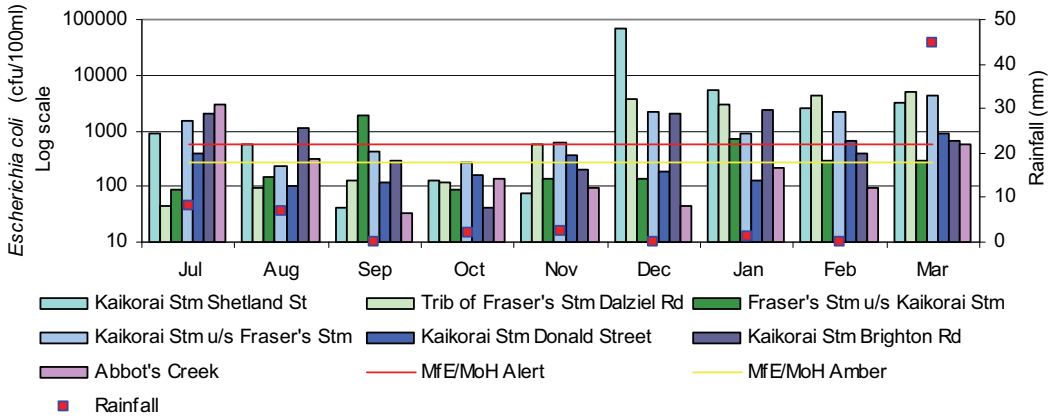

Figure 3.5 *E. coli* (cfu/100ml) levels plotted against the total 48 hr rainfall (mm) recorded at the Green Island rain-gauge

Figure 3.5 shows that the high rainfall just prior to the water quality sampling in March does not appear to have an influence on bacteria numbers, particularly if this month is compared to the December to February period. However, bacteria levels in Abbot's Creek are seen to be responsive to rainfall with the three highest readings corresponding with rainfall events. It appears that there is also a seasonal response to bacteria levels with higher levels corresponding to the warmer months.

Figure 3.6 shows *E. coli* plotted against river flows, as recorded by Kaikorai School. There was not much variation in flows during the sampling period, other than the July sampling round which coincided with a flow of 11.03 cumecs. This higher flow seems to have elevated bacteria levels slightly when compared with August to November results.

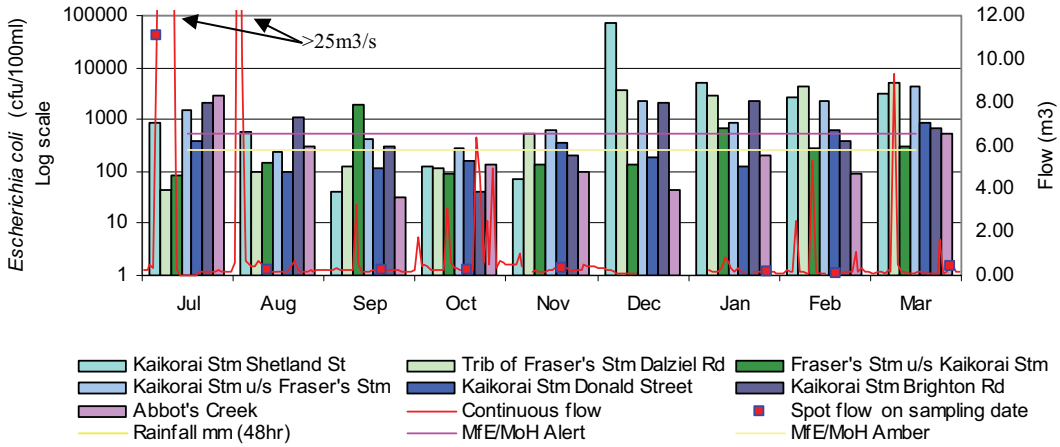

Figure 3.6 *E. coli* (cfu/100ml) levels plotted against the 24 hr average flow taken at Kaikorai Valley College Monitoring Station

3.3.2 Ammoniacal nitrogen

Ammoniacal nitrogen (NH_4) is the combination of ammonium ions and ammonia (NH_3). The ANZECC 2000 high reliability (95%) trigger value for freshwater is 0.9 mg/l. NH_3 is the main toxic component for aquatic organisms, the prevalence of which is dependent on the pH, temperature and salinity of the water. The ANZECC 2000 guideline for NH_3 is 0.021 mg/l. Table 3.5 gives the median values for ammoniacal nitrogen and these are shown graphically in Figure 3.7.

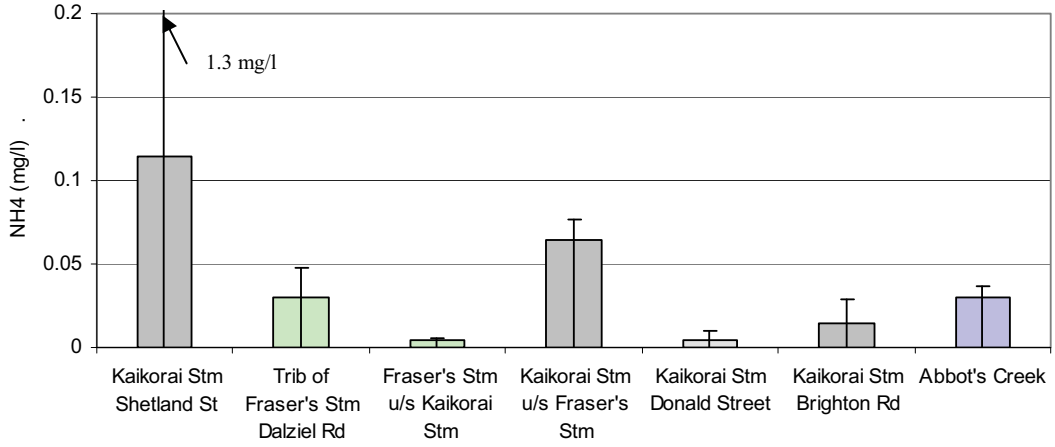

Figure 3.7 Median ammoniacal nitrogen concentrations at each monitoring site (July 2007 to March 2008)

Ammoniacal nitrogen concentrations are elevated in the Kaikorai Stream at Shetland Street and above Fraser's Stream, but at all other sites concentrations are less than 0.03 mg/l. All the sites had median NH_4 concentrations well below the 0.9 mg/l threshold; however, the large error bar shown in Figure 3.7 for Shetland Street is due to one result of 11.3 mg/l (sample taken on 6th December). After taking pH and temperature into consideration, the only sample to exceed the NH_3 guideline value of 0.021 mg/l was this Shetland Street result, which recorded an NH_3 concentration of 0.039 mg/l.

3.3.3 Nitrite/nitrate nitrogen

Median NNN results were most elevated in the main stem, at Shetland Street and upstream of Fraser's Stream. Concentrations decreased with distance downstream, after mixing with Fraser's Stream. All but two of the sites (Abbot's Creek and Fraser's Stream upstream of the Kaikorai Steam) exceeded the ANZECC default trigger value of 0.444mg/l.

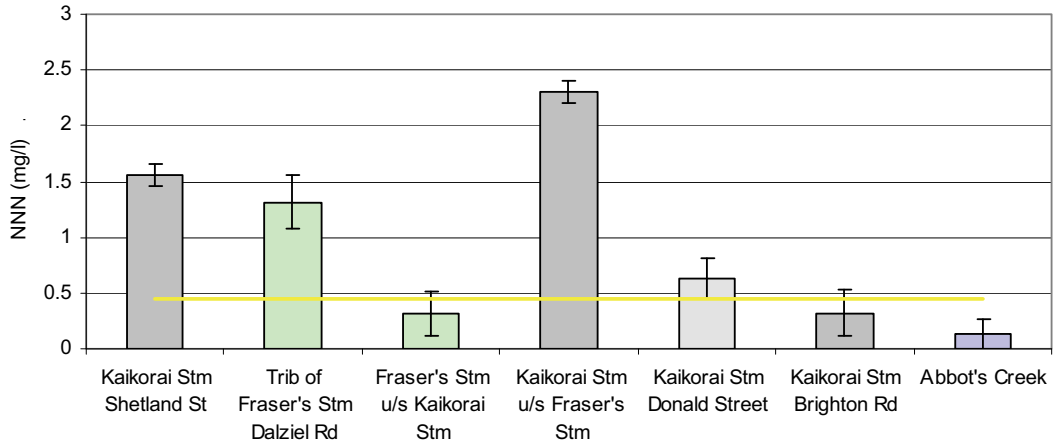

Figure 3.8 Median nitrite/nitrate nitrogen concentrations at each monitoring site (July 2007 to March 2008). The yellow line depicts the ANZECC 2000 default trigger guideline value for NNN (0.444 mg/l)

Figure 3.9 shows NNN concentrations for individual sites plotted against flow and the ANZECC default trigger value (0.444 mg/l). Figure 3.9 shows that the concentration of NNN in the Kaikorai Stream is not consistently below the ANZECC default trigger guideline of 0.444 at any of the sites monitored. The two Kaikorai Stream sites above Fraser's stream are consistently above this guideline value, and Abbot's Creek shows a higher concentration of NNN in winter than during the summer months with the only exceedances being in July and August.

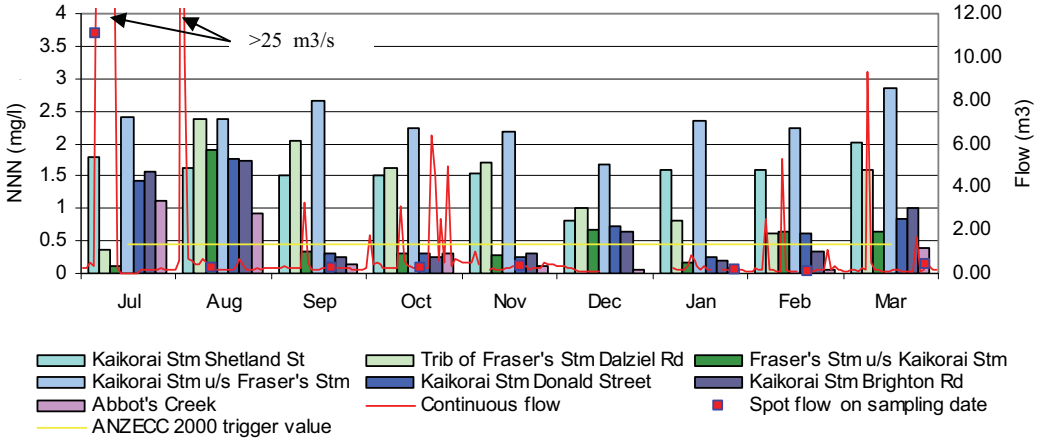

Figure 3.9 Nitrite/nitrate nitrogen (mg/l) concentrations plotted against the 24 hr average flow taken at Kaikorai Valley College Monitoring Station

3.3.4 Total nitrogen

Figure 3.10 shows median TN concentrations at each site. The same pattern as ammoniacal nitrogen is observed with concentrations increasing in the Kaikorai Stream until Fraser's Stream converges. Concentrations then decrease downstream.

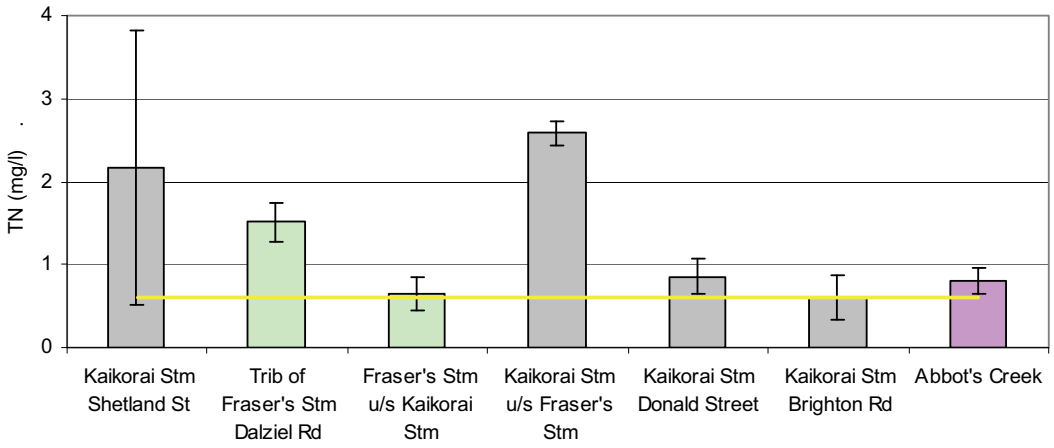

Figure 3.10 Median total nitrogen concentrations at each monitoring site (July 2006 to March 2007). The yellow line depicts the ANZECC 2000 default trigger guideline value for TN (0.614 mg/l)

When all individual results are plotted on a monthly basis against flow (Figure 3.11), a difference can be seen between winter and summer results. Generally all the sites have their highest concentrations of TN in July and August, and during the summer months concentrations reduce. This can be seen particularly at the sites below Fraser's Stream.

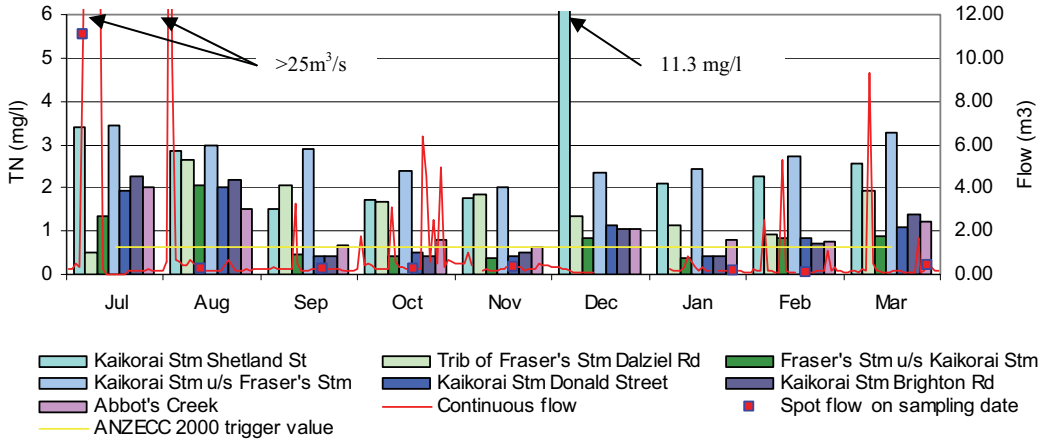

Figure 3.11 Total nitrogen (mg/l) concentrations plotted against the 24 hr average flow taken at Kaikorai Valley College Monitoring Station

3.3.5 Dissolved reactive phosphorus

Median DRP concentrations are shown in Figure 3.12. The median values of DRP at all sites exceed the ANZECC default trigger value. The New Zealand Periphyton Guidelines give a value for DRP concentrations (0.026 mg/l) which has been predicted as the maximum to prevent excess periphyton biomass. No median values exceed this guideline value.

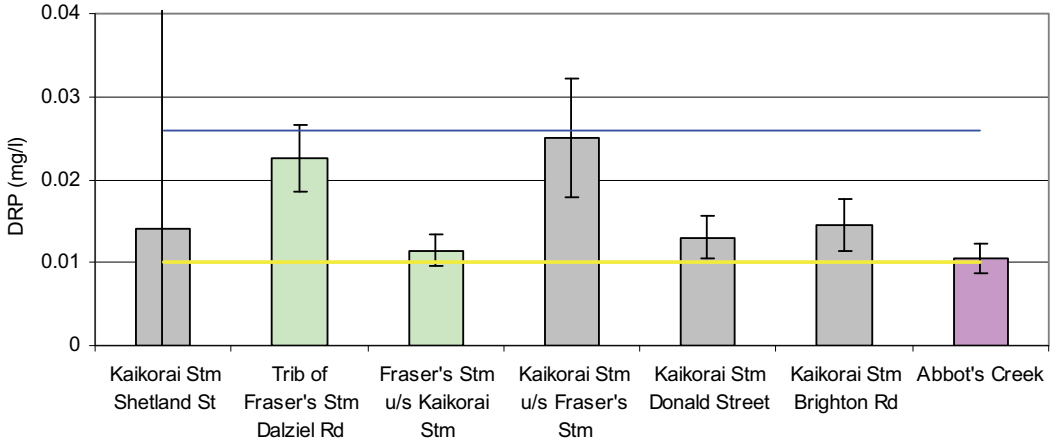

Figure 3.12 Median dissolved reactive phosphorus concentrations at each monitoring site (July 2007 to March 2008). The red line depicts the ANZECC 2000 default trigger guideline value for DRP (0.010 mg/l); the blue line depicts the NZ periphyton guideline (0.026 mg/l)

When individual sites are plotted against month of sampling (Figure 3.13), it can be seen that levels are elevated above the ANZECC 2000 trigger value at all sites during the summer months (December to February). It is also clear that concentrations of DRP are highest in Fraser's Steam at Dalziel Road and the Kaikorai Stream u/s of Fraser's Stream; both these sites regularly exceed the NZ Periphyton Guideline value (0.026 mg/l).

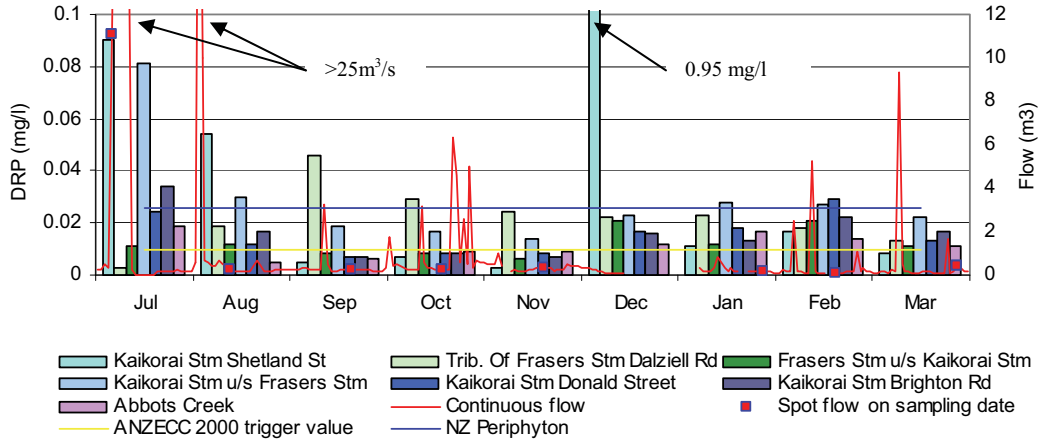

Figure 3.13 Dissolved reactive phosphorus (mg/l) concentrations plotted against the 24 hr average flow taken at Kaikorai Valley College Monitoring Station

3.3.6 Total phosphorus

Figure 3.14 shows median results for TP. It is only Fraser's Stream upstream of Kaikorai Stream that falls within the ANZECC 2000 guideline value (0.033 mg/l); otherwise all the sites exceeded this trigger value.

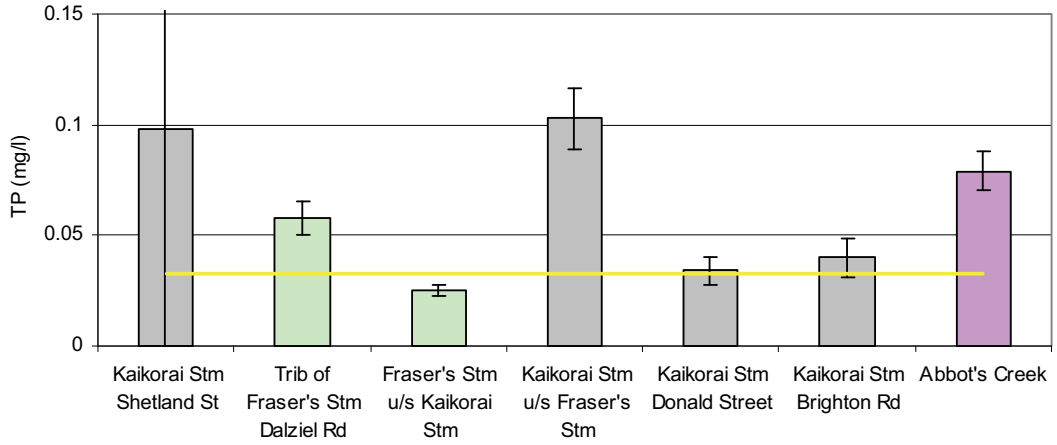

Figure 3.14 Median total phosphorus concentrations at each monitoring site (July 2007 to March 2008). The yellow line depicts the ANZECC 2000 default trigger guideline value for TP (0.033 mg/l)

3.3.7 Dissolved oxygen

Dissolved oxygen usually follows a different pattern to other analytes monitored with higher oxygen concentrations in the upper catchments which then decrease downstream. This however is not the case in the Kaikorai Stream and oxygen levels increase with distance downstream (Figure 3.15).

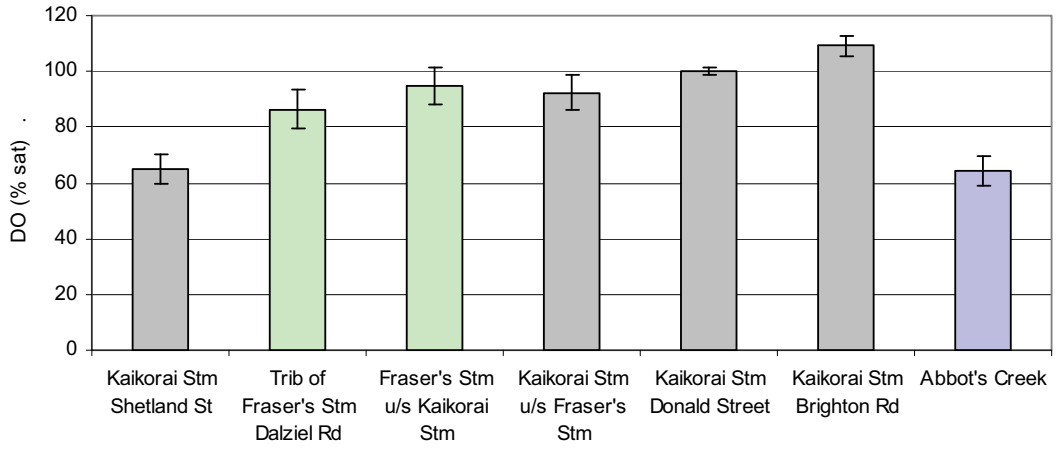

Figure 3.15 Median dissolved oxygen concentrations at each monitoring site (July 2007 to February 2008)

The RMA Third Schedule recommends that oxygen levels remain above 80%. This is not the case at Shetland Street and Abbot's Creek, but oxygen levels exceed this level at the sites downstream. In the lower reaches, this would primarily be due to algal growth.

3.4 Turbidity

Figure 3.16 shows median turbidity at each site. Both the upper Kaikorai sites exceed the ANZECC default trigger guideline of 5.6 NTU, as does Abbot's Creek.

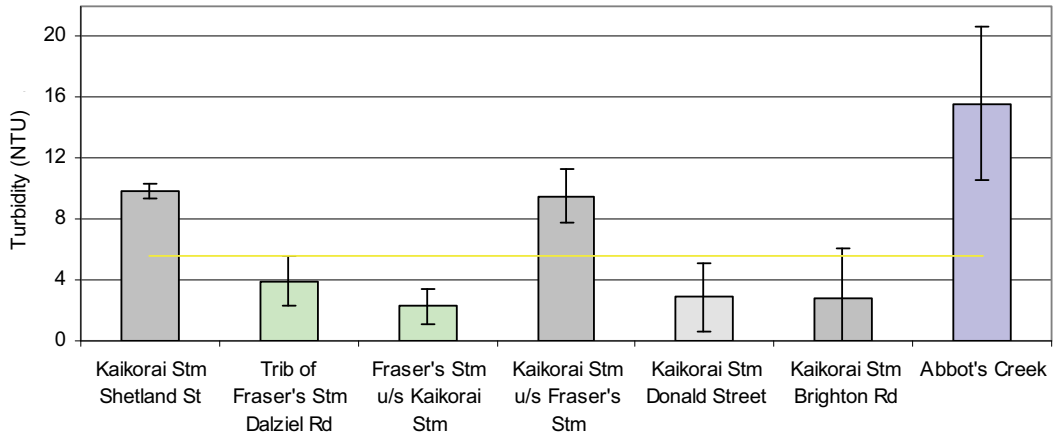

Figure 3.16 Median turbidity at each monitoring site (July 2007 to February 2008)

Figure 3.17 shows turbidity at individual sites plotted on a monthly basis against flow. It is clear that the July sampling round was affected by a flow of over 11 cumecs on the day of sampling. All sites other than Kaikorai Stream at Shetland Street and Fraser's Stream at Dalziel Road had elevated turbidity on this date.

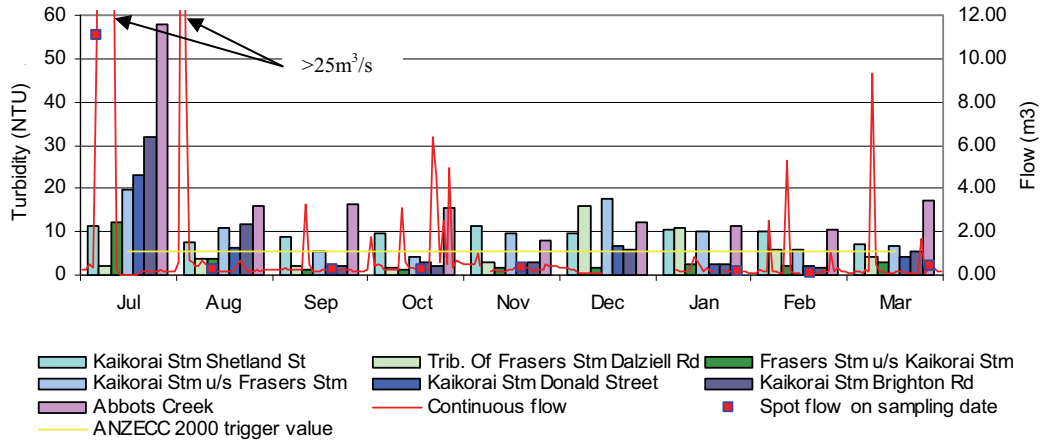

Figure 3.17 Turbidity (NTU) plotted against the 24 hr average flow taken at Kaikorai Valley College Monitoring Station

3.5 Biological monitoring

The Kaikorai Stream is monitored for macroinvertebrate health at Brighton Road (Figure 3.18). The site has been monitored five times since 2001 and results are shown in Table 3.6.

Figure 3.18 Macroinvertebrate monitoring site at Brighton Road, Kaikorai Stream with details of sediment covering the stony substrate

Table 3.6 gives the results for macroinvertebrate monitoring at Brighton Road since 2001. The results are all similar and all results, regardless of which indice is used, fall into the poor category. There has been no improvement or deterioration in macroinvertebrate health/water quality at individual sites since 2001.

Table 3.6 Species richness, EPT species, macroinvertebrate community index (MCI) values and semi-quantitative macroinvertebrate community index (SQMCI) values for macroinvertebrate samples collected from the Kaikorai Stream at Brighton Road between 2001 and 2007

	Kaikorai Stream at Brighton Road			
	No Taxa	**EPT**	**MCI**	**SQMCI**
2001	8	0	67.5	1.57
2003	7	0	54	1.54
2004	7	0	54	1.5
2006	9	0	62	2.6
2007	8	0	73	1.7

MCI and SQMCI scores may be affected by a number of factors other than pollution (e.g. bed stability, recent flow conditions and regimes, water temperature, habitat type). A key component of the MCI index is the availability of suitable habitat. The MCI index is designed specifically for stony riffle substrates in flowing water. MCI values can vary due to the availability of suitable habitat and are not necessarily due to water quality. The Brighton Road site has a good substrate but the stones are generally smothered in fine sediment and algae (Figure 3.18). By comparing changes in MCI values at the same site over a period of time, it can be seen whether there has been an improvement or deterioration in macroinvertebrate health (which may reflect on water quality). Table 3.6 gives the results for macroinvertebrate monitoring at Brighton Road since 2001. The results are all similar and all results, regardless of which indice is used, fall into the poor category. There has been no improvement or deterioration in macroinvertebrate health/water quality at individual sites since 2001.

3.6 Discussion

3.6.1 Water quality

The survey was based on nine samples taken monthly between July 2007 and March 2008.

Water quality in the Kaikorai Catchment improves with distance from the head waters, due to the confluence of Fraser's Stream. Dunedin City Council discharges up to 560 litres per second from the reservoir to MacLeod's Creek (a tributary of Fraser's Stream). This discharge only occurs when the reservoir is full, so that the water in the reservoir is kept fresh and does not stagnate.

It is clear that this water improves the overall water quality of the Kaikorai Stream, and above the confluence of the Fraser's Stream the Kaikorai Stream has poorer water quality. In the headwaters of the Kaikorai Stream many individual samples exceed relevant guideline levels, while at Brighton Road this figure is much lower (Table 3.5). This reflects the findings of the SOE Report (2007) in which a water quality index was used to classify rivers. The WQI was derived from water quality results taken between 2000 and 2006 and used the median values for six variables: turbidity, dissolved oxygen (% saturation), dissolved reactive phosphorus, ammoniacal nitrogen, nitrite/nitrate nitrogen and *E. coli* bacteria. In the SOE report (2007) the Kaikorai Stream near the bottom of the catchment received a water quality index of 'good' with the failing parameter being *E. coli.*

If the WQI is applied to this survey, then the classification for each site is shown in Table 3.7, along with the % exceedances of relevant guideline values (n = 54).

Table 3.7 WQI classification (DRP, NH_4, DO % saturation, NNN, turbidity and *E. coli*) and exceedances of guideline values expressed as a percentage

Site	% Exceedances of guideline values (n = 54)	Water Quality Index
Kaikorai Stream at Shetland Street	78%	Poor
Kaikorai Stream above Fraser's Stream	65%	Poor
Trib. of Fraser's Stream at Dalziel Road	52%	Fair
Fraser's Stream above Kaikorai Stream	37%	Good
Kaikorai Stream at Donald Street	33%	Fair
Kaikorai Stream at Brighton Road	39%	Fair
Abbot's Creek at Flower Road	50%	Poor

It is clear that Fraser's Stream improves water quality downstream, it being the only site with a 'good' classification, as it only failed to meet the guideline for *E. coli*. Abbot's Creek and the Kaikorai Stream at Shetland Street failed to meet the 80% dissolved oxygen guideline level, which automatically places them in the 'poor' category; however, they also failed to meet most other guideline levels.

Improving water quality downstream is not a typical trend in river systems; however, it should be noted that water quality is still not high.

Policy 7.6.1 of the Water Plan has an objective to enhance the water quality in the Kaikorai Stream so that it becomes suitable to support primary contact recreation. High bacteria levels were recorded at all sites. Of the 54 samples taken, the contact recreation guideline (MfE/MoH 2003) was exceeded 32 times (59%) with seven failures each (out of nine) in the Kaikorai Stream upstream of Fraser's Stream and the Kaikorai Stream at Brighton Road. In the upper catchment, this is likely to be due to the number of ducks using the stream and being encouraged to use the stream (by feeding). At Brighton Road, it is more likely to be due to stormwater issues because of the urban nature of the catchment.

Policy 7.6.2 of the Water Plan has an objective to enhance water quality in the lower Kaikorai Stream (below Townley's Road) so that the Macroinvertebrate Community Index is increased. Monitoring at Brighton Road in 2007 shows that macroinvertebrate health is poor over all the macroinvertebrate indices (Table 3.8). The Kaikorai Stream at the Brighton Road site has suitable habitat (stony substrate), therefore it is likely to be the water quality (particularly intermittent stormwater) that limits macroinvertebrates at the site. The water quality at Brighton Road only has a WQI of fair and macroinvertebrate health seems to reflect the water quality.

In the SOE Report (2007) water quality trends for the Kaikorai Stream were analysed (all data up to June 2006). The trends are shown in Table 3.8. It was found that there was a declining trend in TP, but an improvement in *E. coli* and NNN.

Table 3.8 Water quality trends in the Kaikorai Stream (1997 to 2006)
Statistically significant trends are depicted in blue for improving water quality and red for declining water quality (▲=p <0.2, ▲▲=p <0.1, ▲▲▲=p <0.05, ● = no change)

	Kaikorai Stream at Green Island
WQI	Good
Ammoniacal nitrogen	●
Conductivity	●
Escherichia. coli	▲
Nitrite/nitrate nitrogen	▲
Suspended solids	●
Total nitrogen	●
Total phosphorus	▼▼▼
Turbidity	●

Although an improvement in *E. coli* was noted, this survey highlights that Brighton Road still exhibits elevated *E. coli* levels which far exceed the contact recreation guidelines (MfE/MoH 2003).

Most of the nutrients (NNN, DRP, TP) in the Kaikorai Stream follow a similar pattern, decreasing with distance downstream, with the most elevated results being recorded in the Kaikorai Stream at Shetland Street, the Fraser's Stream tributary at Dalziel Road and the Kaikorai Stream u/s of Fraser's Stream. However, there were seasonal differences, for example winter concentrations of TN were higher. This is clearly seen in Figure 3.11 where TN concentrations in July and August are much higher than during the rest of the sampling period. This is not related to rainfall events and is probably due to organic matter being decomposed relatively slowly during the winter. The tributary of the Fraser's Stream at Dalziel Road recorded many exceedances of water quality guidelines. The properties in this area are served by

septic tanks and it is possible that the malfunctioning of these may increase the nutrient and bacteria levels in this stream.

3.6.2 Catchment management

The Water Plan (Policy 7.6.1) specifically identifies the Kaikorai Stream as a water body in need of enhancement so that it becomes suitable for contact recreational activities. This objective is being sought through both point and non-point source contamination.

The main point source discharges that influence water quality in the Kaikorai Stream are the multitude of stormwater outfalls that discharge along the length of the Kaikorai Stream in wet weather. Urban stormwater contains a wide array of contaminants that, in sufficient concentration and quantity, can cause significant pollution of receiving waters by degrading water quality and altering stream habitat and ecology. Urban stormwater enters the watercourse as a point source but the material carried in it can be derived from non-point sources, such as runoff from open land, or from spills. The outfalls are managed by the Dunedin City Council and there is no formal monitoring. However, Dunedin City Council, as a condition of the consent to discharge stormwater into Otago Harbour, is in the process of drawing up catchment management plans specifically to address stormwater in Dunedin.

As well as this initiative, a community catchment programme is in the initial stages of development. Representatives from Otago Regional Council, local schools and the Dunedin Environment Centre have formed a group to address issues in the Kaikorai Catchment, including water quality monitoring, community awareness and restorative projects (including riparian planting).

4. Waitaki River and Carey's Creek

Routine physico-chemical water quality monitoring has been undertaken in these rivers since 1997. More intensive monitoring was undertaken between July 2007 and February 2008 at three sites in the Waitati Catchment and at one site in Carey's Creek.

Waitati River and Carey's Creek flow into the Pacific Ocean at Blueskin Bay. This is a shallow water body of approximately 6.9km^2 situated near to the townships of Waitati, Doctor's Point and Warrington, about 16km north of Dunedin city. It is enclosed by a southward pointing spit and contains gently sloping beaches, broad tidal flats and one main central island. An inlet to the sea is located at the southern end of the spit. The tidal movement through the narrow opening is strong and directional with the flow creating two deep and distinct tide channels flowing to the west and north respectively, which have higher sand banks between them at low tide. The estuary is fed to the north and south by two major water-bodies; Carey's Creek and the Waitati River. Flushing within the estuary is dominated by the tide.

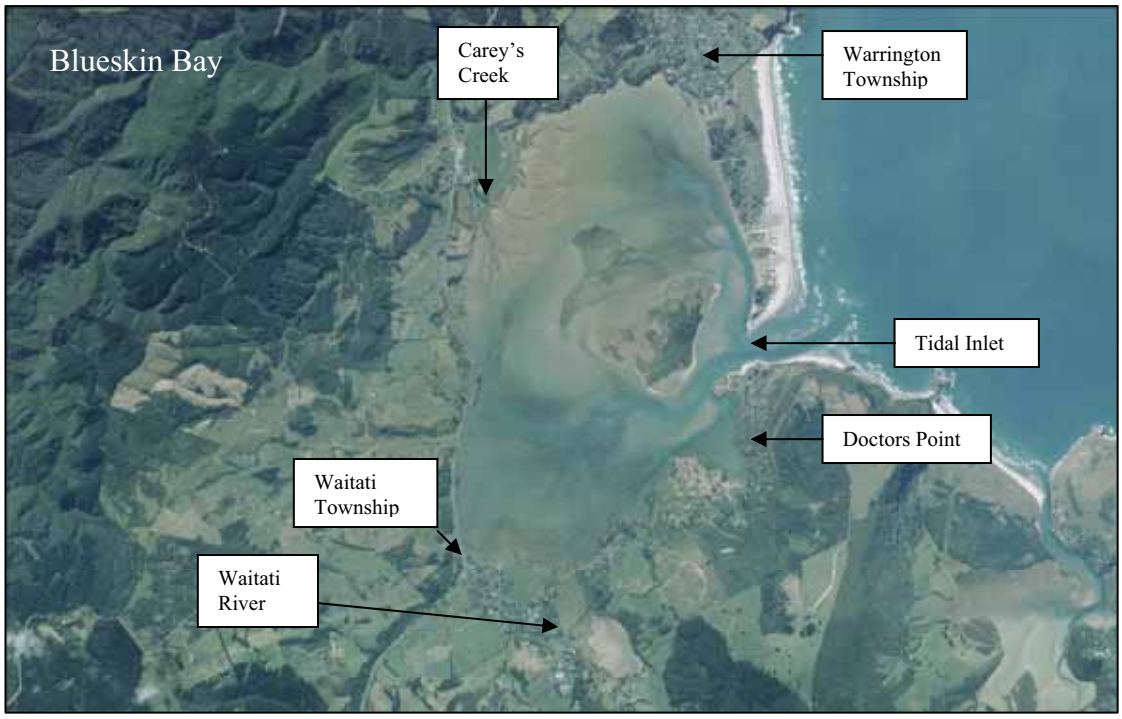

Figure 4.1 Blueskin Bay

Both the Waitati River and Carey's Creek have a significant number of natural values; these are shown in Table 4.1 and include significant trout spawning and a presence of indigenous fish species threatened with extinction. For this reason they are listed in Schedule 1A of the Water Plan. Furthermore, the Waitati River has a high degree of naturalness within the Silverpeaks Scenic Reserve.

Table 4.1 Natural values of Carey's Creek and the Waitati River (Schedule 1A Water Plan)

Water body	*Ecosystem Values*	*Significant indigenous vegetation and significant habitat of indigenous fauna*	*Areas with a high degree of naturalness*
Carey's Creek	Pgravel, Weedfree, Hspawn(t), Hjuve(t), Rarefish, Fishdiv, Invdiv (upper reaches)	*Significant habitat* for koaro and banded kokopu. *Significant habitat* for lamprey (uncommon in Otago)	
Waitati River	Ppass, but major abstractions can result in very low flows in lower stretches. Pgravel, Weedfree, Hspawn (t) (& inanga spawning below I44:205925), Hjuve(t). Hriparian in headwaters. Trout, Rarefish, Invdiv (upper reaches)	*Significant habitat* for koaro. *Significant habitat* for lamprey (uncommon in Otago)	A high degree of naturalness within Silverpeaks Scenic Reserve
Selected codes for ecosystem values supported by lakes and rivers			
Hspawn	Refers to presence of significant fish spawning areas: (t)=trout; (s)=salmon		
Hjuve	Refers to presence of significant areas for development of juvenile fish: (t)=trout; (s)=salmon		
Hriparian	Refers to presence of riparian vegetation of significance to aquatic habitats		
Fishdiv	Refers to presence of a significant range of indigenous fish species		
Rarefish	Refers to presence of indigenous fish species threatened with extinction		

The Waitati River has cultural values associated with being a treasured resource (Waahi taoka). It is listed in Schedule 1D of the Water Plan; this schedule identifies the spiritual or cultural beliefs, values or uses associated with water bodies of significance to Kai Tahu.

4.1 Background information

4.1.1 Carey's Creek

Carey's Creek has a total catchment area of 33.5km^2. It has two branches: one flowing south for approximately 6.5km and the other flowing north for approximately 8.5km before they converge approximately 3.5km upstream of its confluence at Blueskin Bay. The catchment is contained by Kilmog Hill to the east with the Silverpeak range to the west and north dividing it from the Waikouaiti River.

The catchment consists of steep river valleys at an elevation of between 0m at its confluence with Blueskin Bay and 400m at the top of the south branch. The Land Cover Data Base gives a breakdown of land use in the area. Figure 4.2 shows that in the south branch indigenous forest and deciduous hardwoods dominate, while in the north branch, high producing exotic grassland and pine forest dominate. Agribase 2006 gives a detailed breakdown of farming activities in the catchment. It is dominated by forestry in the southern branch and by sheep and beef farming in the northern branch. The northern branch also supports some deer farming.

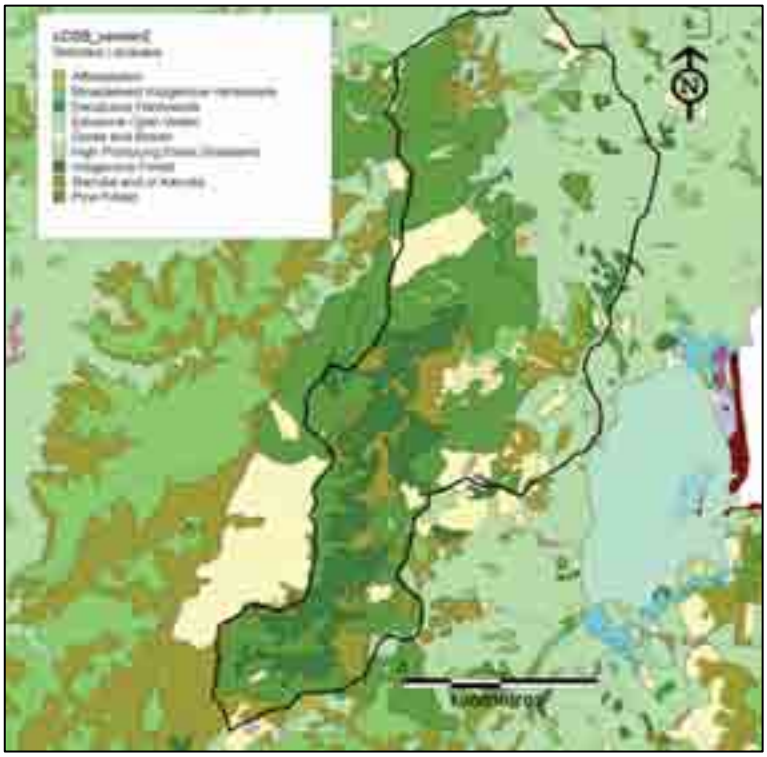

Figure 4.2 Map of land use in Carey's Creek Catchment

4.1.2 Waitati River

Waitati River has a total catchment area of 46.5km^2. The main stem flows for approximately 5.5km in a north easterly direction from Swampy Summit to join Blueskin Bay at Waitati. The catchment is contained by Mount Cargill to the east and south and Swampy Summit and Double Hill to the west from which various tributaries join the main stem before its confluence with the estuary.

The catchment consists of steep river valleys at an elevation of between 0m at its confluence with Blueskin Bay, 676m at Mt Cargill, 739m at Swampy Summit and 423m at Double Hill. The Land Cover Data Base gives a breakdown of land use in the area. Figure 4.3 shows that the lower catchment is dominated by high producing exotic grassland, while the steeper upper catchment is dominated by broad leaved indigenous hardwoods, harvested forestry, manuka and kanuka. Agribase 2006 gives a detailed breakdown of farming activities in the catchment. It is a fairly diverse catchment with mainly sheep and beef in the lower catchment, although lifestyle blocks, deer and dairy also feature. In the upper, steeper catchments the main activity is forestry.

The land forming most of the catchment is zoned rural or rural residential in the current Operative District Plan which allows normal farming activity and forestry planting. The catchment area is almost fully devoted to low intensity pastoral farming on small farms with exotic forestry plantations on the upper slopes of Mount Cargill and on some private properties around Blueskin Bay. There is no intensive factory farming. The soils on the hills are predominately clay-based, thin and subject to sheet and rill erosion so stocking rates and pasture growth have to be well-managed.

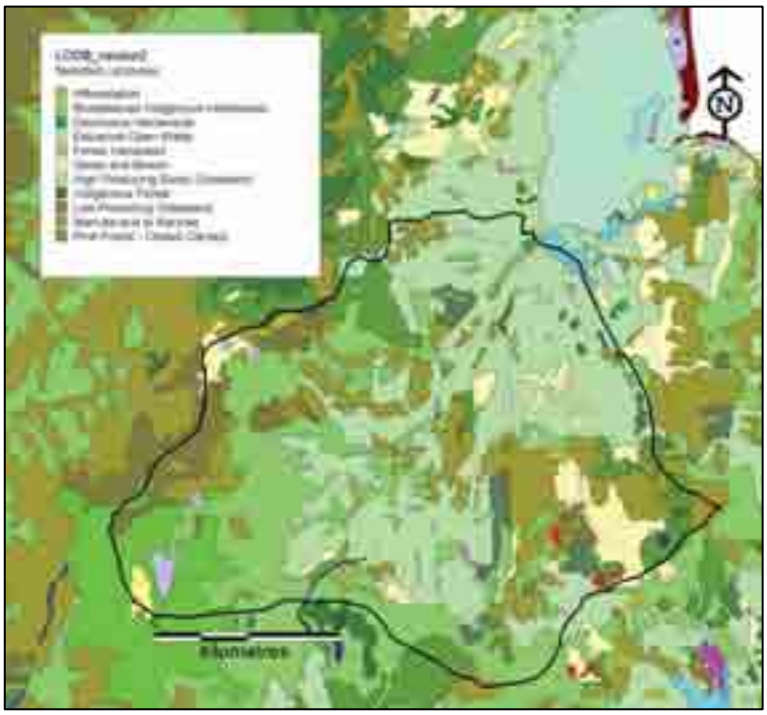

Figure 4.3 Map of land use in Carey's Creek Catchment

4.1.3 Commercial shellfish gathering

Blueskin Bay is used for commercial shellfish gathering; a salinity buoy was installed in the bay in September 2002 and is the primary tool used to calculate whether the waters are of suitable quality for shellfish gathering. This is because rainfall is the primary predictor of contamination events in the bay as it acts as an indirect vehicle and in concert with discharges from other land-based pollution sources.

There is also a relationship between rainfall at Sullivan's Dam and a drop in salinity in the bay. Specific fixed pollution sources (septic tanks, farming activities and sewage treatment plants) have insignificant effect on the bay in the absence of rainfall (Webster 2004).

4.2 Surface water quality monitoring

4.2.1 Water quality monitoring sites

Water quality monitoring has been undertaken at various sites on the Waitati River and Carey's Creek since 1997. The sites still monitored are the Waitati River at Mt Cargill Road and Carey's Creek at State Highway 1.

In addition to these two sites, between July 2007 and March 2008 monthly monitoring was undertaken at an additional site. All monitoring sites are listed in Table 4.2 and the location of these sites is shown in Figure 4.4.

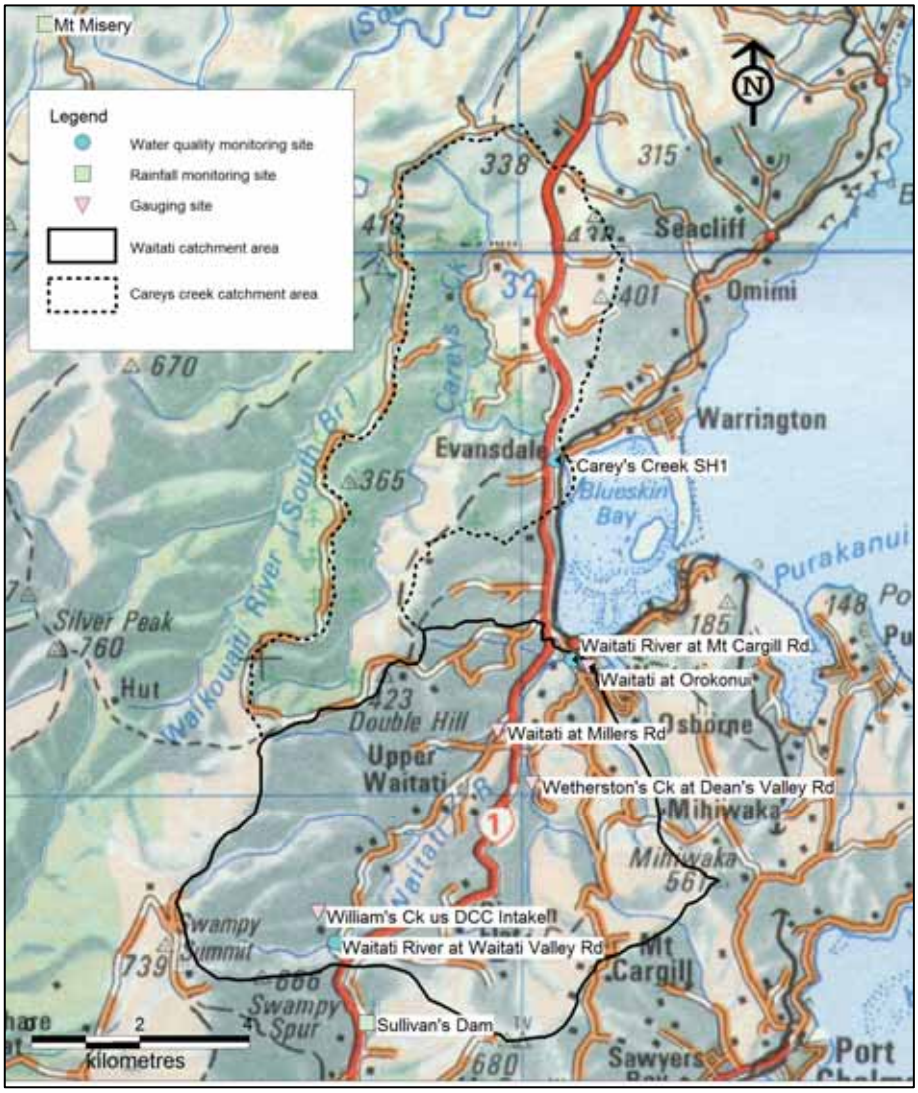

Figure 4.4 Location of water quality monitoring sites, flow stations and rainfall stations in the Waitati and Carey's Creek Catchments

Table 4.2 Water quality monitoring sites in the Waitati and Carey's Creek Catchments, July 2007 to March 2008

River	Site	Northing	Easting
Carey's Creek	d/s SH1 Bridge	2320600	5496200
Waitati River	Waitati Valley Rd	2316530	5487270
Waitati River	Mt Cargill Road	2320900	5492500

4.2.2 Rainfall

The amount of rainfall 72 hours prior to each sampling period was determined at the Mt Misery rain-gauge near Waikouaiti and the Sullivan's Dam rain-gauge (shown in Figure 4.4). Limited rainfall fell in this period and amounts are detailed in Table 4.3.

Table 4.3 Total daily rainfall recorded at Mt Misery rain-gauge and Sullivan's Dam rain-gauge 24 hrs, 48 hrs and 72 hrs prior to each sampling run

	Jul 2007	Aug 2007	Sep 2007	Oct 2007	Nov 2007	Dec 2007	Jan 2008	Feb 2008
Sullivan's Dam								
24hrs	10	0	0	2.5	2.5	6.5	0.5	0
24 to 48 hrs	10.5	0	0	0	0	0	7	0
48 to 72 hrs	12	0	0	0	0	0	0	0
Mt Misery								
24hrs	0	0	0	7.5	0	3.5	0	0
24 to 48 hrs	0	0	0	0	0	0	0	0
48 to 72 hrs	0	0	0	0	0	0	0	0

4.2.3 Flow

ORC has no continuous flow records for either the Waitati River or Carey's Creek.

4.2.4 Historical results

A summary of the water quality results for the Waitati River at Mt Cargill Road and Carey's Creek at SH1 are given in Table 4.4. Key water analytes are compared with the ANZECC 2000 default trigger values for slightly disturbed lowland river ecosystems in New Zealand.

Table 4.4 Median water quality results for the Waitati River at Mt Cargill Road (July 1997 to January 2008) and Carey's Creek at SH1 (July 1997 to January 2008)

Site	Turbidity (NTU)	*E. coli* (n/100ml)	Ammoniacal N (mg/l)	Nitrite/nitrate N (mg/l)	Total N (mg/l)	Dissolved reactive P (mg/l)	Total P (mg/l)
ANZECC 2000	**5.6**	**260***	**0.9**	**0.444**	**0.614**	**0.010**	**0.033**
Waitati River	1.8	100	0.01	0.033	0.22	0.003	0.013
Carey's Creek	2.06	95	0.01	0.053	0.245	0.0025	0.01
*Acceptable/Green Mode of the Ministry for Environment/Ministry of Health (2003) Recreational Water Quality Guidelines							

Table 4.4 indicates that nutrient and bacteria concentrations at both sites are well below the recommended guidelines for DRP, TP, NNN, NH_4, TN and *E. coli*. Turbidity is also well below guideline levels. The median *E. coli* bacteria concentration is also low. Of all the *E. coli* results recorded, Waitati River (26%) and Carey's Creek (21%) exceeded the Ministry for the Environment/Ministry of Health's (2003) Microbiological Water Quality Guidelines for Recreational Areas.

4.3 Surface water quality monitoring 2007-2008

Table 4.5 summarises the results of the more intensive monitoring undertaken between July 2006 and February 2007. Full results can be found in Appendix 1.

Table 4.5 Median water quality results for the Carey's Creek and Waitati River (July 2007 to February 2008) with exceedances of guideline values indicated in bold type

Site	Turbidity (NTU)	E. coli** (cfu/ 100ml)	Ammoniacal N (mg/l)	Nitrite/ nitrate N (mg/l)	Total N mg/l	Dissolved reactive P (mg/l)	Total P (mg/l)
Guideline*	**5.6**	**260**	**0.9**	**0.444**	**0.614**	**0.01**	**0.033**
Carey's Creek							
SH1	0.86	19	0.005	0.31	0.165	0.005	0.011
Waitati River							
Waitati Valley Rd	0.98	69	0.005	0.023	0.145	**0.019**	0.024
Mt Cargill Rd	1.17	30	0.005	0.02	0.18	0.010	0.016

*ANZECC 2000 Default Trigger Value for lowland rivers
**Acceptable/Green Mode of the Ministry for Environment/Ministry of Health (2003) Recreational Water Quality Guidelines

Water quality is good at all the sites. Water quality fell within all the relevant guideline levels at all sites other than for DRP at Waitati Valley Road.

In the following section results from water quality monitoring were compared against guideline values (refer to Table 3.2). Rainfall (mm) was also plotted on relevant graphs.

4.3.1 *E. coli*

Water quality safety is assessed and reported according to the Ministry for the Environment and Ministry of Health (MfE/MoH) 'Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas' (revised and issued in 2003). Table 4.5 shows that the median *E. coli* bacteria concentrations were all below the Mfe/MoH guideline level. As bacteria are not normally distributed it is usual to back-transform the logged mean data (refer to Appendix 3). This is shown in Figure 4.5.

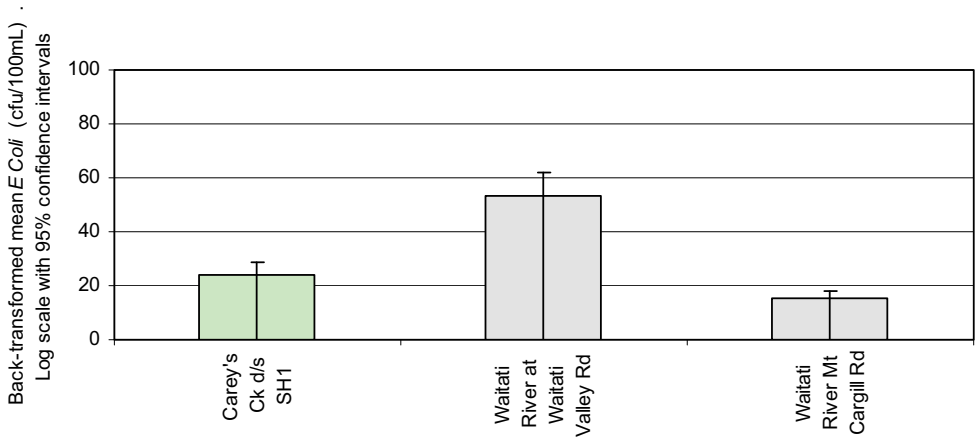

Figure 4.5 Back-transformed mean *E. coli* concentrations with 95% confidence intervals

Figure 4.5 clearly shows that the median *E. coli* levels at all sites is below 126 cfu/100ml (DOH, 1992), indicating that the median recommended recreational water quality guidelines are met and that these streams are generally suitable for contact recreation purposes.

Individual *E. coli* values were plotted against rainfall to see whether there was any correlation between higher bacteria counts (December and January) and rainfall (using the 24 hr rainfall recorded at the Sullivan's Dam rain-gauge).

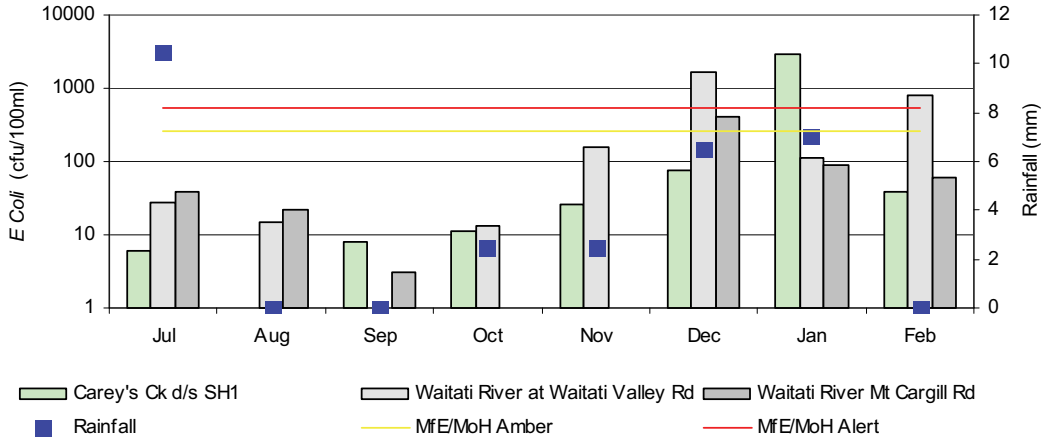

Figure 4.6 *E. coli* (cfu/100ml) levels plotted against the total 48 hr rainfall (mm) recorded at the Sullivan's Dam rain-gauge

Figure 4.6 shows that the rainfall in December and January may have influenced the higher bacteria levels in both rivers. There was one other high bacterial count during the summer that exceeded the MfE/MoH guideline levels, but this cannot be explained by rainfall. There was one other high rainfall event, just prior to the July sampling run. However, this did not result in raised bacterial levels. It is clear that bacteria numbers at all sites increase during the warmer months.

4.3.2 Ammoniacal nitrogen

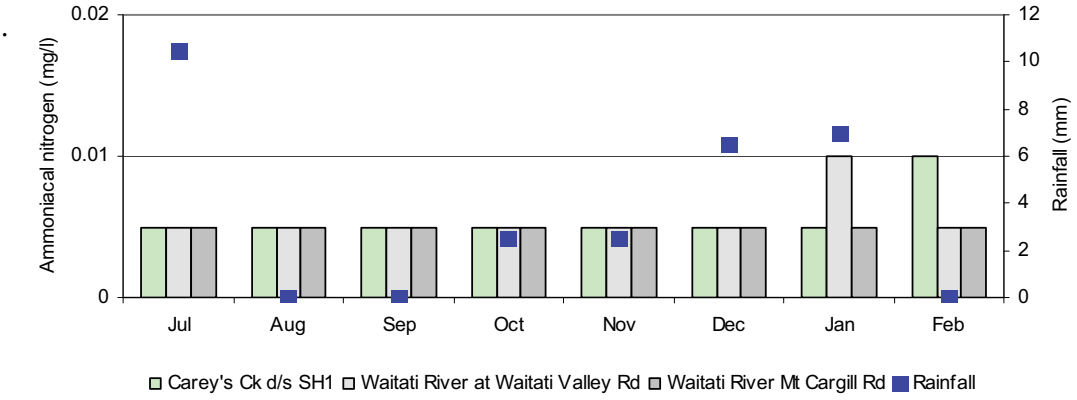

Figure 4.7 Ammoniacal nitrogen concentrations at each monitoring site (July 2007 to February 2008)

Ammoniacal nitrogen is the combination of ammonium ions and ammonia (NH_3). The ANZECC 2000 high reliability (95%) trigger value for freshwater is 0.9 mg/l. NH_3 is the main toxic component for aquatic organisms, the prevalence of which is dependent on the pH, temperature and salinity of the water. The ANZECC 2000 guideline for NH_3 is 0.021 mg/l. Table 4.5 gives the median values for ammoniacal nitrogen and all values are shown graphically in Figure 4.7.

All the results were well below the 0.9 mg/l threshold, and after taking pH and temperature into consideration, none of the individual results exceeded the NH_3 guideline value of 0.021 mg/l.

4.3.3 Nitrite/nitrate nitrogen

Median NNN results were most elevated in Carey's Creek with the lowest value being recorded at Mt Cargill Road (Figure 4.8). None of the sites exceed the ANZECC default trigger value of 0.444mg/l.

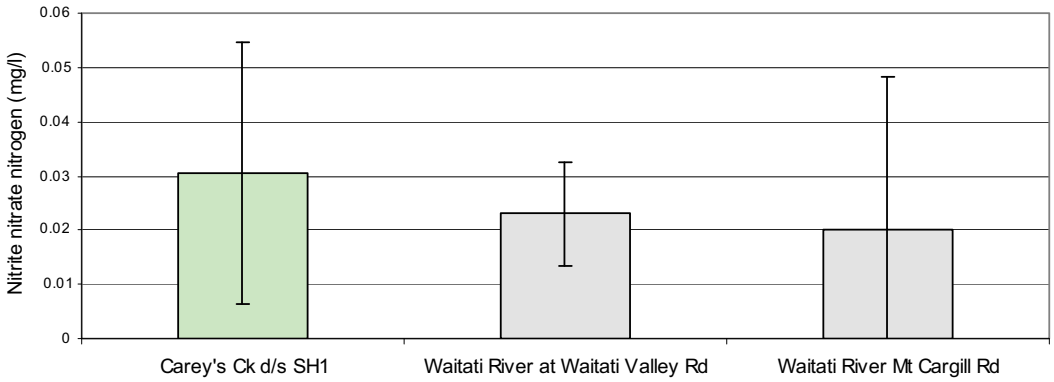

Figure 4.8 Median nitrite/nitrate nitrogen concentrations at each monitoring site (July 2007 to February 2008)

Figure 4.9 shows NNN concentrations for individual sites plotted against rainfall. This clearly shows that the concentration of NNN in winter is higher than during the summer months. Rainfall seems to have little bearing on the results and no individual values exceed the ANZECC default trigger guideline of 0.444 mg/l.

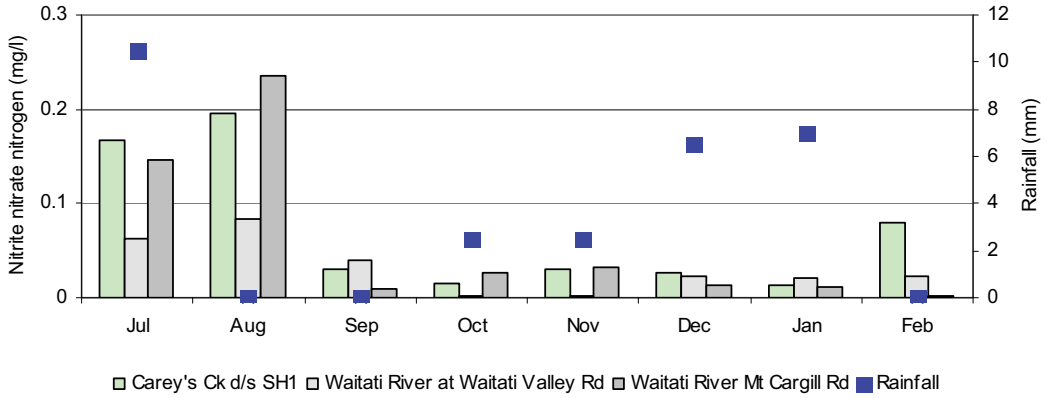

Figure 4.9 Nitrite/nitrate nitrogen (mg/l) concentrations at each site and total 48 hr rainfall (mm) recorded at Sullivan's Dam

4.3.4 Total nitrogen

Figure 4.10 shows median TN concentrations at each site. Median concentrations are highest at the downstream in the Waitati River. None of the sites exceed the ANZECC default trigger value of 0.614mg/l.

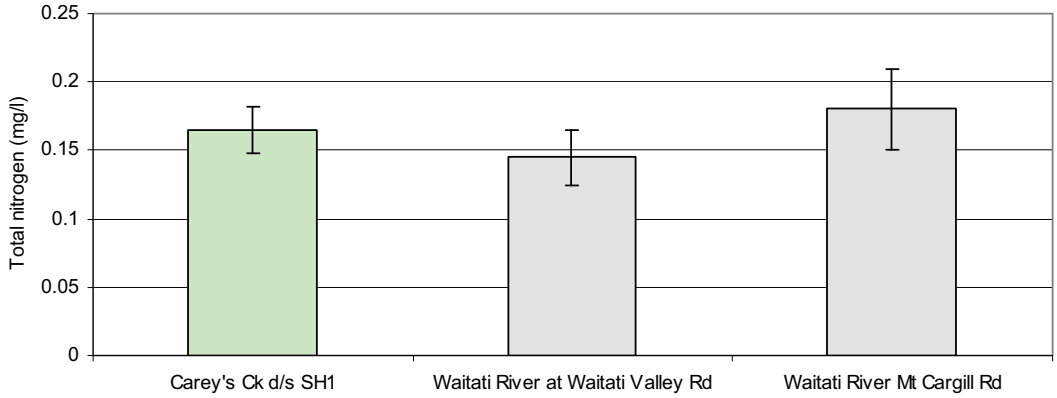

Figure 4.10 Median total nitrogen concentrations at each monitoring site (July 2007 to February 2008)

When all individual results are plotted on a monthly basis against rainfall (Figure 4.11), it can be seen that the highest results are during the winter months of July and August. Rainfall seems to have little bearing on the results and no individual values exceed the ANZECC default trigger guideline of 0.614 mg/l.

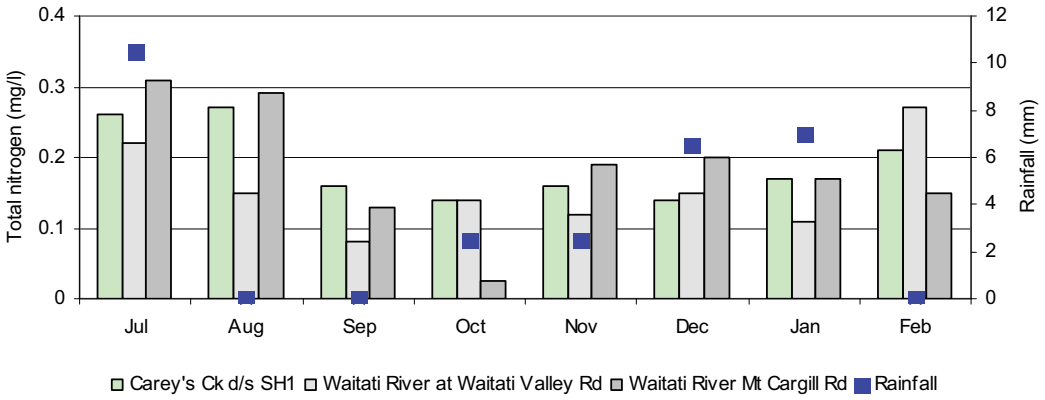

Figure 4.11 Total nitrogen (mg/l) concentrations at each site and total 48 hr rainfall (mm) recorded at Sullivan's Dam

4.3.5 Dissolved reactive phosphorus

Median DRP concentrations are shown in Figure 4.12. The site in the upper reaches of the Waitati River exceeds the ANZECC default trigger value. The New Zealand Periphyton Guidelines give a value for DRP concentrations (0.026 mg/l) which has been predicted as the maximum to prevent excess periphyton biomass; none of the sites exceed this guideline value.

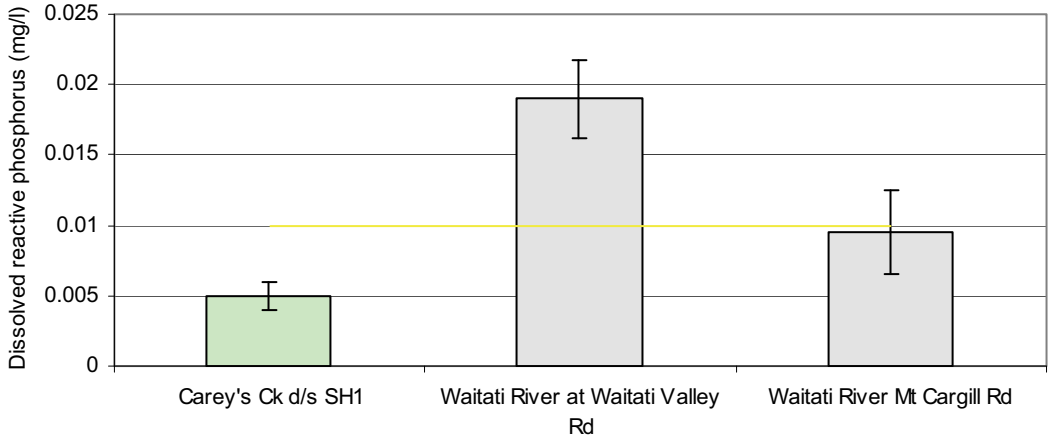

Figure 4.12 Median dissolved reactive phosphorus concentrations at each monitoring site (July 2007 to February 2008). The yellow line depicts the ANZECC 2000 default trigger guideline value for DRP (0.010 mg/l)

When individual sites are plotted against month of sampling (Figure 4.13), there is still no clear seasonal pattern. The NZ Periphyton Guideline value (0.026 mg/l) is exceeded on two occasions in the Waitati River and the ANZECC default trigger guideline of 0.01 mg/l is exceeded frequently over the sampling period, particularly in the Waitati River at Mt Cargill Road.

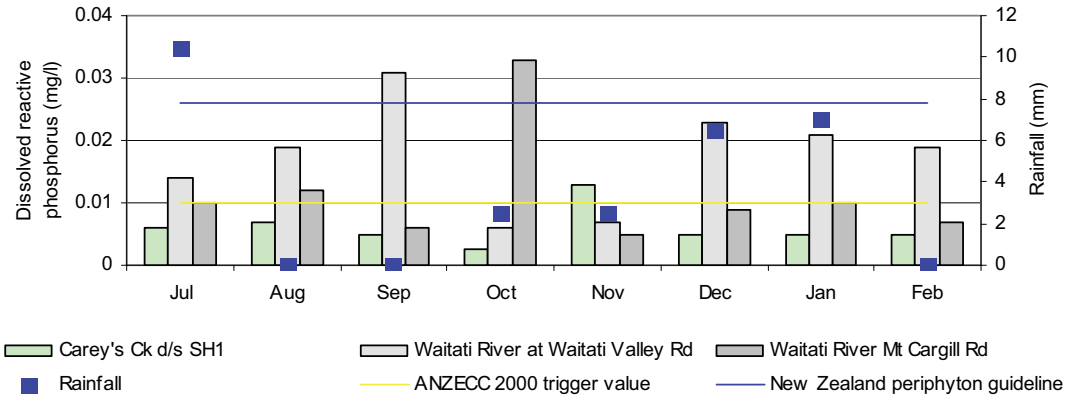

Figure 4.13 Dissolved reactive phosphorus (mg/l) concentrations at each site and total 48 hr rainfall (mm) recorded at Sullivan's Dam

4.3.6 Total phosphorus

Figure 4.14 shows median results for TP. All three sites recorded median values below the ANZECC 2000 guideline value (0.033 mg/l).

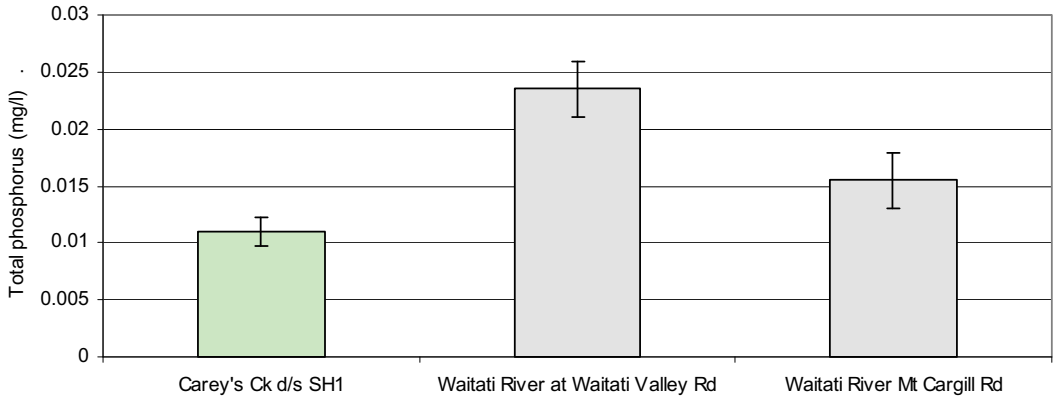

Figure 4.14 Median total phosphorus concentrations at each monitoring site (July 2007 to February 2008)

Figure 4.15 shows TP concentrations for individual sites plotted against rainfall. This clearly shows that concentrations of TP in the upper Waitati are generally higher than in the lower catchment, the exception being October. Rainfall seems to have some bearing on the results, particularly in the Waitati River. Although no individual values exceed the ANZECC default trigger guideline of 0.33 mg/l, TP concentrations in July, November and January, which coincide with rainfall >2.5mm, tend to have higher TP results.

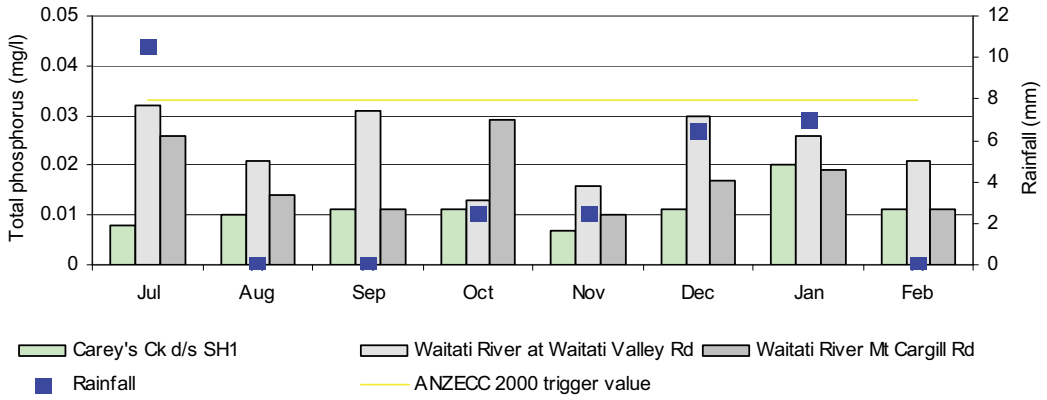

Figure 4.15 Total phosphorus (mg/l) concentrations at each site and total 48 hr rainfall (mm) recorded at Sullivan's Dam

4.3.7 Dissolved oxygen

Dissolved oxygen usually follows a different pattern to other analytes monitored with higher oxygen concentrations in the upper catchments which then decrease downstream. However, this is not the case in the Waitati Catchment and oxygen levels increase with distance downstream (Figure 4.16). Oxygen concentrations are not depleted at the upper Waitati site and increases downstream are primarily due to gradient morphology.

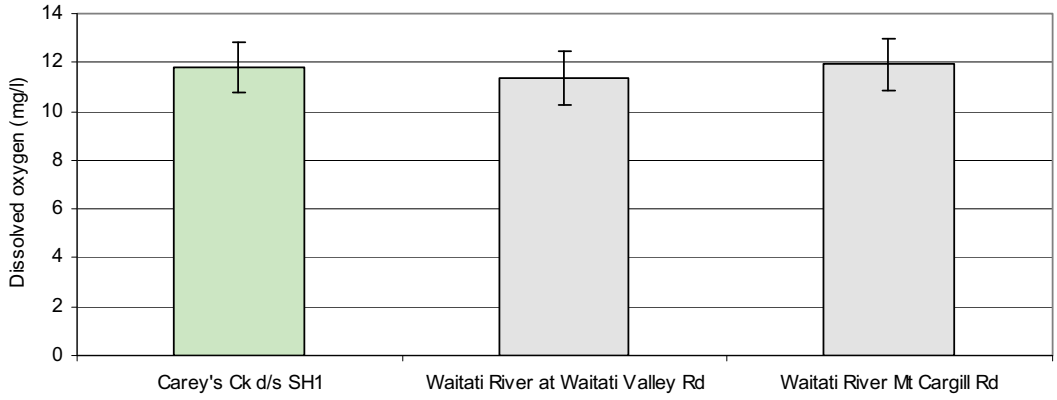

Figure 4.16 Median dissolved oxygen concentrations at each monitoring site (July 2007 to February 2008)

4.3.8 Turbidity

Figure 4.17 shows turbidity for individual sites plotted against rainfall. In July this is clearly shown in the Waitati River which exceeds the ANZECC default trigger guideline of 5.6 NTU. On the other hand, the turbidity in Carey's Creek is not elevated during the July sampling round, and the only peak is noted in January which also coincides with rainfall. There does not seem to be any seasonal variation.

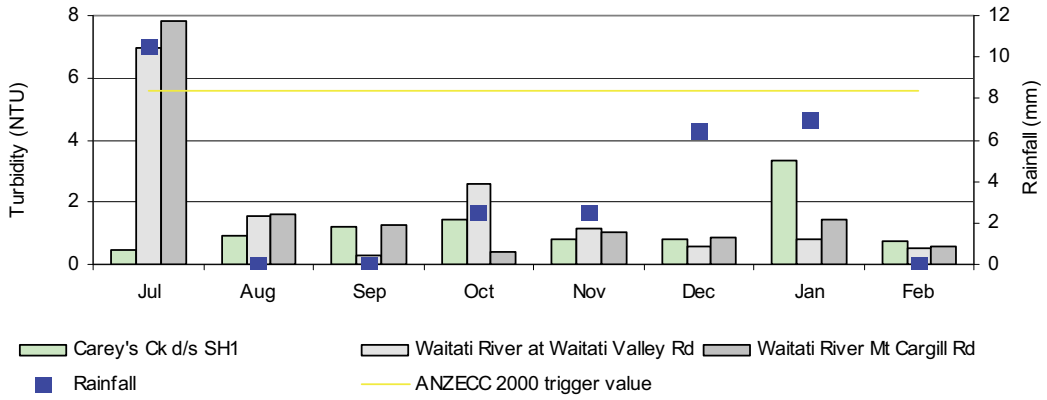

Figure 4.17 Median turbidity at each monitoring site (July 2007 to February 2008)

4.4 Discussion

The survey was based on eight samples taken monthly between July 2007 and February 2008.

Although this is quite a limited dataset, it is clear that Carey's Creek has good water quality with very few individual samples exceeding relevant guideline levels. The same can be said of the Waitati Catchment. This reflects the findings of the SOE Report (2007) in which a water quality index was used to classify rivers. The water quality index was derived from water quality results taken between 2000 and 2006, and used the median values for six variables: turbidity, dissolved oxygen (% saturation), dissolved reactive phosphorus, ammoniacal nitrogen, nitrite/nitrate nitrogen and *Escherichia coli* bacteria. Both the Waitati River and Carey's Creek received a water quality index of 'very good'.

If the water quality index is applied to this survey, then the classification for each site is shown in Table 4.6, along with the % exceedance of relevant guideline values (n = 48). The classifications for the lower catchment sites remain the same, but the upper catchment site in the Waitati River has a classification of 'good' because its dissolved reactive phosphorous median value exceeds that of the ANZECC 2000 guideline value.

Table 4.6 WQI classification (DRP, NH_4, DO % saturation, NNN, turbidity and *E. coli*) and exceedances of guideline values expressed as a percentage

Site	% Exceedances of guideline values (n = 54)	Water Quality Index
Carey's Creek at SH1	6%	Very Good
Waitati River at Waitati Valley Road	21%	Good
Waitati River at Mt Cargill Road	13%	Very Good

Water quality in the Waitati Catchment improves with distance from the head waters with nutrient and bacteria concentrations tending to decrease and dissolved oxygen levels increasing. This is not a typical trend in river systems, and probably reflects the fact that the river is fast flowing with a steep gradient, enabling rapid mixing. Both rivers also flow through undeveloped catchments so that their capacity to assimilate organic loadings will not significantly reduce with distance downstream.

Both rivers had some high bacteria levels. Of the eight samples taken, the contact recreation guideline (MfE/MoH 2003) was exceeded once in both Carey's Creek and the lower Waitati and twice in the upper Waitati Catchment. This is most likely to be due to land use practices, particularly access of stock to water, which is prevalent in the area due to lack of permanent fencing.

In the SOE Report (2007), water quality trends for Carey's Creek and the Waitati River at Mt Cargill Road were analysed (all data up to June 2006). The trends are shown in Table 4.7. It was found that the Waitati River had a declining trend in TP and *E. coli*, but had an improvement in NNN. Carey's Creek showed an improvement in both turbidity and suspended solids. Carey's Creek has managed forestry in its catchment, a land use which can generate high levels of turbidity and SS. It was good to note that the turbidity results from this survey reflect that of the SOE Report (2007) which showed declining trends in SS and turbidity.

Table 4.7 Water quality trends in Carey's Creek and the Waitati River
Statistically significant trends are depicted in blue for improving water quality and red for declining water quality (▲=p <0.2, ▲▲=p <0.1, ▲▲▲=p <0.05, ● = no change)

	Carey's Creek	Waitati River
WQI	Very Good	Very Good
Ammoniacal nitrogen	•	•
Conductivity	•	•
Escherichia coli	•	▼
Nitrite/nitrate nitrogen	•	▲▲
Suspended solids	▲▲	•
Total nitrogen	•	•
Total phosphorus	•	▼▼
Turbidity	▲	•

Most of the nutrients (NNN, DRP, and TP) in the Waitati River followed a similar pattern, decreasing with distance downstream with the most elevated results being recorded at the upper site. However, there were marked seasonal differences in both rivers. During the summer months, flows are lower and there is more uptake of NNN. This is clearly seen in Figure 4.9. During the winter, higher concentrations of TN were found. This cannot be related to high rainfall and is most probably due to the fact that during the summer months, nutrients entering the system as intact organic matter would decompose relatively quickly, as compared to the cold, wet-weather months when decomposition is slow.

5. Conclusions

The background water quality status of Carey's Creek, the Waitati River, the Kaikorai Stream and the Water of Leith Catchments has been identified. This report can now be used to monitor any changes in the future.

The Waitati River and Carey's Creek are characterised by good water quality with bacteria and nutrient concentrations that generally are within recommended contact recreation guidelines. However, in the Waitati River there are many instances of elevated analytes in the upper catchment which require investigation.

The Kaikorai Stream is characterised by poor water quality with bacteria and nutrient concentrations that generally exceed recommended guidelines. Fraser's Stream adds good quality water (from the Deep Stream and Deep Creek Catchments) that provides much needed dilution for the Kaikorai Stream. Even after the confluence of Fraser's Stream, the urban nature of the catchment means that water quality in the Kaikorai Stream is jeopardised, and this is reflected in poor macroinvertebrate health and the water quality index classification for the stream. In the Kaikorai Stream, the objectives of Policies 7.6.1 and 7.6.2 of the Water Plan have not been met; levels of bacteria in the catchment are still high even though there has been some improvement in the long term trend for *E. coli*. Macroinvertebrate health is extremely poor, a reflection of both poor water quality which then contributes to the degradation of the natural habitat.

The Water of Leith is also characterised by poor water quality with bacteria and nutrient concentrations that generally exceed recommended guidelines. This reflects the findings of the SOE Report (2007) which gave both rivers a low classification of fair. Bacterial contamination of both rivers is high and elevated *E. coli* levels far exceed the contact recreation guidelines (MfE/MoH 2003). It is clear that the objective of Policy 7.6.1 of the Water Plan has not been met. Macroinvertebrate health is generally fair (in both the Water of Leith and Lindsay's Creek), although there is poor abundance of pollution sensitive and tolerant species.

6. References

ANZECC. 1992. Australian water quality guidelines for fresh and marine waters. National Water Quality Management Strategy Paper No. 4, Australian and New Zealand Environment and Conservation Council, Canberra.

ANZECC. 2000. Australia and New Zealand guidelines for fresh and marine water quality, Volume 1, The guidelines. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Department of Health. 1992. Provisional microbiological water quality guidelines for recreational and shellfish-gathering waters in New Zealand. Department of Health, Public Health Services, Wellington.

Ministry for the Environment. 2000. New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. Ministry for the Environment, Wellington.

Ministry for the Environment; Ministry of Health. 2003. Microbiological water quality guidelines for marine and freshwater recreation areas. Ministry for the Environment, Wellington.

Otago Regional Council. 1998. Regional Policy Statement for Otago. Otago Regional Council, Dunedin.

Otago Regional Council. 2004. Regional Plan: Water for Otago. Otago Regional Council, Dunedin.

Otago Regional Council, 2007. State of the Environment Report. Surface Water Quality in Otago. Otago Regional Council, Dunedin.

Resource Management Act. 1991. New Zealand Government.

Robertson BM. 1986. Existing ecology of Blueskin Estuary and Bay – with particular emphasis on Warrington tidal flat and sandspit areas – a qualitative appraisal.

Stark JD. 1985. A macroinvertebrate community index of water quality for stony streams. Water and Soil miscellaneous publication 1987. National Water and Soil Conservation Authority, Wellington.

Stark JD. 1993. Performance of the macroinvertebrate community index: effects of sampling method, sample replication, water depth, current velocity, and substratum on index values. New Zealand Journal of Marine and Freshwater Research, 27: 463-478. Published June 2002, updated June 2003.

Webster S. 2004. Blueskin Bay Area 1802. 12-yearly review report April 1991 to October 2003. New Zealand Shellfish Sanitation Programme.

7. Acknowledgements

I am grateful to Simon McMillan who allowed the flow data collected at Kaikorai Valley School to be used in this study.

8. Appendices

Appendix 1 Water of Leith

DATE	TIME	NH4	Cond	DO	DRP	Ec	NNN	SS	Temp	TN	TP	Turb
		mg/l	mS/cm	mg/l	mg/l	cfu/100nl	mg/l	mg/l	Deg C	mg/l	mg/l	NTU
Water of Leith at Malvern Street (Jul and Aug taken at Sullivan's Dam)												
04-Jul-07	11:30	0.010	0.097	11.68	0.005	110	0.559	1.5	5.49	0.640	0.014	4.12
07-Aug-07	09:05	0.005	0.069	9.06	0.003	2	0.024	3	5.4	0.200	0.019	5.07
12-Sep-07	09:30	0.005	0.084	11.58	0.017	96	1.190	1.5	6.59	1.300	0.031	4
03-Oct-07	09:20	0.005	0.125	11.56	0.018	23	1.120	10	6	1.370	0.067	14.9
05-Nov-07	09:15	0.005	0.081	10.82	0.016	210	0.887	3	8.05	1.070	0.037	4.69
05-Dec-07	11:20	0.010	0.135	10.31	0.027	68	0.639	1.5	14.1	0.850	0.043	3.3
07-Jan-08	13:05	0.010	0.105	9.96	0.027	580	0.667	5	15.1	0.990	0.058	5.16
28-Jan-08	11:00	0.010	0.142	3.91	0.026	150	0.556	1.5	15.1	0.750	0.041	2.24
03-Mar-08	12:25	0.005			0.017	4400	1.890	13		2.250	0.065	11.9
	Median	**0.005**	**0.101**	**10.565**	**0.017**	**110**	**0.667**	**3**	**7.32**	**0.990**	**0.041**	**4.69**
	Stan.Err	**0.001**	**0.009**	**0.86**	**0.003**	**475**	**0.175**	**1.41**	**1.49**	**0.191**	**0.006**	**1.42**
Water of Leith u/s Lindsay's confluence												
04-Jul-07	09:35	0.010	0.129	11.81	0.019	160	0.828	1.5	6.11	0.950	0.031	3.46
07-Aug-07	11:30	0.060	0.112	9.83	0.029	4800	0.858	4	6	1.160	0.052	4.66
12-Sep-07	11:15	0.005			0.019	86	0.347	1.5		0.480	0.029	1.13
03-Oct-07	11:45	0.040	0.112	12.24	0.029	2300	0.337	5	6.3	0.620	0.062	7.25
05-Nov-07	11:45	0.100	0.097	11.1	0.040	7000	0.239	8	10.61	0.570	0.076	6.18
05-Dec-07	09:55	0.030	0.201	11.06	0.035	2000	0.678	5	18.1	0.990	0.066	2.47
07-Jan-08	11:55	0.005	0.121	11.07	0.032	510	0.368	1.5	15.84	0.530	0.045	4.09
28-Jan-08	10:35	0.010	0.154	6.64	0.028	240	0.272	3	15.1	0.390	0.036	0.83
03-Mar-08	11:20	0.005			0.018	2800	0.633	4		0.870	0.042	5.27
	Median	**0.010**	**0.121**	**11.07**	**0.029**	**2000**	**0.368**	**4**	**10.61**	**0.620**	**0.045**	**4.09**
	Stan.Err	**0.011**	**0.012**	**0.62**	**0.003**	**795**	**0.081**	**0.72**	**1.73**	**0.089**	**0.005**	**0.73**
Water of Leith at Dundas Street												
04-Jul-07	09:20	0.010	0.138	12.05	0.020	200	1.000	4	6.13	1.150	0.035	4.18
07-Aug-07	12:00	0.050	0.125	9.58	0.026	3800	1.080	3	6.2	1.350	0.048	4.69
12-Sep-07	11:50	0.005	0.096	14.64	0.017	64	0.339	1.5	7.92	0.490	0.029	1.2
03-Oct-07	12:20	0.030	0.122	12.5	0.029	2100	0.455	6	6.8	0.720	0.058	7.8
05-Nov-07	12:15	0.080	0.101	11.65	0.040	3200	0.349	4	11.41	0.720	0.076	3.61
05-Dec-07	11:45	0.030	0.164	10.86	0.028	210	0.383	3	16.6	0.600	0.043	1.36
07-Jan-08	12:40	0.010	0.125	9.21	0.033	2000	0.375	3	16.61	0.590	0.054	1.71
28-Jan-08	12:20	0.010	0.161	5.23	0.030	130	0.279	1.5	17.9	0.430	0.040	0.97
03-Mar-08	13:35	0.005			0.019	1800	0.776	4		1.020	0.042	5.84
	Median	**0.010**	**0.125**	**11.255**	**0.028**	**1800**	**0.383**	**3**	**9.665**	**0.720**	**0.043**	**3.61**
	Stan.Err	**0.008**	**0.008**	**0.93**	**0.002**	**474**	**0.103**	**0.46**	**1.71**	**0.106**	**0.005**	**0.79**

Appendix 1 Water of Leith

DATE	TIME	NH4	Cond	DO	DRP	Ec	NNN	SS	Temp	TN	TP	Turb
		mg/l	mS/cm	mg/l	mg/l	cfu/100nl	mg/l	mg/l	Deg C	mg/l	mg/l	NTU
Lindsay's Creek at Bethune's Gully												
04-Jul-07	10:45	0.005	0.122	11.77	0.013	74	0.837	6	6.31	1.180	0.030	4.75
07-Aug-07	09:40	0.005	0.116	9.9	0.012	52	1.050	3	5.7	1.180	0.022	4.72
12-Sep-07	10:00	0.005	0.085	10.72	0.017	16	0.617	1.5	6.59	0.700	0.025	2.42
03-Oct-07	10:20	0.005	0.103	12.28	0.014	210	0.523	5	5.1	0.690	0.036	5.55
05-Nov-07	10:00	0.005	0.092	10.96	0.015	44	0.476	1.5	8.03	0.600	0.028	2.36
05-Dec-07	08:16	0.020	0.143	11.77	0.021	68	0.584	1.5	10.5	0.470	0.042	1.63
07-Jan-08	10:24	0.005	0.098	10.67	0.024	150	0.307	1.5	12.59	0.430	0.035	1.56
28-Jan-08	08:55	0.005	0.132	5.15	0.025	220	0.282	1.5	12.4	0.390	0.031	1.37
03-Mar-08	09:50	0.005			0.012	2500	0.666	8		0.920	0.035	5.36
	Median	**0.005**	**0.110**	**10.84**	**0.015**	**74**	**0.584**	**1.5**	**7.31**	**0.690**	**0.031**	**2.42**
	Stan.Err	**0.002**	**0.007**	**0.75**	**0.002**	**267**	**0.081**	**0.82**	**1.01**	**0.101**	**0.002**	**0.58**
Lindsay's Creek at North Road Bridge												
04-Jul-07	10:15	0.020	0.152	11.39	0.016	170	1.330	4	6.46	1.520	0.032	5.04
07-Aug-07	10:20	0.020	0.162	9.39	0.015	100	1.760	1.5	6.2	1.990	0.031	4.93
12-Sep-07	10:30	0.005	0.013	15	0.008	140	0.589	1.5	7.28	0.790	0.021	1.63
03-Oct-07	10:50	0.005	0.144	12.87	0.013	900	0.839	4	6.4	1.020	0.041	7.47
05-Nov-07	10:30	0.020	0.125	0.83	0.011	580	0.632	3	10.64	0.850	0.033	3.09
05-Dec-07	09:20	0.005			0.023	690	0.344	3		0.810	0.037	2.84
07-Jan-08	11:10	0.020	0.098	10.67	0.023	5000	0.451	3	15.9	0.750	0.051	3.24
28-Jan-08	09:40	0.050	0.191	7.23	0.014	640	0.338	1.5	15.6	0.550	0.030	1.48
03-Mar-08	10:30	0.020			0.018	3900	1.310	5		1.670	0.053	6.14
	Median	**0.020**	**0.144**	**10.67**	**0.015**	**640**	**0.632**	**3**	**7.28**	**0.850**	**0.033**	**3.24**
	Stan.Err	**0.005**	**0.019**	**1.53**	**0.002**	**601**	**0.169**	**0.42**	**1.45**	**0.165**	**0.003**	**0.68**
Lindsay's Creek 15m u/s Leith confluence												
04-Jul-07	09:45	0.020	0.159	12.08	0.019	1100	1.460	6	6.54	1.640	0.040	6.17
07-Aug-07	11:15	0.020	0.168	9.86	0.017	250	1.810	1.5	6.4	2.050	0.035	4.72
12-Sep-07	10:50	0.005	0.120	15.98	0.013	300	0.550	4	8.2	0.790	0.030	1.64
03-Oct-07	11:25	0.010			0.019	1400	0.941	11		1.220	0.067	9.85
05-Nov-07	12:00	0.030	0.139	11.66	0.022	800	0.874	1.5	13.11	1.100	0.058	1.66
05-Dec-07	09:48	0.010	0.155	9.62	0.022	130	0.330	1.5	14.1	0.500	0.033	1.03
07-Jan-08	11:45	0.020	0.139	11.51	0.037	3800	0.545	7	18.46	0.890	0.073	4
28-Jan-08	10:15	0.020	0.197	5.9	0.032	3600	0.486	1.5	17.8	0.730	0.052	1.68
03-Mar-08	11:20	0.020			0.022	3400	1.440	5		1.740	0.056	6.71
	Median	**0.020**	**0.155**	**11.51**	**0.022**	**1100**	**0.874**	**4**	**13.11**	**1.100**	**0.052**	**4**
	Stan.Err	**0.003**	**0.008**	**1.02**	**0.002**	**509**	**0.174**	**1.10**	**1.70**	**0.174**	**0.005**	**1.00**

Appendix 1 Kaikorai Stream

Date	Time	NH4	Cond	DO	DRP	Ec	NNN	SS	Temp	TN	TP	Turb
		mg/l	mS/cm	mg/l	mg/l	cfu/100mL	mg/l	mg/l	Deg C	mg/l	mg/l	NTU
Kaikorai Stream off Shetland Street												
05-Jul-07	10:55	0.160	0.206	9.48	0.090	900	1.800	7	7.11	3.38	0.226	11.3
07-Aug-07	12:40	0.100	0.101	7.93	0.054	570	1.610	3	7.2	2.87	0.195	7.51
13-Sep-07	09:25	0.060	0.124	8.09	0.005	42	1.500	3	7.38	1.52	0.04	9.01
08-Oct-07	09:00	0.080	0.188	9.1	0.007	130	1.500	4	8.9	1.72	0.043	9.64
06-Nov-07	08:05	0.110	0.122	7.2	0.003	74	1.530	5	9.25	1.75	0.052	11.4
06-Dec-07	08:45	11.200	0.194	5.24	0.950	70000	0.800	9	12.2	16.1	1.45	9.86
08-Jan-08	09:00	0.200	0.161	4.85	0.011	5200	1.590	4	13.83	2.08	0.098	10.5
29-Jan-08	08:00	0.120	0.200	3.31	0.017	2600	1.590	6	14	2.26	0.141	10.1
04-Mar-08	09:40	0.090	0.214	7.91	0.008	3100	2.010	6	13	2.54	0.069	7.24
	Median	**0.110**	**0.188**	**7.91**	**0.011**	**900**	**1.590**	**5**	**9.25**	**2.26**	**0.098**	**9.86**
	Stan.Err	**1.232**	**0.014**	**0.6954**	**0.103**	**7625.1**	**0.109**	**0.662**	**0.9748**	**1.549983**	**0.151**	**0.4936**
Kaikorai Stream u/s Fraser's Stream												
05-Jul-07	13:10	0.100	0.239	10.51	0.081	1500	2.410	19	7.38	3.43	0.147	19.7
08-Aug-07	09:10	0.110	0.269	9.03	0.030	240	2.380	7	7	2.98	0.114	10.7
13-Sep-07	10:00	0.060	0.196	11.26	0.019	420	2.670	3	7.62	2.88	0.181	5.41
08-Oct-07	10:20	0.070	0.276	10.79	0.017	270	2.240	1.5	9	2.38	0.065	4.02
06-Nov-07	09:20	0.040	0.171	10.61	0.014	630	2.180	6	8.51	2.01	0.056	9.54
06-Dec-07	09:25	0.070	0.211	10.82	0.023	2200	1.670	13	11.7	2.33	0.13	17.5
08-Jan-08	09:45	0.030	0.226	9.96	0.028	900	2.360	6	13.72	2.44	0.077	10.1
29-Jan-08	08:30	0.010	0.296	4.06	0.027	2200	2.250	4	14.4	2.73	0.103	5.85
04-Mar-08	12:20	0.070	0.313	9.06	0.022	4300	2.860	5	12.6	3.28	0.08	6.64
	Median	**0.070**	**0.239**	**10.51**	**0.023**	**900**	**2.360**	**6**	**9**	**2.73**	**0.103**	**9.54**
	Stan.Err	**0.011**	**0.016**	**0.7354**	**0.007**	**442.93**	**0.110**	**1.83**	**0.966**	**0.156399**	**0.01377**	**1.8118**
Trib. of Fraser's Stream Dalziel Road												
04-Jul-07	12:10	0.005	0.046	12.21	0.003	44	0.362	1.5	4.52	0.49	0.014	2.23
07-Aug-07	13:20	0.030	0.116	8.66	0.019	98	2.380	4	6.8	2.65	0.044	3.93
13-Sep-07	09:00	0.170	0.087	10.15	0.046	130	2.030	1.5	7.23	2.04	0.07	1.97
08-Oct-07	09:45	0.030	0.115	10.89	0.029	120	1.630	1.5	9.7	1.69	0.052	1.71
06-Nov-07	08:40	0.080	0.089	10.34	0.024	550	1.700	5	8.53	1.86	0.05	2.89
06-Dec-07	12:19	0.030	0.138	9.62	0.022	3800	0.999	12	15.3	1.33	0.082	16
08-Jan-08	11:50	0.020	0.123	7.34	0.023	2900	0.824	18	19.63	1.13	0.088	10.9
29-Jan-08	14:10	0.020	0.137	3.14	0.018	4400	0.613	11	18.1	0.92	0.068	5.89
04-Mar-08	13:20	0.040	0.111	8.14	0.013	5100	1.600	12	13.9	1.92	0.058	4.07
	Median	**0.030**	**0.115**	**9.62**	**0.022**	**550**	**1.600**	**5**	**9.7**	**1.69**	**0.058**	**3.93**
	Stan.Err	**0.017**	**0.010**	**0.8764**	**0.004**	**706.28**	**0.227**	**2.005**	**1.791**	**0.218813**	**0.00741**	**1.6176**

Appendix 1 Kaikorai Stream

Date	Time	NH4	Cond	DO	DRP	Ec	NNN	SS	Temp	TN	TP	Turb
		mg/l	mS/cm	mg/l	mg/l	cfu/100mL	mg/l	mg/l	Deg C	mg/l	mg/l	NTU
Fraser's Stream Kaikorai Valley Rd												
05-Jul-07	12:45	0.010	0.087	11.73	0.011	86	0.118	5	5.37	1.36	0.036	12.1
08-Aug-07	09:00	0.005	0.121	9.93	0.012	150	1.910	1.5	5.7	2.04	0.024	3.72
12-Sep-07	12:45	0.005	0.039	11.53	0.008	1900	0.322	1.5	7.8	0.48	0.018	1.44
08-Oct-07	10:10	0.005	0.059	11.1	0.008	88	0.311	1.5	8.1	0.41	0.012	1.42
06-Nov-07	09:10	0.005	0.036	11.08	0.006	140	0.278	3	8.75	0.36	0.018	1.58
06-Dec-07	09:55	0.005	0.126	11.86	0.021	140	0.675	2.5	11.3	0.85	0.029	1.62
08-Jan-08	09:55	0.005	0.046	10.4	0.012	700	0.172	5	14.9	0.37	0.025	2.69
29-Jan-08	08:55	0.005	0.125	4.57	0.021	280	0.632	1.5	13.7	0.83	0.033	2.25
04-Mar-08	12:30	0.005	0.074	9.41	0.011	300	0.652	3	12.4	0.9	0.026	3.11
	Median	**0.005**	**0.074**	**11.08**	**0.011**	**150**	**0.322**	**2.5**	**8.75**	**0.83**	**0.025**	**2.25**
	Stan.Err	**0.001**	**0.012**	**0.7535**	**0.002**	**195.59**	**0.182**	**0.48**	**1.1466**	**0.185585**	**0.00255**	**1.1297**
Abbot's Creek Flower Road												
05-Jul-07	09:50	0.080	0.217	9.55	0.019	3000	1.120	26	5.91	2.03	0.083	58.1
08-Aug-07	10:30	0.050	0.284	9.5	0.005	310	0.934	7	5.6	1.51	0.049	16.1
12-Sep-07	13:15	0.020	0.203	7.96	0.006	32	0.137	15	8.52	0.67	0.062	16.5
08-Oct-07	11:10	0.020	0.269	7.57	0.009	140	0.307	10	10.2	0.81	0.049	15.6
06-Nov-07	10:55	0.030	0.216	6.65	0.009	96	0.120	5	11.4	0.61	0.049	8.1
06-Dec-07	11:30	0.030	0.340	5.93	0.012	44	0.052	7	15.3	1.03	0.101	12.2
08-Jan-08	11:20	0.040	0.253	5.23	0.017	210	0.077	7	18.84	0.8	0.112	11.2
29-Jan-08	13:30	0.030	0.263	2.37	0.014	94	0.044	4	20	0.75	0.109	10.6
04-Mar-08	09:00	0.040	0.255	6.65	0.011	550	0.387	13	9.9	1.2	0.079	17.2
	Median	**0.030**	**0.255**	**6.65**	**0.011**	**140**	**0.137**	**7**	**10.2**	**0.81**	**0.079**	**15.6**
	Stan.Err	**0.006**	**0.014**	**0.7423**	**0.002**	**317.48**	**0.134**	**2.286**	**1.745**	**0.155582**	**0.00869**	**5.071**
Kaikorai Stream Donald Street												
05-Jul-07	10:30	0.020	0.149	11.57	0.024	400	1.430	15	5.81	1.93	0.071	23.2
08-Aug-07	09:45	0.030	0.181	11.87	0.012	100	1.760	3	6	2	0.034	6.12
13-Sep-07	10:15	0.005	0.060	12.9	0.007	120	0.307	1.5	6.94	0.42	0.018	1.9
08-Oct-07	10:50	0.005	0.095	11.57	0.008	160	0.319	1.5	9	0.49	0.015	2.87
06-Nov-07	09:50	0.005	0.057	11.4	0.008	370	0.254	1.5	8.8	0.41	0.021	2.35
06-Dec-07	10:20	0.050	0.161	10.27	0.017	190	0.734	2.5	13.6	1.14	0.052	6.52
08-Jan-08	10:30	0.005	0.079	10.31	0.018	130	0.247	1.5	15.27	0.43	0.034	2.7
29-Jan-08	12:50	0.005			0.029	640	0.624	1.5		0.86	0.051	2.23
04-Mar-08	11:20	0.005	0.122	9.68	0.013	900	0.846	3	4.6	1.1	0.032	4.12
	Median	**0.005**	**0.109**	**11.485**	**0.013**	**190**	**0.624**	**1.5**	**7.87**	**0.86**	**0.034**	**2.87**
	Stan.Err	**0.005**	**0.016**	**0.3478**	**0.003**	**92.257**	**0.182**	**1.461**	**1.2774**	**0.2101**	**0.00614**	**2.2492**

Appendix 1 Kaikorai Stream

Date	Time	NH4	Cond	DO	DRP	Ec	NNN	SS	Temp	TN	TP	Turb
		mg/l	mS/cm	mg/l	mg/l	cfu/100mL	mg/l	mg/l	Deg C	mg/l	mg/l	NTU
Kaikorai Stream Brighton Rd												
05-Jul-07	09:20	0.070	0.293	11.31	0.034	2100	1.560	29	6.15	2.27	0.1	31.8
08-Aug-07	12:45	0.120	0.284	12.25	0.017	1100	1.730	7	6.8	2.17	0.054	11.9
13-Sep-07	10:45	0.005	0.103	14.64	0.007	300	0.247	1.5	7.49	0.42	0.018	2
08-Oct-07	12:15	0.005	0.167	12.95	0.008	42	0.243	1.5	10.7	0.43	0.015	2.04
06-Nov-07	10:30	0.020	0.101	11.32	0.007	200	0.306	3	9.73	0.5	0.02	2.78
06-Dec-07	10:50	0.040	0.211	11.09	0.016	2100	0.649	2.5	15	1.05	0.04	5.71
08-Jan-08	10:50	0.010	0.130	10.92	0.013	2300	0.195	3	17.82	0.44	0.032	2.56
29-Jan-08	11:20	0.005	0.314	53.4	0.022	400	0.328	1.5	18.6	0.71	0.053	1.75
04-Mar-08	08:10	0.030	0.187	9.36	0.017	670	1.000	9	10.8	1.37	0.049	5.61
	Median	**0.020**	**0.187**	**11.32**	**0.016**	**670**	**0.328**	**3**	**10.7**	**0.71**	**0.04**	**2.78**
	Stan.Err	**0.013**	**0.027**	**4.6558**	**0.003**	**303.49**	**0.199**	**2.954**	**1.553**	**0.24765**	**0.0088**	**3.2409**

Appendix 1 Waitati River and Carey's Creek

Date	Time	NH4	Cond	DO	DRP	Ec	NNN	SS	Temp	TN	TP	Turb
		mg/l	mS/cm	mg/l	mg/l	cfu/100mL	mg/l	mg/l	Deg C	mg/l	mg/l	NTU
Carey's Creek d/s SH1 Bridge												
24-Jul-07	12:10	0.005	0.252	14.17	0.006	6	0.167	1.5	2.8	0.260	0.008	0.46
27-Aug-07	11:10	0.005	0.231	12.6	0.007	1	0.196	1.5	5.33	0.270	0.010	0.92
11-Sep-07	12:50	0.005	0.155	12.04	0.005	8	0.030	1.5	6.67	0.160	0.011	1.23
02-Oct-07	13:45	0.005	0.235	11.8	0.003	11	0.016	1.5	9	0.140	0.011	1.44
05-Nov-07	13:20	0.005	0.240	10.93	0.013	26	0.031	1.5	9.7	0.160	0.007	0.79
12-Dec-07	12:30	0.005	0.164	9.56	0.005	74	0.027	1.5	15.46	0.140	0.011	0.79
16-Jan-08	13:15	0.005	0.244	4.42	0.005	2900	0.013	5	15	0.170	0.020	3.35
26-Feb-08	13:30	0.010			0.005	39	0.080	1.5		0.210	0.011	0.73
	Median	**0.005**	**0.235**	**11.8**	**0.005**	**19**	**0.031**	**1.5**	**9**	**0.165**	**0.011**	**0.855**
	Stan.Err	**0.001**	**0.013**	**1.05**	**0.001**	**339**	**0.024**	**0.41**	**1.58**	**0.017**	**0.001**	**0.31**
Waitati River at Waitati Valley Road												
24-Jul-07	12:50	0.005	0.140	13.28	0.014	28	0.062	6	5.4	0.220	0.032	6.96
27-Aug-07	12:10	0.005	0.186	12.32	0.019	15	0.084	1.5	8.41	0.150	0.021	1.55
11-Sep-07	11:45	0.005	0.126	11.35	0.031	1	0.040	1.5	5.22	0.080	0.031	0.28
02-Oct-07	13:15	0.005	0.116	14.04	0.006	13	0.003	1.5	10.6	0.140	0.013	2.57
05-Nov-07	14:00	0.005	0.174	9.95	0.007	160	0.003	1.5	12.2	0.120	0.016	1.14
12-Dec-07	13:20	0.005	0.216	9.67	0.023	1700	0.023	4	18.48	0.150	0.030	0.55
16-Jan-08	13:55	0.010	0.235	4.2	0.021	110	0.021	5	20	0.110	0.026	0.82
26-Feb-08	14:15	0.005			0.019	800	0.023	1.5		0.270	0.021	0.54
	Median	**0.005**	**0.174**	**11.35**	**0.019**	**69**	**0.023**	**1.5**	**10.6**	**0.145**	**0.024**	**0.98**
	Stan.Err	**0.001**	**0.015**	**1.09**	**0.003**	**202**	**0.010**	**0.63**	**1.96**	**0.021**	**0.002**	**0.74**
Waitati River at Mt Cargill Road												
24-Jul-07	12:30	0.005	0.146	13.28	0.010	38	0.146	5	5.2	0.310	0.026	7.83
27-Aug-07	11:45	0.005	0.184	12.32	0.012	22	0.236	1.5	8.34	0.290	0.014	1.62
11-Sep-07	12:20	0.005	0.117	11.35	0.006	3	0.009	1.5	9.1	0.130	0.011	1.28
02-Oct-07	12:30	0.005	0.116	14.04	0.033	1	0.027	1.5	6.5	0.025	0.029	0.39
05-Nov-07	13:40	0.005	0.171	9.95	0.005	1	0.033	1.5	13.4	0.190	0.010	1.06
12-Dec-07	12:55	0.005	0.201	9.67	0.009	400	0.013	3	20.59	0.200	0.017	0.84
16-Jan-08	13:40	0.005	0.230	4.2	0.010	90	0.012	1.5	21.7	0.170	0.019	1.42
26-Feb-08	13:55	0.005			0.007	61	0.003	1.5		0.150	0.011	0.6
	Median	**0.005**	**0.171**	**11.35**	**0.010**	**30**	**0.020**	**1.5**	**9.1**	**0.180**	**0.016**	**1.17**
	Stan.Err	**0.000**	**0.014**	**1.09**	**0.003**	**45**	**0.028**	**0.42**	**2.23**	**0.030**	**0.002**	**0.81**

Appendix 2 Water quality index and guideline compliance

Table A2: 1 Water quality index, guideline compliance (median values)

Site Name		Guideline compliance (median values)					
	Rank	Amm. N	DO	DRP	Ec	NNN	Turb
		>0.9 mg/l	<80 %	>0.01 mg/l	>126 cfu/ml	>0.444 mg/l	>5.6 NTU
River	**Site**						
Kaikorai Stream	Marae off Shetland St	✔	✘	✘	✘	✘	✘
Kaikorai Stream (culverted)	Confluence with Fraser's Stm	✔	✔	✘	✘	✘	✘
Kaikorai Stream	Donald Street	✔	✔	✘	✘	✘	✔
Kaikorai Stream	Green Island bridge	✔	✔	✘	✘	✔	✔
Fraser's Stream	Dalziel Road	✔	✔	✘	✘	✘	✔
Fraser's Stream	Kaikorai Valley Rd	✔	✔	✔	✘	✔	
Abbott's Ck	Flower Rd	✔	✘	✘	✘	✔	✘
Carey's Creek	d/s SH1 Bridge	✔	✔	✔	✔	✔	✔
Waitati River	Waitati Valley Rd	✔	✔	✘	✔	✔	✔
Waitati River	Mt Cargill Road	✔	✔	✔	✔	✔	✔
Lindsay's Creek	Bethune's Gully	✔	✔	✘	✔	✘	✔
Lindsay's Creek	North Road Bridge	✔	✔	✘	✘	✘	✔
Lindsay's Creek	15 m u/s Leith	✔	✔	✘	✘	✘	✔
Water of Leith	Sullivan's Dam*	✔	✔	✘	✔	✘	✔
Water of Leith	Malvern Street*						
Water of Leith	Dundas St bridge	✔	✔	✘	✘	✔	✔
Water of Leith	u/s Lindsay's confluence	✔	✔	✘	✘	✔	✔

Appendix 3 Back-transformation

Many biological variables do not meet the assumptions of parametric statistical tests: they are not normally distributed, the variances are not homogeneous, or both. Using a parametric statistical test (such as an anova or linear regression) on such data may give a misleading result. In some cases, transforming the data will make it fit the assumptions better.

Using the actual data from the Water of Leith Catchment, it can be seen, in the first graph below, that *E. coli* are not normally distributed; there are a lot of sampling occasions with a small number of *E. coli* and fewer samples with a higher number. Applying the log transformation makes the data more normal, as shown in the second graph.

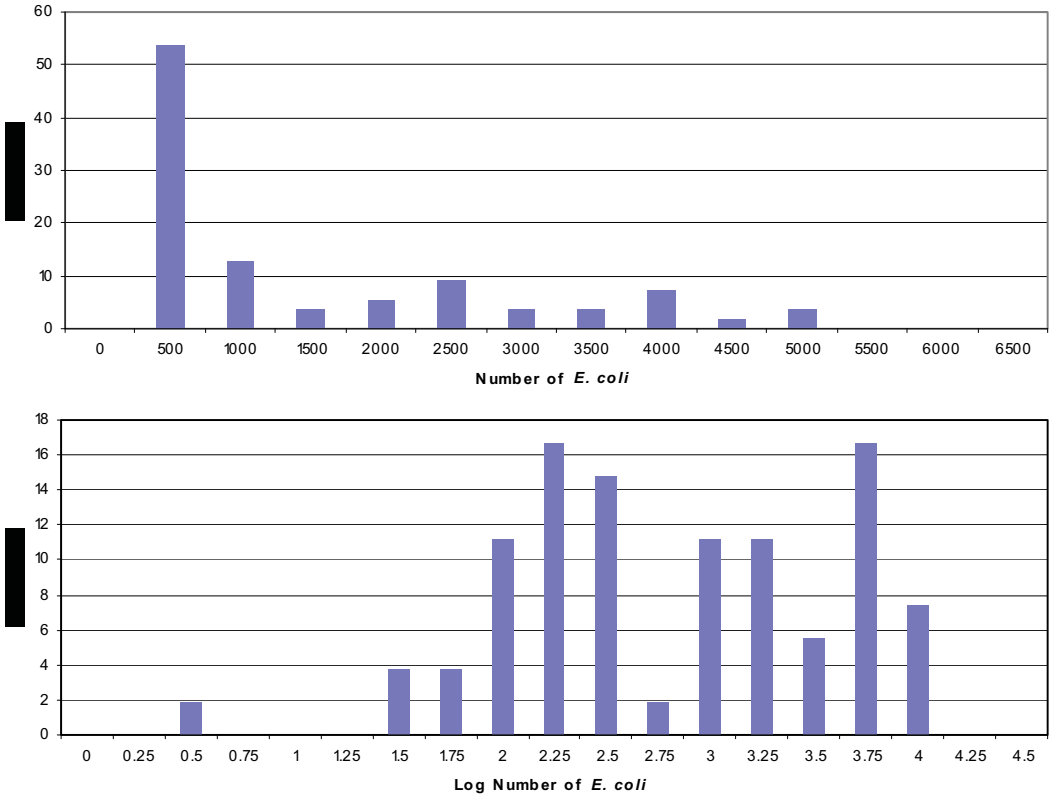

Figure A3: 1 Histograms of number of *E. coli*. Untransformed data in first graph, log-transformed data in second graph

However, means, standard errors, etc are not reported in transformed units. Instead, they are back-transformed. This involves doing the opposite of the mathematical function used in the data transformation. The back transformation is to raise 10 or *e* to the power of the number. If zeros or negative numbers are in the dataset, the log can't be taken and a constant should be added to each number to make them positive and non-zero. If some counts are zero, the convention is to add 0.5 to each number.