West Coast Surface Water Quality

THE WEST COAST
REGIONAL COUNCIL

State of the Environment Technical Report 08002

June 2008

A technical report presenting results of the West Coast Regional Council's Surface Water Quality Monitoring Programme from 1996 to 2007 and incorporating monitoring data collected by other organisations from 1989 to 2007.

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Executive Summary

This report summarises results from the West Coast Regional Council (WCRC) Surface Water Quality Monitoring Programme (SWQMP), for data up until 2007. This programme assesses surface water quality state and trends at selected sites where human impacts/pressures occur.

From 1996 to 2007, 41 sites were sampled for physical, chemical, and bacteriological water quality parameters, as well as periphyton and macroinvertebrate communities. Sites were sampled four to six times per year. Ten of these were reference sites, eight of which had a corresponding 'impact' sites down stream. An additional five sites were sampled as a part of the National River Water Quality Network (NRWQN). Other data included in this report came from the WCRC Contact Recreation water quality programme, a subset of the SWQMP. This consisted of 21 sites (in 2007), sampled monthly from November to March each year.

This report is intended to identify differences in water quality state, and changes in water quality over time at the various sites. Individual water quality parameters were compared with guidelines, and levels found in other parts of New Zealand.

State of water quality in the West Coast Region

In the previous WCRC Surface Water Quality Report many significant differences in physical, chemical, and biological water quality parameters were observed between the River Environment Classification (REC) classes of flow source, geology, land cover, and stream size. Fundamental relationships observed for these parameters amongst REC classes in 2006 remain current in 2008 (refer to Horrox 2005).

Using a combination of all water quality parameters, waterways in pasture dominated catchments had poorer water quality than those in indigenous forest, which was consistent with previous analysis (Horrox 2005). Significant water quality deterioration was observed between the upper and lower parts of a number of catchments, although there were anomalies for certain parameters at some sites. Past and present opencast and underground mining caused significant lowering of pH in areas where sufficient quantities of exposed pyrite generated acid rock drainage. When combined with high levels of dissolved and particulate metals, which often accompanied this source of acidity, significant negative effects on aquatic ecology were evident. This was not apparent where mining occurred in areas with little exposed pyrite, or where highly calcareous rock buffered pH.

The WCRC Water Plan (WCRC 2007) sets two water quality management purposes, in accordance with Schedule 3 of the RMA. These are: Contact Recreation for specific bathing and secondary contact sites; and Aquatic Ecosystem, which applies to all West Coast water bodies. Other additional guidelines from various literature have been used for assessment in this document.

Comparison of individual water quality parameters to guidelines and standards indicated a broad range of results among sites. The data collected at reference sites and the comparison between reference and impact sites suggested that the natural characteristics of water bodies vary across the region. These natural characteristics could mitigate or exacerbate anthropogenic effects and are an important consideration when comparing water quality among sites. For example, soft sedimentary geology exacerbated turbidity. Ammoniacal nitrogen levels did not pose a risk to aquatic animals, although samples at two sites exceeded this threshold 10-20% of the time. Many sites have had *Escherichia coli (E. coli)* levels above what is deemed appropriate for stock consumption. One site had *E. coli* levels over this threshold for more than 50% of the time. Invertebrate indices suggested that the top three quarters of sites had slight to un-impacted water quality, with the bottom quarter consistently rating moderate to poor water quality.

Contact recreation monitoring at contact recreation monitored sites showed that lake sites had good water quality, as did to a lesser extent those situated in open coastal locations. Improvements for some river and lagoon sites were apparent, although levels of faecal indicator bacteria at some have been consistently above contact recreation guidelines. Less than 5% of contact recreation monitoring samples in 2008 indicated unsafe swimming conditions.

Trends in West Coast water quality

Water quality improvement was evident in levels of ammoniacal nitrogen, clarity, turbidity, and faecal coliforms – consistent with national patterns. Improvements in these parameters benefit aquatic ecosystems, and value for commercial and recreational use. While ammoniacal nitrogen has decreased, other forms of nitrogen – total nitrogen (TN) and nitrate - have increased, which is also consistent across New Zealand. It appears that while point source pollution has decreased, diffuse source pollution has increased.

With the recent upgrade to Westport's municipal sewage treatment, major improvement in bacterial water quality occurred at Marrs and Shingle Beach's near the Buller River mouth. There were fewer guideline exceedances at many swimming sites in the last two to three years.

When data from all sites were combined, significant improving trends were apparent for turbidity, faecal coliforms, and *E. coli*. While not statistically significant at a $p<0.05$ level, ammoniacal nitrogen and clarity were also tending toward improvement. As might be expected given the overall regional trend, most individual sites trended toward improved clarity. Of the sites with statistically significant trends in clarity, the downstream site on the Orowaiti River displayed a major improvement in clarity, over the sampling record. Faecal coliforms also decreased at many individual sites, consistent with the regional trend.

Although occurring at levels below those typical in New Zealand and not having an adverse effect, TN levels in the Grey and Buller Rivers have increased at a rate above the national average. Dissolved reactive phosphorous (DRP) decreased in the Buller River ($p<0.01$). Total phosphorus (TP) increased in the Grey River ($p<0.09$), although this trend was not statistically significant.

Lake Brunner

Phosphorus may be the nutrient that is most likely to limit algal growth in Lake Brunner based on TN:TP ratios >20:1. However, the information from TN:TP ratios is still not unequivocal, because of seasonal variation, and caution is necessary when ascribing a single nutrient limitation at TN:TP ratios of between 1:5 and 1:35.

The median TN:TP ratio was ~ 34:1 in both the 1990's and 2000's. Seasonal patterns were apparent for some parameters, particularly clarity and nitrate. Clarity was poorest during summer and highest in late winter/early spring. Nitrate concentrations were lowest in summer increasing to a peak at the end of winter, then heading down again as the weather warmed. DRP and TN displayed a similar albeit less defined pattern.

The WCRC Proposed Water Management Plan (2007) states that water quality in Lake Brunner shall be maintained or improved. Trend analysis accounting for seasonality was conducted on data collected at the central lake monitoring site. From 1992-2007, a statistically significant trend was observed for increasing TN, phytoplankton (as inferred from chlorophyll a), TP, and decreasing clarity. Analysing a shorter data record of 2001-2007, nitrate decreased but phytoplankton remained on an upward trend.

Cashmere Bay had the poorest water quality, compared with Iveagh Bay and the central lake, with localised conditions the probable cause. While the data record for Iveagh and Cashmere Bay is shorter than that of the central lake, there appeared to be some consistency with patterns observed at the central lake site, particularly decreasing clarity.

Modelling has allowed for estimation of flow volumes and nutrient loads in the catchment and main tributaries of the lake. 18.9% of the catchment consists of high producing exotic grassland. Nutrient loadings per hectare were higher in agriculturally developed catchments, e.g. the Orangipuku River had the highest concentrations of TN. Phosphorus concentrations in tributaries increased with flow (except in the lake fed Poerua River), with less of a relationship between flow and nitrogen. Estimated nutrient yields from high producing pasture in the Lake Brunner catchment were consistent compared to the rest of the country for TN, but over double for TP.

Statement of data verification and liability

The West Coast Regional Council recognises the importance of good quality data. This third comprehensive surface water quality technical report provides interpretation of results from the West Coast Regional Council Surface Water Quality Monitoring Programme and is a summary of relevant information available at the time the report was produced.

Data collection and management systems follow systematic quality control procedures. International Accreditation New Zealand (IANZ) laboratories carried out sample analysis excluding field analysis. When possible expert staff have been involved in each stage of the monitoring process. Internal and external review of this report has been implemented.

While every attempt has been made to ensure the accuracy of the data and information presented, the West Coast Regional Council does not accept any liability for the accuracy of the information. It is the responsibility of the user to ensure the appropriate use of any data or information from the text, tables or figures. Not all available data or information is presented in the report. Only information considered reliable, of good quality, and of most importance to the readers has been included.

Acknowledgements

The following people and organisations are acknowledged for their efforts, which contributed to this report:

- Staff and ex-staff of the West Coast Regional Council: Chris Ingle, Simon Moran, Trevor James for ideas and review; Jack Grinsted, Emma Chaney, and Steffi Henkel for technical support; Les Gibbs and Mikhael Schumacher for computer systems support.

- National Institute of Water and Atmospheric Research staff: Mike Scarsbrook, Catherine Chague-Goff, Bob Spigel, Kit Rutherford, Alistair McKerchar, Bob Wilcock, Lawrence Kees, Mike O'Driscoll, and John Porteous.

- Olivier Ausseil (Aquanet Consulting Ltd) for peer review.

- Bill Dyck and FRST for financial assistance.

- The Cawthron Institute for laboratory analysis of water samples.

- The Ministry for the Environment for financial assistance and information.

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1 Introduction

1.1 Rationale

The West Coast Region is renowned for its natural and physical attributes, including its lakes, rivers, and coastal areas. It is also renowned for its wet climate - something that has played an important role over time to help form the unique features we see today. These attributes, or resources, must be sustainably managed in support of their many uses that include recreation, industry, energy, and agriculture, not to mention maintaining the integrity of ecological and cultural values.

Under the Resource Management Act 1991 the West Coast Regional Council (WCRC) is responsible for the management of: water, air and land (soil conservation, natural hazards, and hazardous substances); activities in the Coastal Marine Area; the discharge of contaminants; and the use of river and lakebeds. As a result of these responsibilities the WCRC is required to monitor the overall state of the regions environment. This monitoring is important because it helps the Regional Council and the West Coast community to gauge the state of environmental quality and how it changes over time. The WCRC regularly monitors the quality of the Coast's key natural and physical resources using a range of scientific techniques - surface water being one of the main ones and the focus of this report. This monitoring allows us to make better decisions on how we manage the West Coast's water resources. It also provides feedback as to how effective our policies are i.e. if water quality is improving, stable, or deteriorating.

The WCRC will prepare a State of the Environment (SOE) report every five years to provide information about the quality of the West Coast's water resources. This technical report synthesises information from the WCRC surface water quality monitoring programme, and includes some information from territorial authorities, and other resource management agencies and institutes. Separate technical reports are produced to discuss the state of the West Coast's groundwater, and air quality.

1.2 The monitoring programme

The Surface Water Quality Monitoring Programme (SWQMP) has involved the collection of data on water quality, periphyton (algae on the stream bottom) and stream invertebrates from selected rivers and streams since the mid-nineties. Additional information has also been collected during the Council's contact recreation surveys, and as part of scientific studies carried out in the West Coast region. Detailed specifications of the WCRC sampling programme are provided in Appendix 5.2. The National Institute of Water and Atmospheric Research (NIWA)'s National River Water Quality Network (NRWQN) has five sites within the West Coast region which have been sampled monthly since 1989, and data from this programme is incorporated into analysis presented in this report. Lake Brunner is a particular area of focus where bi-monthly monitoring is conducted at a range of sites in the lake and its tributaries as part of the SWQMP.

An outline of analyses used in this report, and methods and explanations of some of the measurements and guidelines associated with the SWQMP used to assess water quality, are provided in Section 5.3 Maps showing the location of SWQMP sites are provided in Section 5.2.

Aims of the West Coast SWQMP are:

- To determine the quality of surface waters in the West Coast region in reference to accepted standards (for public health, recreational and ecological values).

- To identify short and long term trends in water quality (bearing in mind that accurate trend analysis on quarterly data is only achievable after 15-20 years of data collection).

- To identify cumulative environmental effects from multiple discharges into surface waters.

- To understand the nature of surface water quality problems/issues in order to provide information that enables defensible management responses to be enacted. Such responses include seeking reviews to Council resource management plans, regulations, and resource consent conditions.

- To identify new issues and monitoring requirements.

- To identify factors that cause change in surface water quality (i.e. impact monitoring).

The SWQMP was designed to achieve these aims. However, the programme must work within a number of constraints. Given the resources available, quarterly sampling is undertaken. Sampling only occurs at base flow so very little is known about water quality after rain or flood flow conditions. For the Contact Recreation Water Quality Monitoring Programme, sites are sampled monthly from November-March, also during base flow and non-rainfall periods. While information from the SWQMP will give clues as to the cause of poor water quality, it is often only after intensive sampling within a catchment that clear conclusions of cause and effect relating to specific land-use activities can be drawn. Such follow-up investigations are undertaken on a prioritised basis. The programme targets areas where the most significant human pressures, such as point source discharges, exist or are suspected, while maintaining a few sites in pristine areas for reference. A number of sites form upstream/downstream pairs on the same waterway – the upper site having the purpose of being a reference. Sites in the programme were chosen to try to achieve a balance within and between the following criteria:

(a) Geographical spread throughout the West Coast region;

(b) Range of waterway sizes represented (from large main-stem rivers to small creeks);

(c) Range of different environmental pressures represented at different sites;

(d) In areas with high human use (such as for recreation or drinking) or significant ecological values.

In order to address its aims while working within the constraints mentioned above, design of the SWQMP involved careful choice of indicators (measures) of water quality, sites, and methods. In addition to the intrinsic ecological values of waterways the issue of water quality is also related to community values. Therefore, the choice of environmental indicators may differ between monitoring sites with different values. For example, one stretch of river may be highly valued as a fishery resource, but may be seldom used for swimming, while another may be popular for swimming. In this example water clarity, ammonia and macroinvertebrates would be the most important indicators for a river valued for its fishery, but faecal bacteria (*E. coli* and faecal coliforms), which are indicators of potential human disease, would be the most crucial indicators at monitoring sites valued for contact recreation. Indicators were, therefore, chosen partly to reflect community values, as well as to be consistent (as far as practical) with indicators recommended by Ministry for the Environment (1998).

This report begins with an analysis of the state of West Coast surface water quality, followed by an assessment of surface water quality trends. A separate section covers state and trends of surface water quality in the Lake Brunner catchment. Supporting information can be found in the appendices including: site maps; explanations of the SWQMP structure, analytical methods, guidelines, and the basic science around water quality parameters; and presentation of more detailed analysis.

2 State of surface water quality on the West Coast

Summary of surface water quality state on the West Coast

Many of the conclusions drawn in the previous Surface Water Quality SOE report, using the REC framework, remain supported. Due to the West Coast Region's topography and climate water quality in larger waterways tended to fare better in the face of human induced environmental pressure compared with smaller ones. Smaller streams in lowland areas were more susceptible to being affected by human development. Spring fed streams that are located on agricultural plains form a stream type with their own characteristics. With a high base flow proportional to their catchment size stemming from recharge from groundwater sources beyond their surface water catchment boundaries, water quality was often higher in them than what might have been expected relative to the level of development in their catchment.

Using a combination of all water quality parameters, waterways in pasture dominated catchments had poorer water quality than those in indigenous forest, agreeing with previous analysis (Horrox 2005). It was also shown that water quality deteriorated downstream when comparing paired impact/reference sites, although there were anomalies for certain parameters at some sites. Several water quality parameters showed a strong relationship with the percentage of natural land cover in the catchment. These were faecal indicator bacteria, nitrogen and phosphorus concentrations, and invertebrate community structure (MCI & %EPT). This is consistent with relationships observed right around New Zealand.

Comparison of individual water quality parameters to guidelines and benchmarks indicated a broad range of results among sites. Some sites rated poorly for many parameters, while other sites only rated poorly for some. The particular natural characteristics of a water body, upstream or between paired impact reference sites, were apparent when comparing results. These natural characteristics could mitigate or exacerbate anthropogenic effects, and are an important consideration when comparing water quality among sites. Invertebrate indices suggested that the top three quarters of sites had slight to un-impacted water quality, with the bottom quarter consistently rating moderate to poor water quality. Nuisance periphyton growths have been infrequent at most sites. A combination of higher nutrients and suitable climatic conditions are required for nuisance growths to occur.

Contact recreation monitoring at contact recreation monitored sites showed that lake sites had good water quality, as did to a lesser extent those situated in open coastal locations. Improvements for some river and lagoon sites were apparent, although levels of faecal indicator bacteria at some were consistently above their respective contact recreation guidelines. Less than 5% of contact recreation monitoring samples in 2008 indicated unsafe swimming conditions.

2.1 Conclusions from previous REC analysis in 2005

The previous WCRC SOE report covered WCRC data records up until 2004 – 2005, conducting analysis under the framework of the River Environment Classification (REC). Patterns and relationships that were apparent then are assumed to be consistent now, and a summary of conclusions made in the last Surface Water Quality report are presented here.

The REC was used to group sites by climate, source of flow, geology, land cover, and stream order. Refer to Section 5.5 for a further description of the REC. Analysis was conducted investigating relationships between these REC classes and water quality.

Many significant differences in physical, chemical, and biological water quality parameters were observed between the REC classes of source of flow, geology, land cover, and stream order. Patterns observed for these parameters amongst REC classes suggested that streams could be characterised as:

- Streams with a hill source of flow; hard sedimentary or plutonic geology; often incorporating larger rivers; with higher, less variable water quality; brown trout more abundant.

- Lowland streams (low elevation source of flow); higher turbidity, nutrients and temperature (which may not solely have been a response of human activity); smaller, more variable and susceptible to impact; potentially higher fish and invertebrate diversity.

- Streams draining predominantly agricultural catchments (sub-set of lowland streams); comparatively poorer water quality with fewer sensitive macroinvertebrate taxa.

- Stream catchments with soft sedimentary geology; higher turbidity; distinctive physically and chemically from other geology classes; smaller size; lower source of flow.

2.2 Overall ranking of SWQMP sites based on multiple parameters

An overall site rank was calculated, providing a high level summary of water quality at each site that was then related to land use (Figure 2.1).

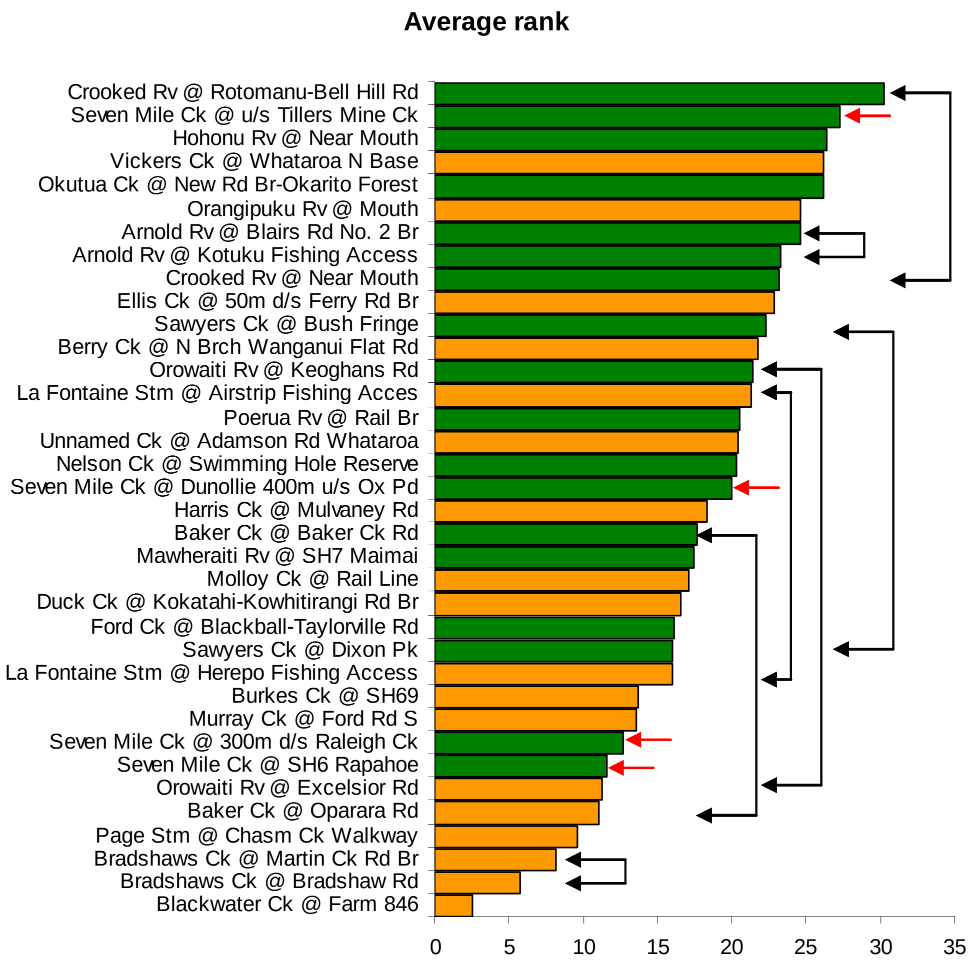


Figure 2.1 *Average water quality rank for each site. Green sites are Indigenous Forest (IF) and orange are Pasture (P) according to the REC. Lines link paired sites on the same river. Red arrows indicate the four sites on Seven Mile Creek.*

Not too much emphasis should be placed on ranking between sites from different catchments, especially if they are ranked closely. The ranking technique used is appropriate to provide a general comparison of sites.

The water quality rank clearly shows a separation of paired upstream-downstream sites on some rivers. This separation is particularly strong for the Orowaiti River, Crooked River, Sawyer's Creek, Baker Creek and La Fontaine Stream. In contrast, differences between upstream and downstream sites are relatively minor for the Arnold River and Bradshaw's Creek.

2.3 Effect of land use on water quality

A two-sample t-test showed a statistically significant difference in mean water quality rank between Indigenous Forest and Pasture (P=0.01) sites. Despite this the top half of Figure 2.1 has many streams classified in the Pasture category. It is worth noting that these predominantly pasture catchments occur on the alluvial plains near large rivers. These streams are typified by a high base flow compared to their mean flow and catchment size, which is due to a significant supply of high quality water from groundwater/spring sources.

SWQMP sites were separated into either predominantly Pasture or Indigenous Forest catchment type, according to REC. Concentrations of nutrients (dissolved reactive phosphorus or DRP, and all nitrogen species), levels of faecal indicator bacteria, levels of suspendable fine sediments, conductivity and most biological indices (Taxa richness, %EPT (Ephemeroptera, Plecoptera, Chichoptera), MCI (Macroinvertebrate Community Index) and SQMCI (Semi-Quantitative Macroinvertebrate Community Index), differed significantly between REC Pasture and Indigenous Forest catchment types (Table 2.1).

Table 2.1 Results of Mann-Whitney U test between Pasture and Indigenous Forest groups. Negative differences in median values indicate that values for a particular variable were elevated in pasture vs. indigenous forest. Differences that were significant ($P<0.05$) are given in bold and highlighted.

Variable	Difference between medians	p-value
%EPT	**7.40**	**0.003**
Clarity	-0.61	0.683
Dissolved oxygen (mg)	0.63	0.174
Dissolved oxygen (% sat.)	1.75	0.189
Dissolved reactive phosphorus	**-0.01**	**0.027**
Conductivity	**-23.00**	**0.031**
E. coli	**-260.00**	**0.001**
Embeddedness	0.00	0.931
EPT taxa	-2.00	0.316
Faecal coliforms	**-212.50**	**<0.001**
Fine sediment deposits	-1.00	0.803
Flow	-67.75	0.845
MCI	**10.64**	**<0.001**
Ammoniacal nitrogen	**-0.01**	**0.031**
Nitrate	**-0.18**	**0.008**
Periphyton	0.67	0.151
pH	0.32	0.155
Conductivity	**-32.25**	**0.025**
SQMCI	**1.47**	**0.006**
Temperature	-0.50	0.079
Total nitrogen	**-0.35**	**0.003**
Total phosphorus	-0.01	0.286
Taxa richness	**-7.50**	**0.043**
Turbidity	-0.10	0.877

The percentage of 'natural' land cover (LCDB2, MfE 2008a) in the catchment of individual SWQMP sites was significantly correlated with improved levels of faecal indicator bacteria, nitrogen and phosphorus concentrations, and invertebrate communities requiring higher water quality (MCI & %EPT)(Table 2.2). This is consistent with relationships observed across NZ (MfE 2008b). Nationally, agriculture has the widest impact on water quality. Nationally, it covers 40% of New Zealand's land area, and accounts for four times all other modified land covers combined (MfE 2008b).

Table 2.2 Spearman rank correlation of water quality variables (global site median) with land cover (%Natural). Statistically significant correlations are highlighted with significance levels indicated as: * <0.05 and **<0.01. N = number of samples.

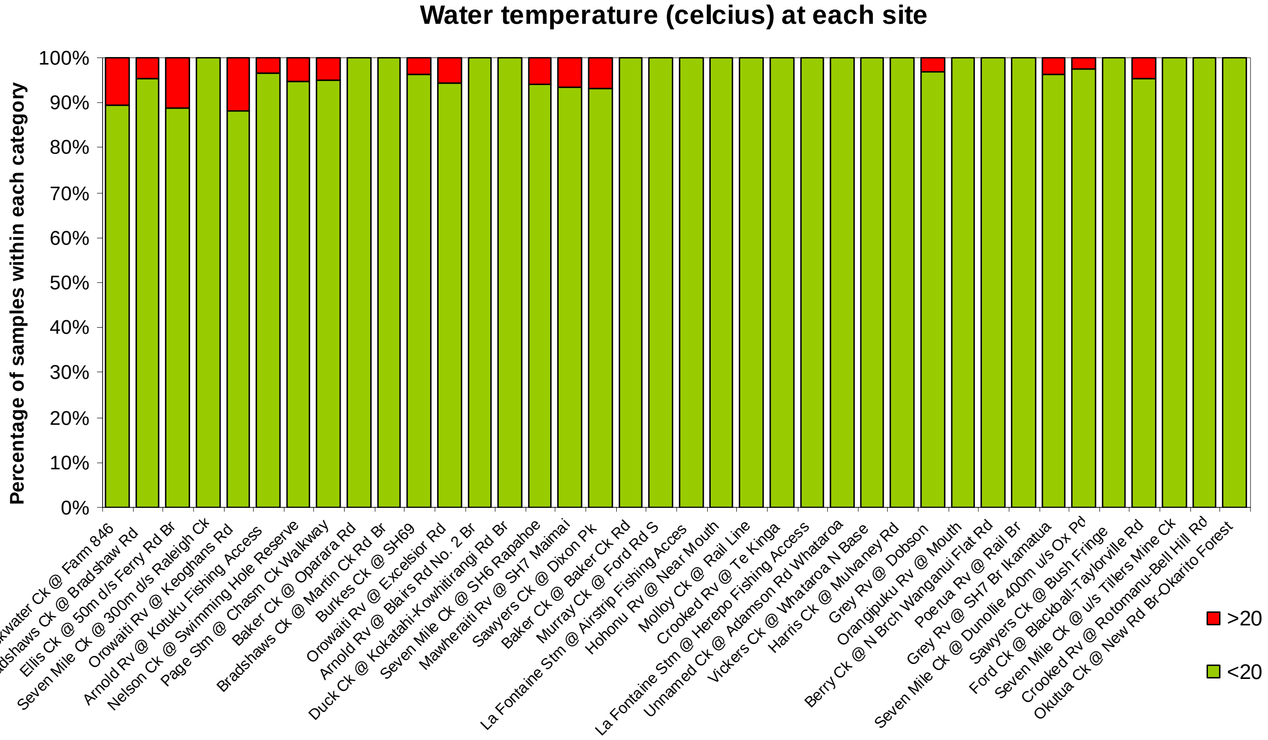
Variable	N	Correlation co-efficient
Dissolved oxygen (%)	36	-0.01
Temperature	36	-0.16
Conductivity	36	-0.28
pH	36	0.05
Turbidity	36	0.11
Faecal coliforms	36	-0.51 **
E. coli	36	-0.51 **
Ammoniacal nitrogen	36	-0.13
Total nitrogen	14	-0.69 **
Total phosphorus	12	-0.34
Dissolved reactive phosphorus	16	-0.53*
Nitrate	20	-0.56 *
Periphyton	31	0.22
Clarity	36	-0.2
Fine sediment deposits	34	-0.06
Embeddedness	34	0.03
Taxa richness	31	-0.28
% EPT	31	0.47**
EPT taxa	31	-0.15
MCI	31	0.59 **
SQMCI	31	0.39 *

2.4 Comparison of WCRC SWQMP sites to water quality guidelines

Sites are ordered according to their median value for that parameter. Sites moving towards the right have higher water quality i.e. the median will be increasing or decreasing depending on what is desirable for a particular parameter. Further information on the origin, meaning and rationale behind these guidelines is presented in Section 5.3. A model of one of these percentage bar graphs is provided in Section 5.6 to aid interpretation. The reader is directed to box and whisker plots in Section 5.7 for more detailed information on data ranges for each water quality parameter, per site.

2.4.1 Temperature

Few sites appear to have had issues with high temperature i.e. above 20°C (Figure 2.2). This temperature is only restrictive for the more temperature sensitive species e.g. trout, certain stoneflies etc. Sites where temperatures exceeded 20°C had varying catchment and physical characteristics. The Arnold River @ Kotuku Fishing Access has high water quality and is close to the outlet of Lake Brunner. Warm summer surface layers in the lake are likely to be the cause of elevated river temperatures, which appeared to decrease downstream through dilution from cooler tributaries. Generally, a lack of riparian shading and/or small flows are conditions likely to lead to high temperatures in warm, sunny weather. Five sites have recorded temperatures over 22°C, with only Burke Creek @ SH69 recording a temperature over 24°C.

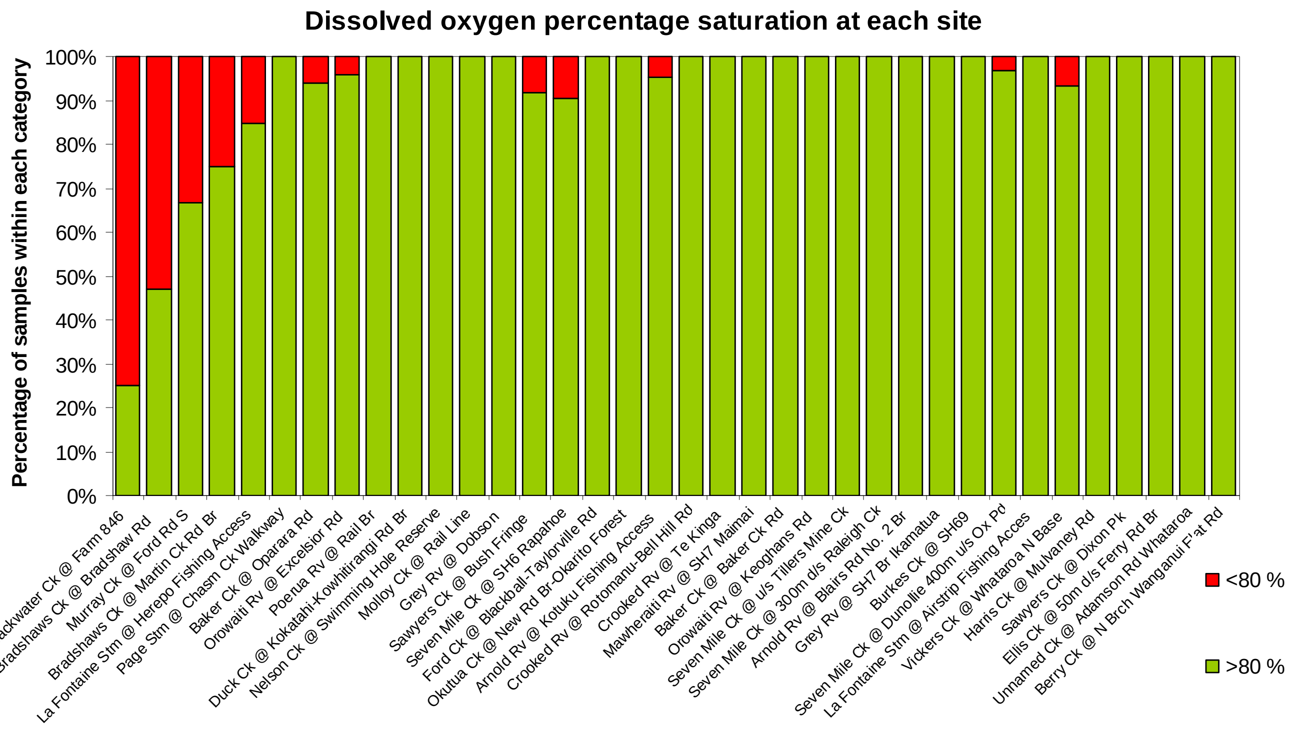


Figures 2.2 Percentage of samples in respective water temperature categories for individual WCRC SWQMP sites.

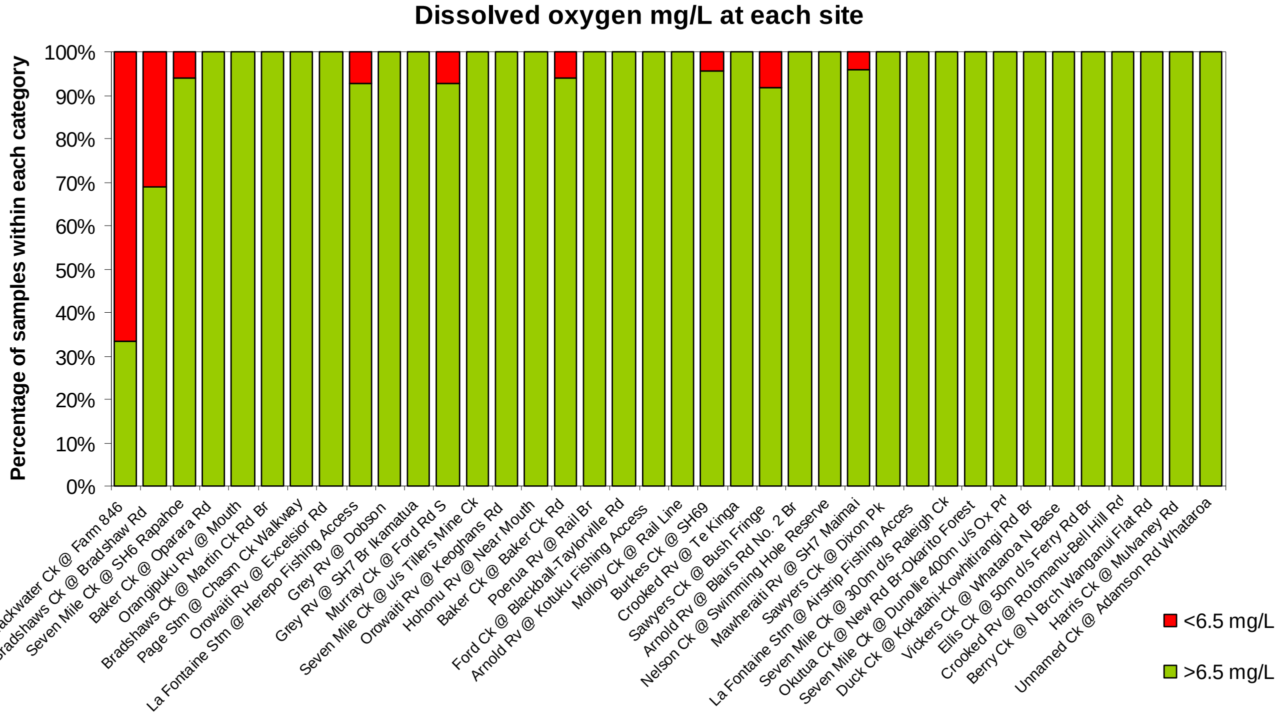
2.4.2 Dissolved oxygen

Most sites in the SWQMP rarely have dissolved oxygen saturations below 80% (Figure 2.3). Blackwater Creek consistently had low dissolved oxygen, both in terms of saturation and concentration (Figure 2.4).

Given the generally poor water quality observed at the Blackwater site, bacterial activity associated with organic enrichment seems like a plausible reason for this oxygen depletion. Bradshaws Creek @ Bradshaws Road had reduced oxygen levels albeit to a lesser extent, and probably due to similar reasons as for Blackwater Creek, although plant respiration may have played a role here. The percentage saturation of oxygen indicates how much oxygen is in the water relative to what it can potentially hold. For example, we assume that if dissolved oxygen saturation is below 80%, then there are living organisms consuming it faster than it can be replenished. The actual quantity of oxygen - expressed in mg/L - is the most relevant in terms of life sustaining capacity, with levels below 6.5 mg/L considered restrictive for sensitive animals. Two things are important to note. Firstly, that warmer water carries less oxygen eg. 5°C water with 80% saturation has 9.2mg/L oxygen, but 20°C water with 100% saturation has 8.2 mg/L. Also, when there's no light, plants only consume oxygen, so streams with abundant algae and plant growth can have low dissolved oxygen, particularly early in the morning before sunrise. Streams like Murray Creek and the La Fontaine Stream are examples of this, with an abundance of aquatic plants and a gentle flow. Warmer water temperatures are likely contributors to occasional low dissolved oxygen observations at many sites. The role of nutrient rich discharges and run-off in causing plant/algal proliferations and biologically oxygen demand is unclear.



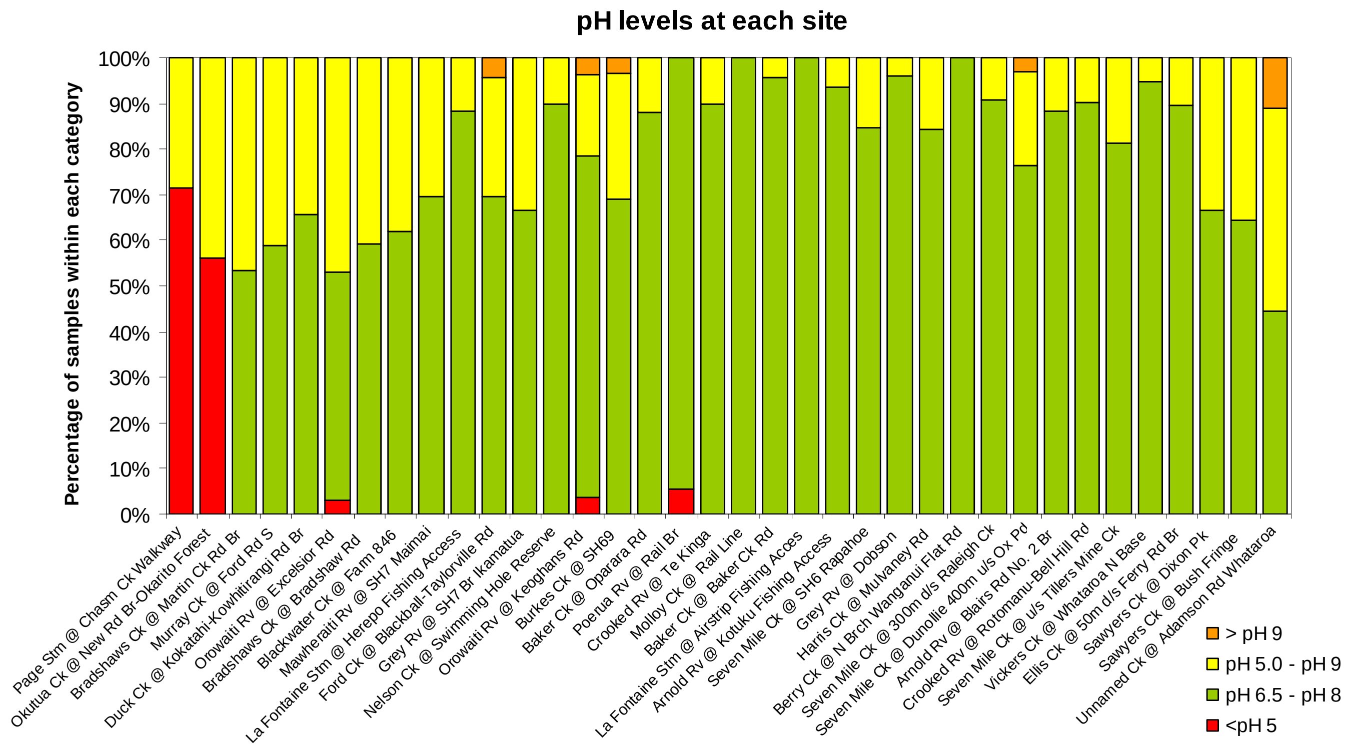
Figures 2.3 Percentage of samples in respective dissolved oxygen (percentage saturation) categories for individual WCRC SWQMP sites.



Figures 2.4 Percentage of samples in respective dissolved oxygen (mg/L) categories for individual WCRC SWQMP sites.

2.4.3 pH

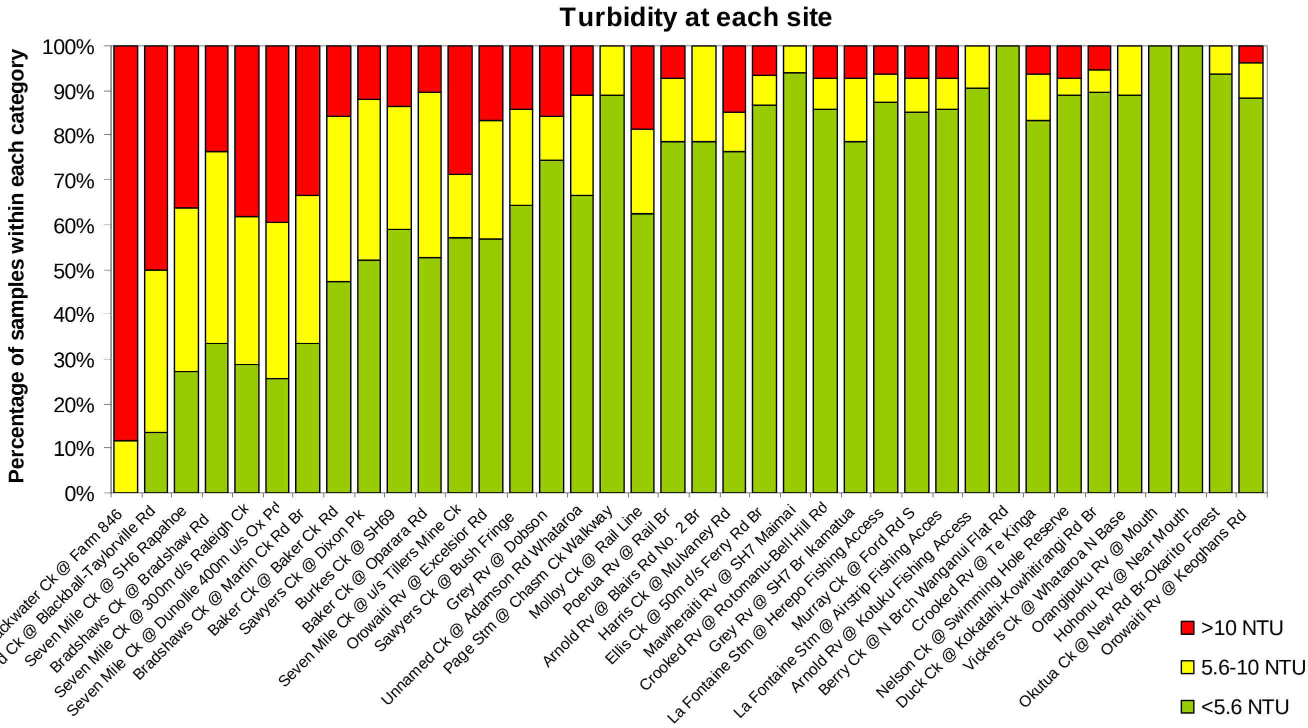
Levels of pH were within normal or acceptable ranges for most sites (Figure 2.5). Page and Okutua Streams make an interesting comparison. Okutua Stream is a reference site with high water quality. Low pH's at this site can be attributed to an abundance of organic acids leached from humic soil substances. The acidity in Page Stream however originates from acid rock drainage associated with historic mining activity. Elevated metals are often an associated part of acid rock leachate, eg. high levels of aluminium at Page Stream. At the other end of the pH scale, Un-named Creek @ Adamson Road had a median pH of 8, with several readings over 9. Afternoon oxygen super-saturation associated with abundant plant growth will have been one contributing factor to this (refer to figure 5.4.1 for more information). A broad range of pH's have been recorded in the Orowaiti River.



Figures 2.5 Percentage of samples in respective pH categories for individual WCRC SWQMP sites.

2.4.4 Turbidity

Two sites had median turbidity at or over 10 NTU, with six more site medians over 5.6 NTU (Figure 2.6). These sites have a range of characteristics contributing to higher turbidity. Erodible sedimentary geology is a common component, usually combined with varying degrees of anthropogenic influence. Sediment contributions from current and historic mining related activities are a feature in the Ford and Seven Mile Creek catchments, with urban land use a feature in Seven Mile and Sawyers Creeks. In general, agricultural land use within a catchment leads to increased turbidity downstream. It is worth noting again the important influence of geology: For example, reference sites on Sawyers and Baker Creeks – both draining catchments with predominantly soft sedimentary geology – have higher median turbidity than the Orangipuku River. Much of the Orangipuku River drains intensive agricultural land, but inputs from tributaries with hard plutonic catchments and springs on the alluvial plains yield water of very low potential turbidity.

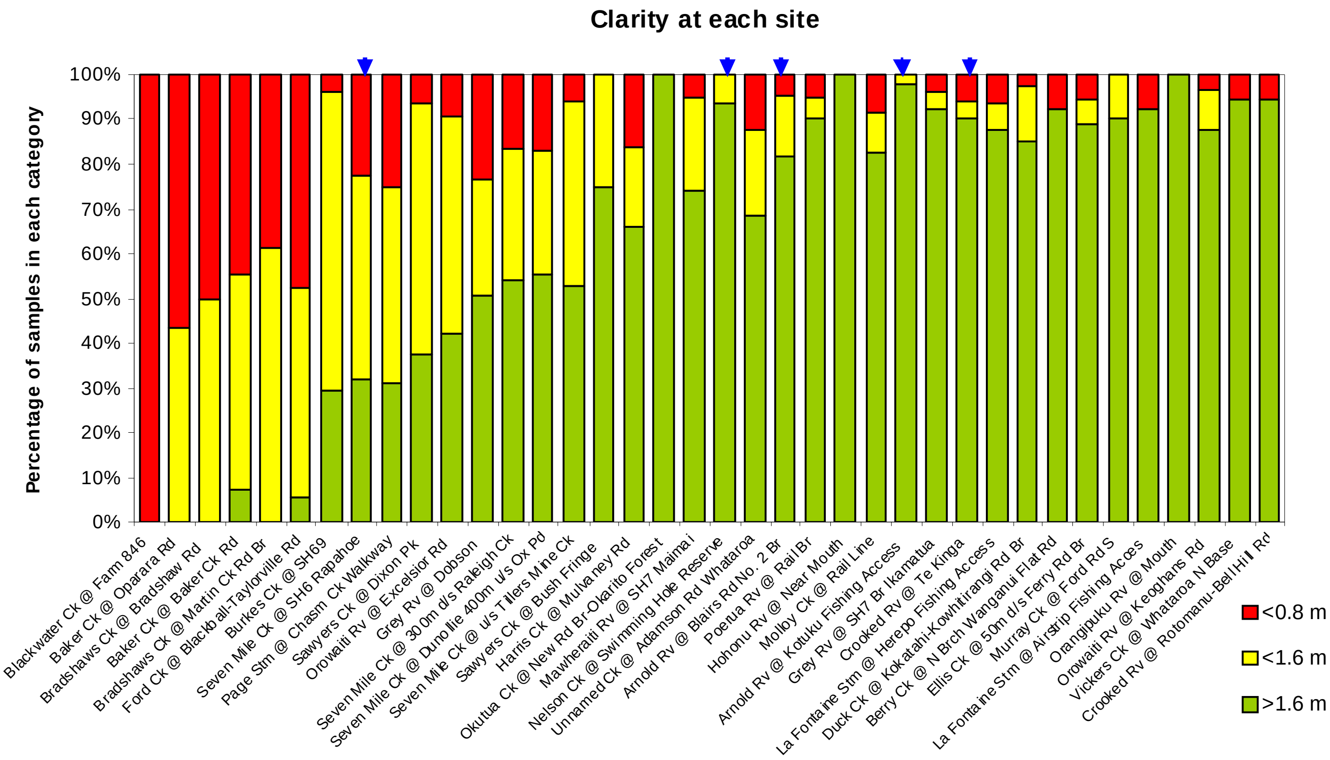


Figures 2.6 Percentage of samples in respective turbidity categories for individual WCRC SWQMP sites.

2.4.5 Clarity

Patterns in clarity among sites were similar to those observed in turbidity, and the causes of poor clarity are similar to those that increase turbidity (Figure 2.7). Brown tannin staining – a natural feature of many West Coast waterways, particularly those draining lowland areas – is a natural factor which can reduce water clarity. This could be the reason for the relatively low clarity observed in the Okutua Stream, a reference site in Okarito Forest. Median clarity for this site was in the middle of the field for SWQMP sites, yet the amount of mobile sediment was low, and median clarity at Okutua Stream has never failed the 1.6 m contact recreation guideline.

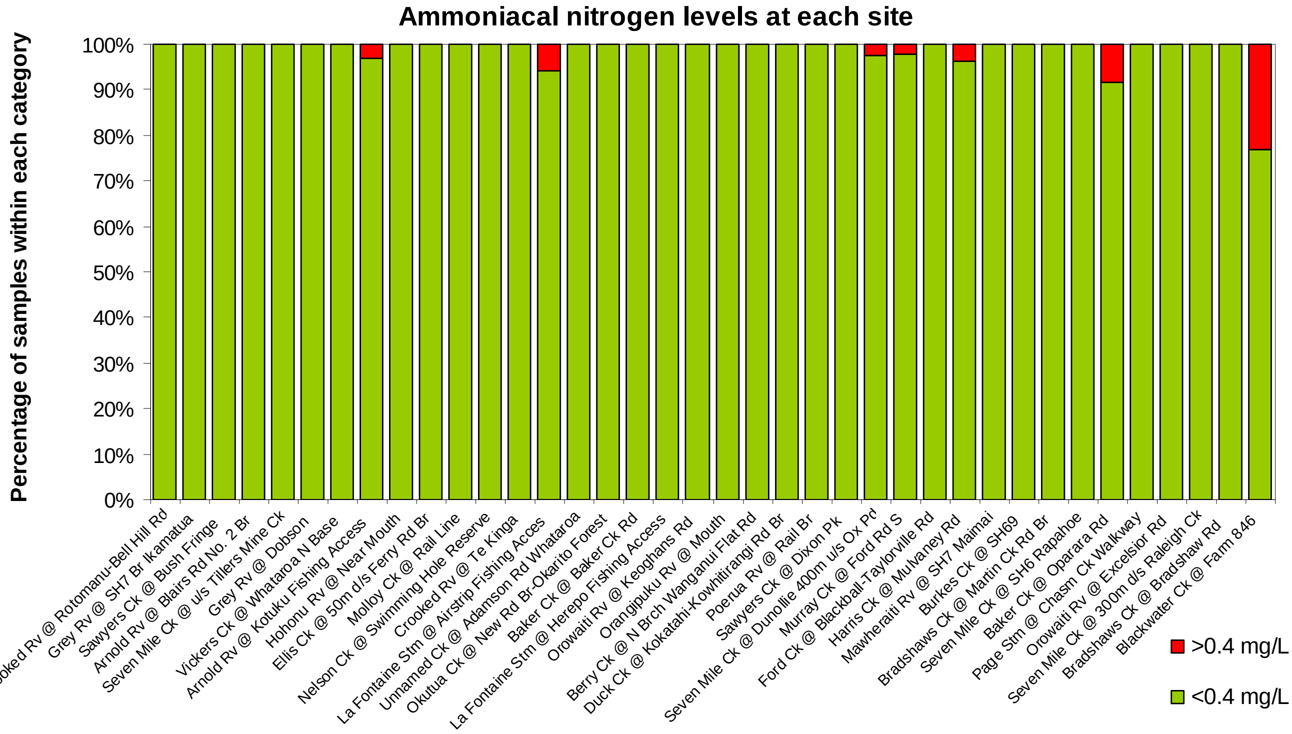
Six of the sites in Figure 2.7 have been monitored for contact recreation suitability (as marked by the blue arrows). Of these, only Seven Mile Creek @ SH6 Rapahoe has had clarity consistently below that recommended for swimming. Management for contact recreation suitability does not apply to the other sites shown, but under the WCRC Water Plan (2007) all water bodies are to be managed for aquatic ecology, for which the 0.8 m clarity threshold applies. Three sites had median clarity below this. The overall 2007 median for clarity at all WCRC sites was 2.4 m, compared to the 1 – 1.9 m median range for the rest of the country.



Figures 2.7 Percentage of samples in respective clarity categories for individual WCRC SWQMP sites. Blue arrows indicate sites also monitored for contact recreation suitability.

2.4.6 Ammoniacal nitrogen

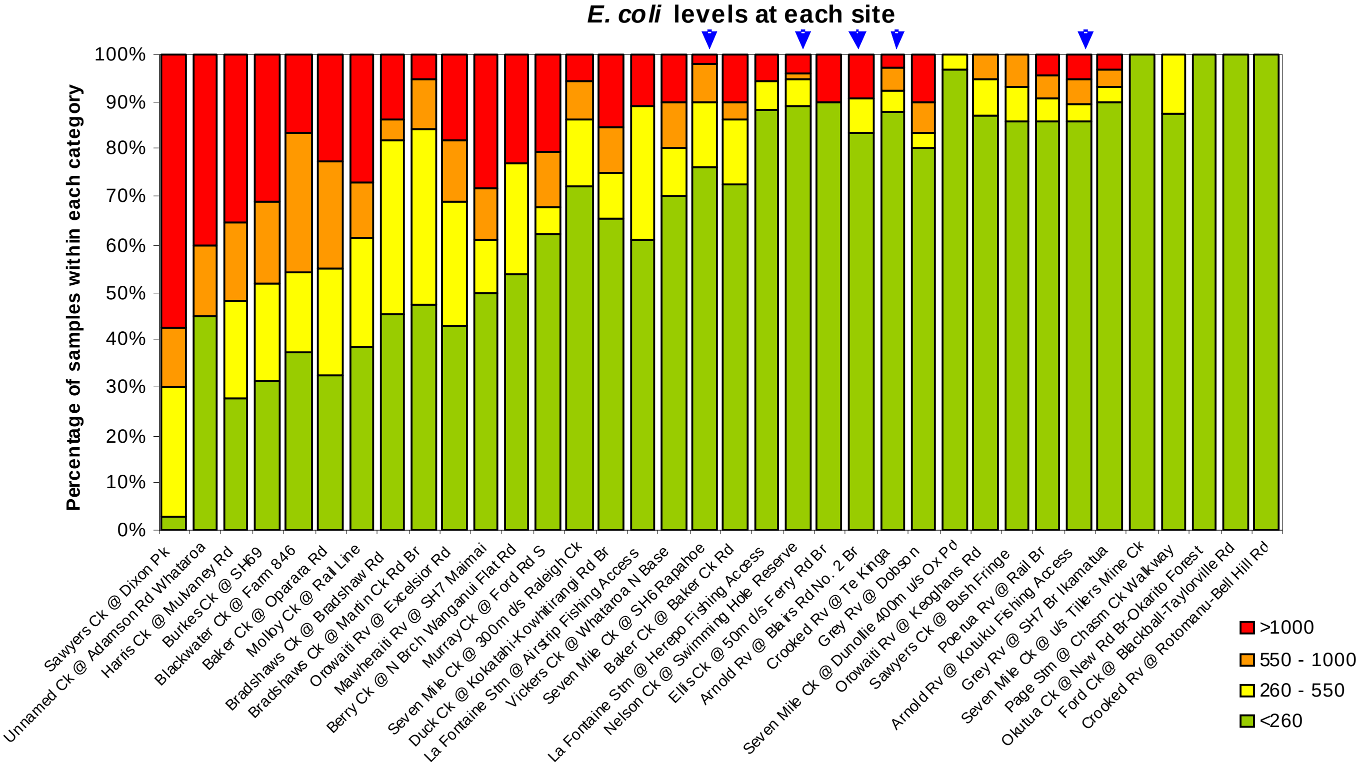
The threshold chosen for our ammoniacal nitrogen category was based on a level delivering a 95% level of ecosystem protection based on a maximum pH level of pH 8.5 (ANZECC 2000). Figure 2.8 indicates that most sites did not have samples with ammoniacal nitrogen levels above a level likely to cause harm to aquatic life. Seven sites did have exceedances, although these were apparent for less than 10% of samples at five sites. Sites on two small waterways, Baker Creek @ Oparara Rd and Blackwater Creek exceeded this guideline by 10% and 20% of the time, respectively. Median ammoniacal nitrogen levels at SQWMP sites ranged between 0.005 – 0.09 mg/L, excluding Blackwater Creek with a median of 0.28 mg/L. Refer to figure 5.4.7 for detailed explanation of ammonia toxicity, and Section 5.8 for more detailed graphical display of ammoniacal nitrogen levels among sites.



Figures 2.8 Percentage of samples in respective ammoniacal nitrogen categories for individual WCRC SWQMP sites.

2.4.7 *Escherichia coli*

The faecal coliform *Escherichia coli* is an indicator of faecal contamination of the water, which can lead to the presence of pathogen hazard for humans and stock but faecal coliforms are not harmful to aquatic organisms. *E. coli* is a useful indicator of faecal source contamination from warm-blooded animals such as people, livestock, and birds. The categories used here are based on contact recreation and stock drinking guidelines (refer to Figure 5.4.8). The top category of 1000 represents the ANZECC (1992) stock drinking water guideline for faecal coliforms. All lower categories are based on single sample guidelines for contact recreation suitability (refer Section 2.6). As mentioned previously for clarity, only a group of specified sites on the West Coast are managed and monitored for contact recreation, as stipulated in the WCRC Water Plan. Many sites have had *E. coli* levels above what is deemed appropriate for stock consumption. One site had E. coli levels over this threshold for more than 50% of the time. This would be a consideration for any sites where stream water is being used as a source for stock drinking water.

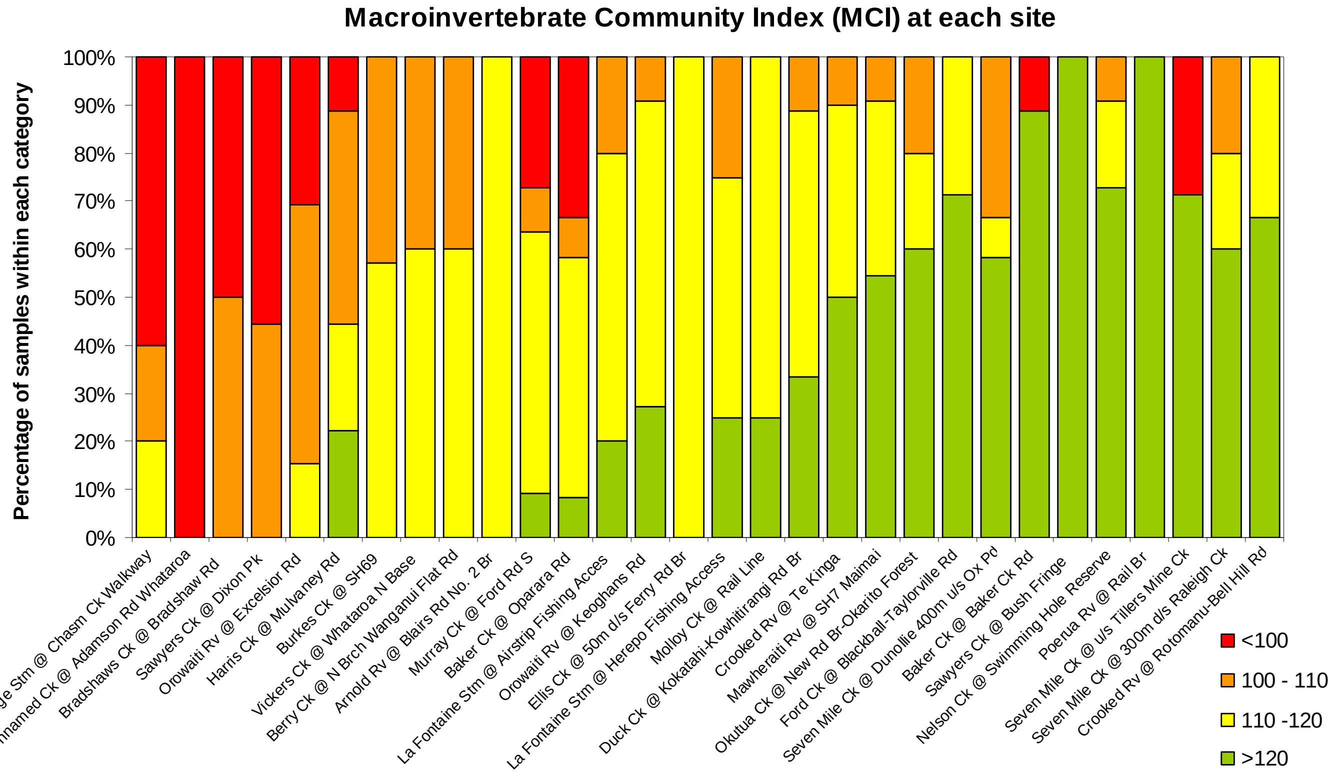


Figures 2.9 Percentage of samples in respective E. coli categories for individual WCRC SWQMP sites. Blue arrows indicate sites also monitored for contact recreation suitability.

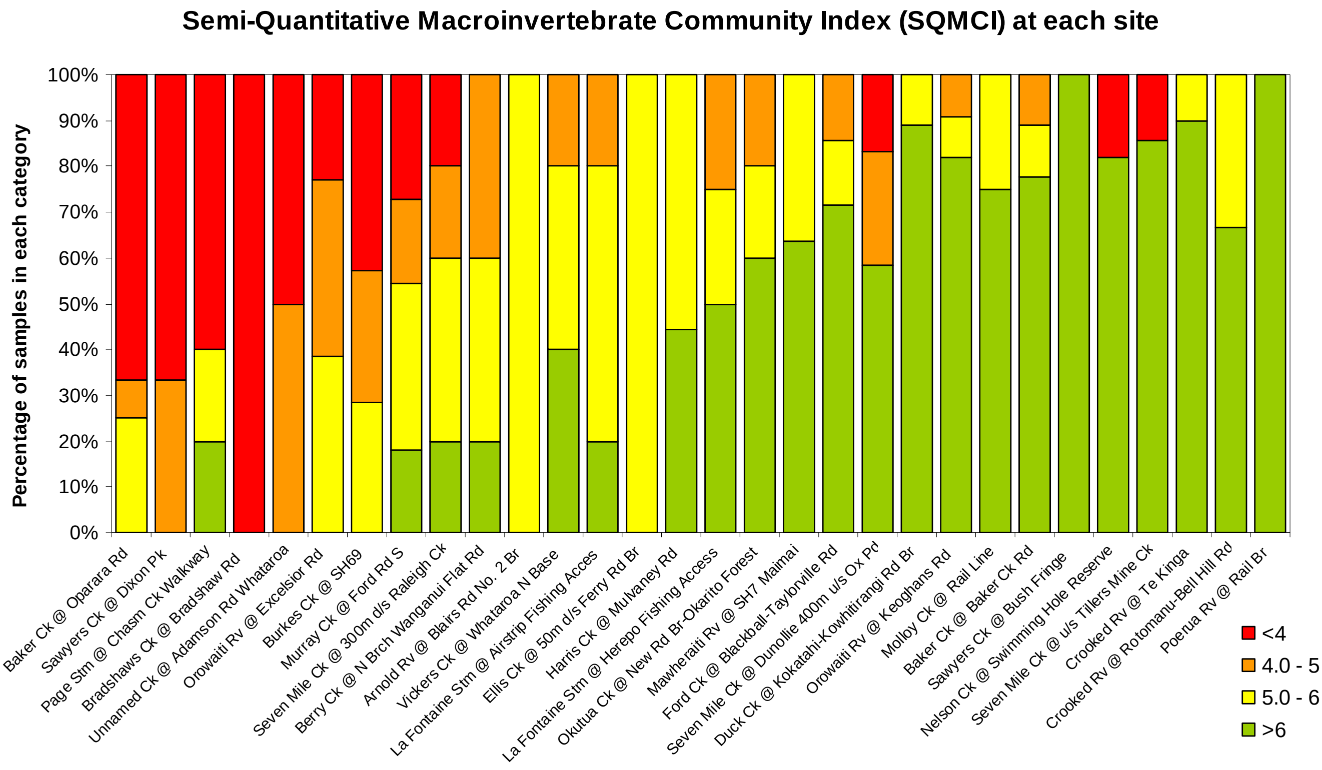
2.4.8 Macroinvertebrates

The Macroinvertebrate Community Index (MCI) and Semi-Quantitative Macroinvertebrate Community Index (SQMCI) evaluate water quality based on the types and tolerances of macroinvertebrates found at a site (Figures 2.10 and 2.11). The four categories relate to water quality classes going from poor (<80) to excellent (>120) (refer Section 5.4). The rank of sites based on median for MCI and SQMCI differs. Some sites differ greatly e.g. Baker Creek @ Oparara Road. The SQMCI takes into account the abundance as well as the type of each macroinvertebrate collected. A lower SQMCI compared to MCI indicates that while there are pollution sensitive macroinvertebrate taxa present, they are not present in large numbers. The opposite – high SQMCI and lower MCI – might indicate that there are pollution tolerant species present, but the pollution sensitive types are numerically dominant. Hence both indices have their uses. Baker Creek @ Oparara Road is a good example of this: some pollution sensitive macroinvertebrates are often present at this site, but they are not as abundant as the pollution tolerant ones.

A range of environmental factors influence macroinvertebrate community composition. Chemical and physical properties of water are the most obvious. Habitat type is also very important. Some habitat degradation can result from anthropogenic activity e.g. poorly managed land development can lead to excessive sediment suspended in the water, and deposited on the stream bed (refer figure 5.4.4 for more information on sediment effects). Overall, the top three quarters of sites had MCI and SQMCI scores indicative of slight to un-impacted water quality, with the bottom quarter consistently rating moderate impact to poor water quality.

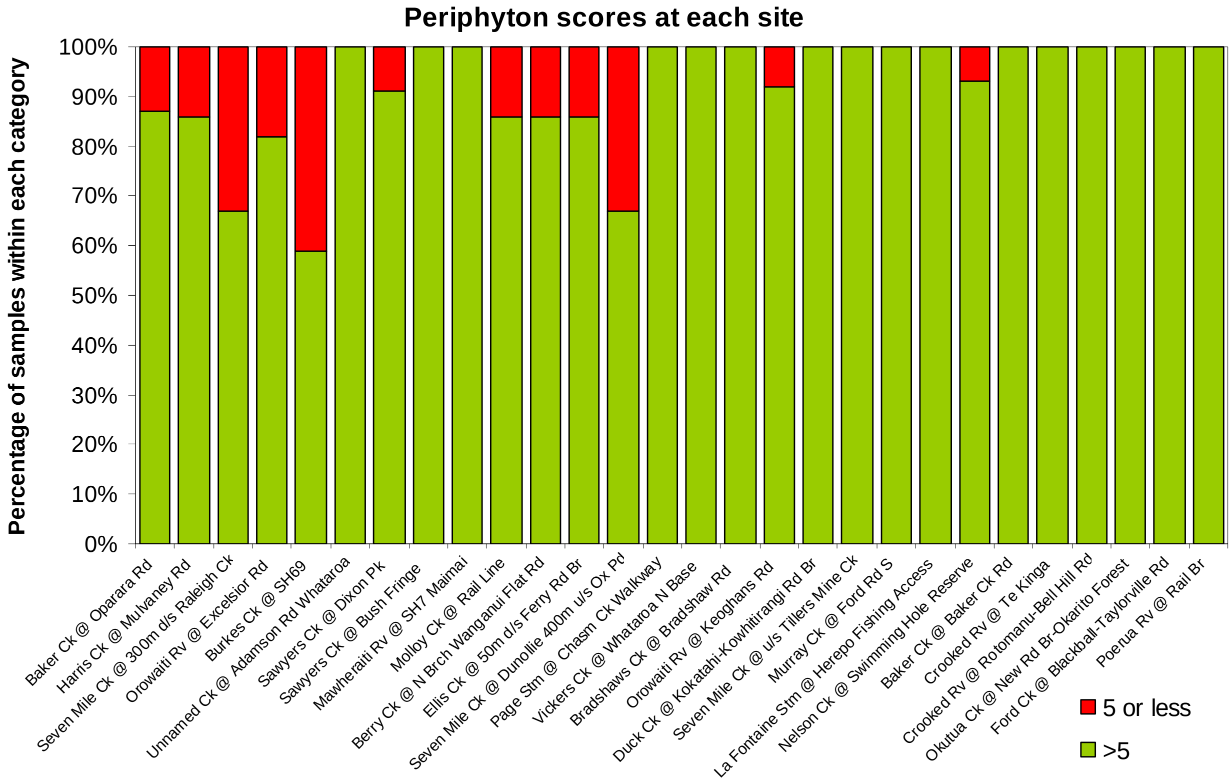


Figures 2.10 Percentage of samples in respective MCI categories for individual WCRC SWQMP sites.



Figures 2.11 Percentage of samples in respective SQMCI categories for individual WCRC SWQMP sites.

Figure 2.12 indicates the percentage of periphyton surveys for a site that generated an enrichment score of five or less – a threshold which is indicative of nuisance periphyton growth (refer to section 5.4). As well as nutrient levels, other environmental conditions can be required for large algal proliferations. These include: adequate light, warmth, and stable conditions. Such conditions can occur simultaneously during summer low flows, and high algal biomass during these periods may relate more with climatic regimes than nutrients. Alternatively, high nutrient levels will not cause nuisance periphyton growth if, for example, flow stability and light are not adequate for major growth to occur. A full range of nutrients are not monitored for most of the SWQMP sites, therefore a comparison of periphyton scores with nutrient levels is not possible. Algal proliferations are only likely to be a problem if occurring frequently and this appears not to be the case for most SWQMP sites. Sites that have had nuisance biological growths were typically: smaller; occurring in either intensively farmed catchments or having a major upstream nutrient sources e.g. sewerage; and subject to stable flow periods. Only two streams (three sites) recorded nuisance growths for between 30 % - 40 % of the time.



Figures 2.12 Percentage of samples with periphyton scores equal or less than 5, for individual WCRC SWQMP sites. Note that lower scores indicate more periphyton.

2.5 Longitudinal differences in water quality

Many sites that are part of the WCRC SWQMP are located on the same waterway, within suitable proximity of each other to allow for upstream to downstream water quality comparisons. Longitudinal water quality patterns, for these sites over time, are presented in Section 5.8. We will discuss some of the patterns observed in the following paragraphs.

Occasional spikes at the upstream sites may have related to chance events – either natural or human induced. It should be noted that most reference sites have, to varying degrees, current or historic anthropogenic influences upstream of them.

The faecal indicator bacteria *E. coli* increased downstream for all sites but Bradshaws Creek. Particle settling due to lower velocity, and tidal flushing, may have assisted with reducing faecal coliform levels at the lower Bradshaw site. Ammoniacal nitrogen increased downstream for all sites excluding both Bradshaws and the La Fontaine Stream. Ammoniacal nitrogen levels in La Fontaine Stream were low, with both the upstream and downstream sites displaying similar patterns in ammoniacal nitrogen over time.

For turbidity, four downstream sites had total medians *lower* than upstream sites, including Bradshaws, Baker and La Fontaine, and Crooked. This was an unusual result for the Crooked River, and differed from upstream/downstream clarity patterns observed at this site – clarity being a better measure on this river due to its typically clear waters. Three and a half times more samples were taken at the lower Crooked site, which will have affected (lowered in this case) computation of the median relative to the upstream site.

The similar patterns over time displayed by upstream and downstream sites indicated the likely role climatic regimes had on baseline turbidity. Like turbidity, not all waterways increased in temperature downstream. It seems evident that downstream warming from solar radiation was offset by inputs from cooler tributaries and groundwater contributions.

Patterns in dissolved oxygen are difficult to interpret as many processes can be pushing dissolved oxygen in different directions simultaneously. In a direct sense, higher dissolved oxygen is better than lower. However, this might not correspond to improving water quality. At higher levels, approaching 100% saturation (measured during ample daylight), downstream increases may indicate greater photosynthesis due to more abundant plant/algal presence – itself potentially indicative of greater eutrophication and poorer downstream water quality. Then for the sites where dissolved oxygen decreased – was this a sign of improving water quality? Very unlikely, given that other parameters for these sites indicated higher upstream water quality.

Levels of pH, like dissolved oxygen, are influenced by many factors and vary significantly over the length of a day at some sites (refer Figure 5.4.1). The often close pH relationship between paired upstream and downstream samples highlights the role of climatic influence on pH levels.

2.6 Suitability for contact recreation

The following graphs in this section display all data collected at the WCRC's contact recreation monitoring sites. Sites are located in a range of environments including: freshwater lakes and rivers, tidal and brackish estuaries and lagoons, and coastal beaches. Feacal coliforms and *E. coli* are measured at all sites, while Enterrococci are only measured in marine or brackish environments - therefore are not sampled as widely.

MfE (2003) provides guidelines for bathing suitability based on single samples of *E. coli* and Enterrococci. These categories are: Low Health Risk (<260 *E.coli*/100ml or <140 Enterococci/100ml); Moderate Risk, increased health risk but still within an acceptable range (260-550 *E.coli*/100ml or 140-280 Enterococci/100ml); and High Risk, the water poses an unacceptable health risk (>550 *E.coli*/100ml or >280 Enterococci/100ml).

Figure 2.13 summarises overall annual regional contact recreation quality. The level of sampling effort has increased over time, with the number of sites increasing and a [more variable] overall increase in samples (Table 2.3). Since 2000, 80% of samples have been in the low health risk category, excluding a dip to 70% in 2004. From 2006 to 2008 improvement was observed, with the [2007 to] 2008 season the best on record. Overall median levels of faecal indicator bacteria have decreased in the last five years (Figure 2.14).

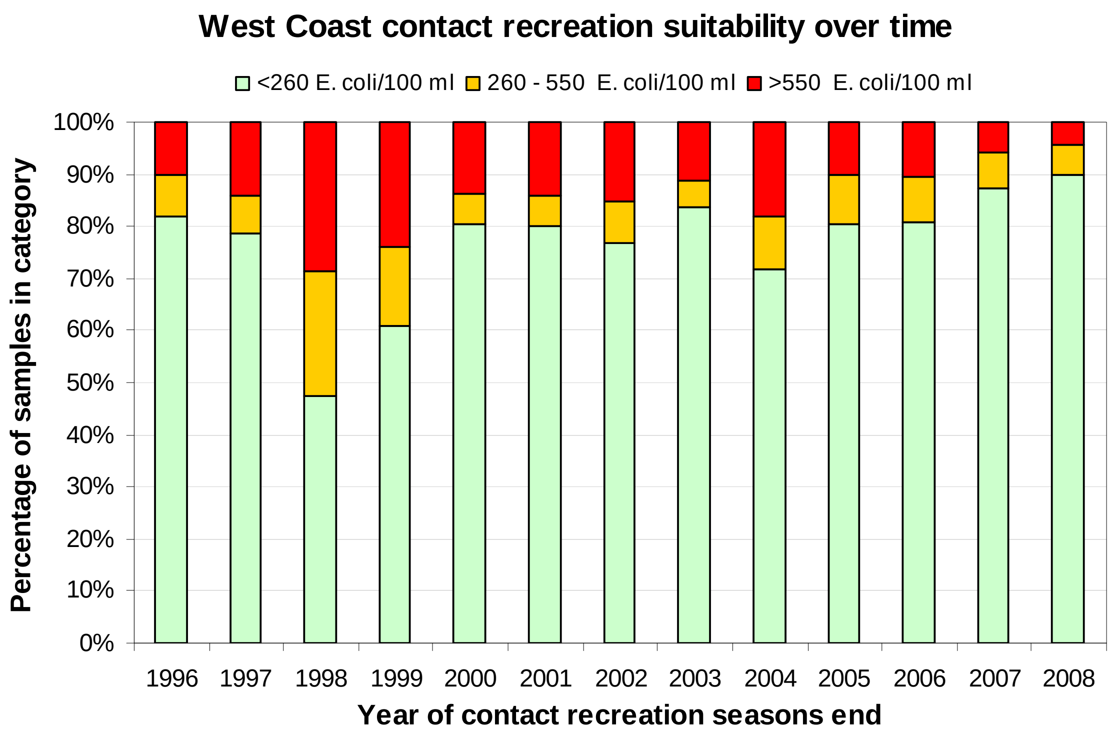
Chronological results at individual sites suggested that the overall regional improvement observed was due to certain sites improving more significantly than others (Section 5.9). With the upgrade to Westport's municipal sewage treatment in 2007, major improvement in bacterial water quality has occurred at Marrs and Shingle Beach's, near the mouth of the Buller River (accepting the 2008 exceedance associated with major rainfall). There have been fewer guideline exceedances at many sites, especially in the last two to three years. Poor water quality results recorded at Hokitika Beach in 2006 were not evident in subsequent years.

The Orowaiti Lagoon and Seven Mile Ck @ SH6 Rapahoe have had some of the poorest bacterial water quality of all. Some improvements can be observed for the Orowaiti Lagoon, although exceedances still occurred in 2008. Seven Mile Lagoon has not had any alert levels since 2005, but several moderate health risk levels have been recorded.

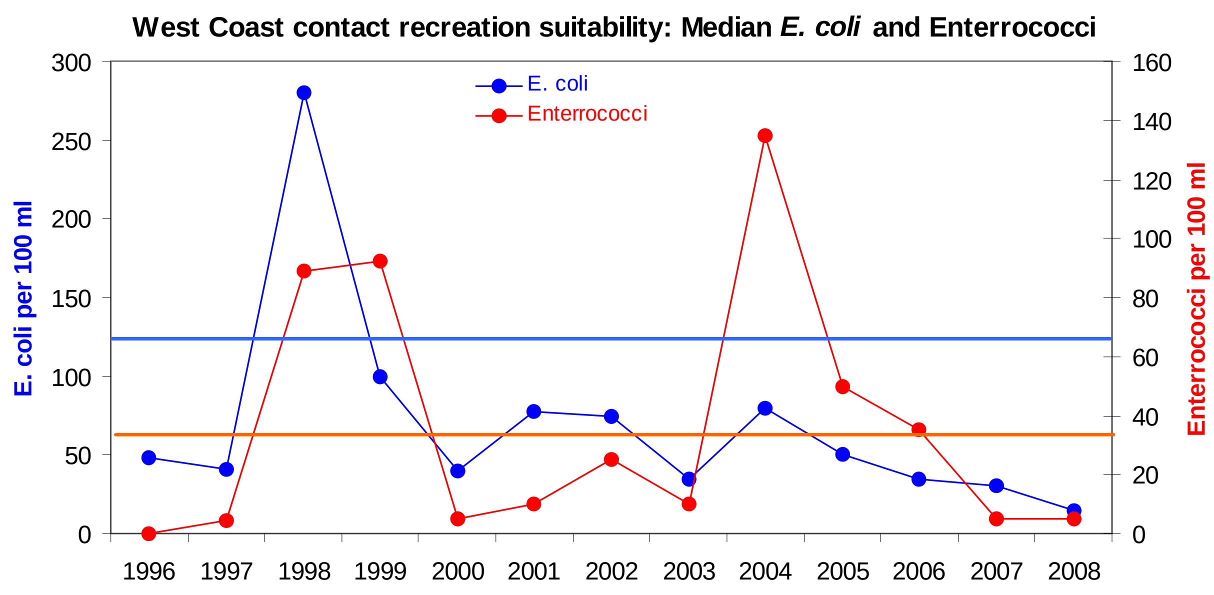
Overall, the lake sites had good water quality, as do those to a lesser extent at open coastal locations. Improvements for some river and lagoon sites were apparent, although exceedances still occurred consistently at some. It has been found nationally that coastal beaches have better water quality than inland waters. Of the contact recreation monitoring sites across the country in 2006-07, 60% were suitable for at least 95% of the time (MfE 2008b). The West Coast results for the 2006-08 period had approximately 70% of sites in this '95% suitable' situation.

Table 2.3 Total site and sample numbers involved with contact recreation monitoring from 1995 (year ending in 1996) to 2008.

Season	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total number of sites	5	7	11	10	12	16	18	18	18	20	21	21	22
Total number of samples	30	14	24	49	37	51	88	100	104	127	118	121	119



Figures 2.13 *Proportional suitability for contact recreation at monitored contact recreation sites. All sites and samples collected within the contact recreation period (November – March) at contact recreation monitoring sites have been pooled for each season e.g. 1996 includes the summer of 1995-1996. The three categories are based on MfE (2003) E. coli single sample criteria for bathing suitability.*



Figures 2.14 *Suitability for contact recreation at monitored contact recreation sites based on annual medians. All sites and samples collected within the contact recreation period (November – March) at contact recreation monitoring sites have been pooled for each season e.g. 1996 includes the summer of 1995-1996. MfE (2003) guidelines for bathing suitability based on annual medians are shown for E. coli (blue line) and Enterrococci (red line).*

3 Trends

Summary of surface water quality trends on the West Coast

Trends for particular water quality parameters were apparent in West Coast waterways monitored as part of WCRC and NIWA monitoring. Water quality improvement was evident in levels of ammoniacal nitrogen (NH_x-N), clarity, turbidity, and faecal coliforms – consistent with national patterns. Improvements in these parameters benefit aquatic ecosystems, and value for commercial and recreational use. Organic pollutants have decreased in New Zealand since the 1980's, reflecting better management of point source discharges (MfE 2008b). High levels of these parameters, particularly ammoniacal nitrogen and faecal coliforms, are commonly associated with dairy shed effluent and municipal wastewater.

While ammoniacal nitrogen has decreased, other forms of nitrogen – total nitrogen and nitrate - have increased, which is also consistent across New Zealand. It appears that while point source pollution has decreased, diffuse source pollution has increased. Total nitrogen levels in the lower Grey and Buller Rivers are below those typical in New Zealand Rivers but the rate of increase has been much greater than that observed nationally. There has been a recent trend for increasing intensification of agriculture across the country. Since the 1980's, stocking rates and fertiliser application has increased, with the use of nitrogen fertilisers doubling since the 1990's. From 1996 – 2006 the size of the New Zealand dairy herd increased by 24%. Dairying is the dominant form of agriculture on the West Coast and from 2001-2008 the regional West Coast herd increased 49.7%, with the area of dairy land increasing by 36.6% over the same time period (Westland Milk Products unpublished data).

Phosphorus associated with increasing intensification of agriculture could be offset by gains made through better management of point source pollution. This could have been the case in the Buller River, but not the Grey River, where a meaningful increase in phosphorus was apparent. While dissolved inorganic nitrogen at the NIWA Grey River @ Dobson site has periodically been above guidelines for nuisance periphyton growth, low levels of dissolved reactive phosphorus at all sites suggest nutrients were consistently below levels conducive to algal proliferation. National patterns in phosphorus have varied. Both significant increases and decreases in total phosphorus have been observed in New Zealand rivers (Scarsbrook 2006), while dissolved reactive phosphorus has increased more consistently across the board.

Despite the likely effect of anthropogenic pressures on water quality trends, the role of natural events and climatic influence should be considered as a potential factor responsible for changes in some of the water quality parameters observed over time.

3.1 Long-term trends: NIWA sites

Trends were investigated among parameters measured at NIWA's National River Water Quality Network sites. These sites have a large dataset suitable for individual analysis of trends. Of these five sites, four of them consist of two upstream/downstream pairs on the Buller and Grey Rivers. Buller @ Longford and the Grey @ Waipuna are the upstream sites for these two rivers. Haast @ Roaring Billy is a single site for that catchment. The analysis conducted determined either positive, negative, or no trends for all parameters at each site. Only some parameters had significant trends, which are defined as those with a p-value <0.05, *and* an annual rate of change of more than 1%. These significant trends are the main focus of following discussion. All results for this analysis are presented in Table 3.1, which details the rate of annual change for each parameter.

Ammoniacal nitrogen was observed to decrease at all sites. The rate of decrease varied between sites (a range of medians from 1.6% – 9.4% per annum) (Table 3.1). Ammoniacal nitrogen has decreased nationally over the same time period, with the national average median level (0.005 mg/L) similar to the downstream Dobson and Te Kuha sites. Total nitrogen (TN) increased for all sites (excluding Haast), which was also consistent for the rest of the country. Nationally, TN has been increasing at an annual rate of 1%, compared with 2.7% and 2.9% at the Te Kuha and Dobson sites, respectively. Median TN concentrations at these two sites are a little lower (0.14 mg/L for Te Kuha, 0.19 mg/L for Dobson) than the national average (0.22 mg/L).

Nitrate also increased at both sites on the Grey River, and at the lower Buller site, but dropped at Longford further up the Buller River. Grey @ Dobson had both the highest median concentration and rate of increase (0.075 mg/L, 4.1% per annum).

Decreasing ammoniacal nitrogen was an improvement for water quality. Other improvements were increasing clarity at Buller @ Longford, Grey @ Dobson, and the Haast River site. Biological oxygen demand (BOD_5) decreased at Haast and the Buller @ Longford. Clarity and BOD_5 have improved nationally (Scarsbrook 2006).

Dissolved reactive phosphorus (DRP) decreased significantly at Buller @ Te Kuha, despite total nitrogen increasing over the same period. There has been a consistent national trend for increasing DRP. National trends in total phosphorus (TP) have varied, with TP increasing at most sites in the South Island, and decreasing in the North Island. The Grey @ Dobson had a meaningful increasing TP trend ($p=0.09$), while no TP pattern was apparent for any of the other sites.

Increased nutrient levels may lead to changes in the type and biomass of aquatic plant and algal species, which in turn can affect aquatic fauna. For nutrients to have any significant effect on periphyton biomass in flowing waters, dissolved reactive phosphorus (DRP) needs to be above 0.015-0.03 mg/L and dissolved inorganic nitrogen (DIN) needs to be above 0.04-0.1 mg/L (MfE 1992). The Grey River @ Dobson had the highest DIN levels out of the five NIWA sites, with a median DIN of 0.081 mg/L. A third of samples from the Dobson site had DIN levels above the upper end of the guideline (i.e. >0.1 mg/L). However, at all NIWA sites, the levels of DRP have always been below their respective guidelines. Therefore it is unlikely that all forms of nutrient enrichment have been sufficient to cause problematic algal growths in these rivers.

The water quality improvements observed at the Haast River @ Roaring Billy site may relate to decreases in grazing e.g. the Landsborough Valley, ongoing possum control programme in much of the catchment, and climatic variation. While a small proportion of the Haast catchment continues to be grazed, the Landsborough no longer does as of approximately 2003. Prior to this the Landsborough had a herd of approximately 350 breeding cows, with stock densities increasing periodically to twice this level. Land clearance and fertilizer use was also occurring from the early 1990's. Possum control has been conducted on a 3-4 year rotational basis in much of the Haast catchment, which has significantly reduced possum densities. Of the indicators closely aligned with enrichment, only ammoniacal nitrogen and biological oxygen demand had a meaningful trend of improvement. Climatic patterns and natural events my have contributed to changes in conductivity, clarity and pH in the Haast River.

Table 3.1 Seasonal Kendall test for NIWA water quality site data on the West Coast. Arrows indicate an increasing or decreasing trend. Blue indicates improvement, red indicates deterioration, and grey indicates non-significant. FA=Flow adjusted; P-value's of <0.05 are significant and are highlighted. Annual rate of change is indicted as a percentage of the median.

Variable	Site	Median (Non-FA)	P-value (FA)	Trend direction	Annual rate of change (%)
Dissolved oxygen (%)	Buller @ Te Kuha	98.95	0.01	↘	-0.1
Dissolved oxygen (%)	Grey @ Dobson	99.60	0.72	↘	0.0
Dissolved oxygen (%)	Grey @ Waipuna	99.80	0.07	↘	-0.1
Dissolved oxygen (%)	Haast @ Roaring Billy	98.90	0.01	↗	0.0
Dissolved oxygen (%)	Buller @ Longford	100.40	0.92	-	0.0
BOD (mg/L)	Grey @ Waipuna	0.25	0.60	-	-0.5
BOD (mg/L)	Haast @ Roaring Billy	0.25	**0.00**	↘	-7.6
BOD (mg/L)	Buller @ Longford	0.35	**0.00**	↘	-5.8
BOD (mg/L)	Buller @ Te Kuha	0.40	0.32	-	-1.2
BOD (mg/L)	Grey @ Dobson	0.40	0.88	-	-0.1
Clarity (m)	Buller @ Te Kuha	1.86	0.17	↗	0.7
Clarity (m)	Grey @ Dobson	1.60	**0.00**	↗	2.2
Clarity (m)	Grey @ Waipuna	2.90	0.19	↗	0.6
Clarity (m)	Haast @ Roaring Billy	2.07	**0.01**	↗	2.7
Clarity (m)	Buller @ Longford	3.67	**0.00**	↗	3.1
Conductivity (uScm)	Buller @ Te Kuha	66.10	0.87	↗	0.0
Conductivity (uScm)	Grey @ Dobson	55.00	0.03	↗	0.2
Conductivity (uScm)	Grey @ Waipuna	51.25	0.01	↗	0.4
Conductivity (uScm)	Haast @ Roaring Billy	79.90	0.01	↘	-0.2
Conductivity (uScm)	Buller @ Longford	55.60	0.13	↗	0.1
DRP (ug/L)	Buller @ Te Kuha	2.00	**0.00**	↘	-1.7
DRP (ug/L)	Grey @ Dobson	2.00	0.48	↗	0.4
DRP (ug/L)	Grey @ Waipuna	2.00	0.93	-	-0.1
DRP (ug/L)	Haast @ Roaring Billy	1.08	0.35	↘	-0.7
DRP (ug/L)	Buller @ Longford	1.00	0.62	↘	-0.5
NO_x – N (ug/L)	Buller @ Te Kuha	42.00	**0.00**	↗	2.8
NO_x – N (ug/L)	Grey @ Dobson	74.92	**0.00**	↗	4.1
NO_x – N (ug/L)	Grey @ Waipuna	25.55	**0.00**	↗	2.7
NO_x – N (ug/L)	Haast @ Roaring Billy	32.00	0.96	↘	-0.1
NO_x – N (ug/L)	Buller @ Longford	23.96	**0.01**	↗	-1.6
NH_x – N (ug/L)	Buller @ Te Kuha	4.86	**0.00**	↗	-4.0
NH_x – N (ug/L)	Grey @ Dobson	6.00	**0.00**	↗	-2.4
NH_x – N (ug/L)	Grey @ Waipuna	4.00	**0.00**	↗	-6.3
NH_x – N (ug/L)	Haast @ Roaring Billy	3.00	**0.00**	↗	-8.7
NH_x – N (ug/L)	Buller @ Longford	3.00	**0.00**	↗	-9.4

Table 3.1 continued Seasonal Kendall test for NIWA water quality site data on the West Coast.

Varaible	Site	Median (Non-FA)	P-value (FA)	Trend direction	Annual rate of change (%)
pH	Buller @ Te Kuha	7.59	0.36	-	0.0
pH	Grey @ Dobson	7.34	0.12	-	0.0
pH	Grey @ Waipuna	7.48	0.99	-	0.0
pH	Haast @ Roaring Billy	7.69	0.00	↘	0.0
pH	Buller @ Longford	7.65	0.49	-	0.0
Temperature ('C)	Buller @ Te Kuha	11.30	0.65	↗	0.1
Temperature ('C)	Grey @ Dobson	11.80	0.82	↗	0.0
Temperature ('C)	Grey @ Waipuna	10.60	0.02	↗	0.4
Temperature ('C)	Haast @ Roaring Billy	8.35	0.03	↘	-0.5
Temperature ('C)	Buller @ Longford	10.60	0.71	↘	-0.1
TN (ug/L)	Buller @ Te Kuha	135.00	**0.00**	↗	2.7
TN (ug/L)	Grey @ Dobson	194.56	**0.00**	↗	2.9
TN (ug/L)	Grey @ Waipuna	101.48	**0.00**	↗	2.2
TN (ug/L)	Haast @ Roaring Billy	63.90	0.17	↘	-0.6
TN (ug/L)	Buller @ Longford	80.88	**0.00**	↗	1.3
TP(ug/L)*	Buller @ Te Kuha	9.25	0.54	↗	0.3
TP(ug/L)*	Grey @ Dobson	9.00	0.09	↗	1.1
TP(ug/L)*	Grey @ Waipuna	5.00	0.62	↗	0.4
TP(ug/L)*	Haast @ Roaring Billy	5.00	0.67	↘	-0.5
TP(ug/L)*	Buller @ Longford	4.79	0.37	↗	0.5
Turbidity (NTU)	Buller @ Te Kuha	1.80	0.69	↘	-0.4
Turbidity (NTU)	Grey @ Dobson	2.25	**0.03**	↘	-1.7
Turbidity (NTU)	Grey @ Waipuna	0.90	0.98	-	0.0
Turbidity (NTU)	Haast @ Roaring Billy	1.60	0.73	-	0.3
Turbidity (NTU)	Buller @ Longford	0.81	0.79	-	-0.2
Flow (cumecs)	Buller @ Te Kuha	255.25	.	.	.
Flow (cumecs)	Grey @ Dobson	233.55	.	.	.
Flow (cumecs)	Grey @ Waipuna	34.73	.	.	.
Flow (cumecs)	Haast @ Roaring Billy	125.07	.	.	.
Flow (cumecs)	Buller @ Longford	56.79	.	.	.

* Log_{10} transformed.

3.2 Long-term trends: WCRC sites

Investigation of trends in water quality parameters for WCRC sites was conducted using two techniques. The first grouped data annually for all sites prior to trend analysis using Spearman rank correlation. The second used Seasonal Kendall tests carried out on individual WCRC sites for the 1998-

2007 period. Sites for the latter needed to have greater than 40 sampling occasions (i.e., potentially quarterly samples over 10 years). Results are given in Table 3.3

3.2.1 Trends in regional water quality parameter medians

When data from all sites were combined, significant decreasing trends were apparent for turbidity, faecal coliforms, and *E. coli*. While not statistically significant at a $p<0.05$ level, ammoniacal nitrogen and clarity were also tending toward improvement (decreasing and increasing, respectively) (Table 3.2). Graphical description of these trends is presented in Section 5.10.

These patterns are consistent with trends observed at West Coast NIWA sites. Turbidity and clarity are usually closely correlated (Maasdam and Smith. 1994) and in general these have improved in many of the region's waterways. Despite the absence of suspended sediment monitoring, improved clarity and turbidity imply a reduction of suspended solids over time. Ammoniacal nitrogen has also decreased – another improvement observable at both groups of sites. Measurement of faecal coliforms has not occurred for long enough at NIWA sites for this to be analysed, so trends in WCRC SWQMP faecal coliform monitoring can't be compared to NIWA data.

Table 3.2 Trends in regional medians over a 10-year period (1998-2007). Trends are expressed as Spearman rank correlation coefficients. Significant trends are highlighted, and the level of significance indicated by asterisks: **<0.05 *<0.01

Variable	Year	N
Dissolved oxygen (% saturation)	-0.372	10
Temperature	-0.636	10
Conductivity	-0.103	10
pH	-0.103	10
Turbidity	**-0.802 ****	10
Faecal coliforms	**-0.648 ***	10
E. coli	**-0.673 ***	10
Ammoniacal nitrogen	-0.492	10
Specific conductivity	-0.115	10
Periphyton	0.317	10
Clarity	0.638	10
Taxa richness	0.319	9
% EPT	-0.117	9
EPT taxa	-0.094	9
MCI	-0.133	9
SQMCI	0.217	9

3.2.2 Trends in regional water quality parameters: individual sites

As might be expected given the overall regional trend, most individual sites trended toward improved clarity. Of the sites with statistically significant trends in clarity, the downstream site on the Orowaiti River displayed a major improvement in clarity, over the sampling record. Faecal coliforms also decreased at many individual sites, consistent with the regional trend. Regional improvement in faecal coliform levels were observed at many contact recreation monitoring sites (refer to Section 5.9).

However, a significant decrease in clarity has occurred in the Crooked River. The trend was more significant at the lower site, yet a decreasing trend in clarity at both sites was clearly obvious suggesting climatic influence or processes occurring in the native bush headwaters of the catchment. Some pastoral land use occurs above the upstream site, but this consists of low intensity grazing. Conductivity decreased in the Crooked River, in particular at the upper site. How this might to relate to declining clarity is unclear. Conductivity has been increasing in most of the countries rivers where significant agriculture land use exists. Conductivity patterns are less clear on the West Coast. Significant increases were observed in the Grey River, yet other WCRC sites have trended downward over the last decade. Therefore it is hard to determine whether a decrease in conductivity in the Crooked River was climate related or land use induced.

Improvement in water quality in the Arnold Rv @ Kotuku Fishing Access may reflect improvements in Moana's municipal sewage treatment system during the monitoring period.

Table 3.3. Annual rates of change calculated by the Seasonal Kendall test on 11 sites for period 1998-2007. Highlighted results in bold are statistically significant ($P<0.05$).

	Electrical conductivity	pH	Faecal coliforms	*E. coli*	Ammoniacal nitrogen	Clarity
Arnold Rv @ Kotuku Fishing Access	**-9.55**	0.62	-7.77	-27.73	-2.86	0.89
Crooked Rv @ Near Mouth	-1.48	0.24	-8.50	-5.31	-4.00	**-7.11**
Crooked Rv @ Rotomanu-Bell Hill Rd	**-4.30**	-0.33	0.00	0.00	0.00	-5.78
Duck Ck @ Kokatahi-Kowhitirangi Rd Br	-0.98	0.04	**-9.05**	**-9.51**	-1.11	6.17
Harris Ck @ Mulvaney Rd	-2.12	0.50	-8.77	-13.41	-7.35	5.26
Murray Ck @ Ford Rd South	-0.45	-0.58	-3.44	-5.41	4.39	4.35
Nelson Ck @ Swimming Hole Reserve	-5.06	-0.39	0.00	0.00	-9.09	-1.83
Orowaiti Rv @ Excelsior Rd	-6.71	-0.14	**-10.04**	-6.16	0.53	**6.05**
Orowaiti Rv @ Keoghans Rd	-4.13	0.14	-8.16	-7.84	-2.22	-0.86
Seven Mile Ck @ Dunollie 400m u/s Ox Pond	-0.46	0.71	0.00	0.00	1.74	5.18
Seven Mile Ck @ SH6 Rapahoe	-2.55	0.14	-7.48	-5.23	2.27	6.14

4 Lake Brunner catchment

Summary of surface water quality in the Lake Brunner catchment

Water quality monitoring in Lake Brunner began in the in the early 1990s. From this data set, trends in some parameters indicated that the water quality of Lake Brunner had deteriorated over that time, although water quality in the lake was still relatively pristine. Most notable were increases in spring-time phytoplankton biomass (an indication of overall lake productivity) and nitrogen concentrations, both indicators of eutrophication. In 2001, the West Coast Regional Council initiated further monitoring in the Brunner catchment, which has expanded to include monitoring of three sites in the lake, and sampling in the three main tributaries. Long term trends in lake water quality are based on data from 0-25 m depth composite water quality samples collected at the centre of the lake.

Seasonal mixing processes in large lakes are extremely important for the ecology of the lake, and are driven mainly by patterns in solar exposure, wind, and river inflows. Phosphorus may be the nutrient that is most likely to limit algal growth in Lake Brunner based on TN:TP ratios >20:1. However, the information from TN:TP ratios is still not unequivocal, because of seasonal variation. The work of Francoeur et al. (1999) and Dodds (2003) suggests that caution is necessary when ascribing a single nutrient limitation at TN:TP ratios of between 1:5 and 1:35. The median TN:TP ratio was ~ 34:1 in both the 1990's and 2000's. Seasonal patterns were apparent for some parameters, particularly clarity and nitrate. Clarity was poorest during summer and highest in late winter/early spring. Nitrate concentrations were lowest in summer increasing to a peak at the end of winter, then heading down again as the weather warmed. Dissolved reactive phosphorus (DRP) and total nitrogen (TN) displayed a similar albeit less defined pattern.

Trend analysis that accounted for seasonality was conducted on data collected at the central lake monitoring site. From 1992-2007, a statistically significant trend was observed for increasing TN, phytoplankton (as inferred from chlorophyll a), total phosphorus (TP), and decreasing clarity. This indicated gradual enrichment of the lake. Analysing a shorter data record of 2001-2007, nitrate decreased but phytoplankton remained on an upward trend.

Cashmere Bay had the poorest water quality, compared with Iveagh Bay and the central lake, with localised conditions the probable cause. While the data record for Iveagh and Cashmere Bay is shorter than that of the central lake, there appeared to be some consistency with patterns observed at the central lake site, particularly decreasing clarity.

Modelling has allowed for estimation of flow volumes and nutrient loads in the catchment and main tributaries of the lake. 18.9% of the catchment consists of high producing exotic grassland. Nutrient loadings per hectare were higher in agriculturally developed catchments. For example, the Orangipuku River had the highest TN concentrations. Phosphorus concentrations in tributaries increased with flow (except in the lake fed Poerua River), with less of a relationship between flow and nitrogen. Estimated nutrient yields from high producing pasture in the Lake Brunner catchment were consistent for TN compared to the rest of the country, but over double for TP.

4.1 Limnology of Lake Brunner

Seasonal mixing processes in large lakes are extremely important for the ecology of the lake, and are driven mainly by patterns in solar exposure, wind, and river inflows (Figure 4.1). In lakes with very long residence times (several years) these exchanges dominate the thermal regime of the lake and control patterns of mixing and stratification. In such lakes inflows and outflows generally play a minor role in determining temperature structure in the lake. In contrast, in lakes with very short residence times (weeks), inflows and outflows dominate the thermal regime and control mixing and stratification, with climate factors playing a secondary role. With a residence time of approximately 1.2 years, Lake Brunner falls in neither of these categories. Although it is a deep lake of reasonable size, inflows and outflows are also reasonably large. Hence, one can expect that both climate factors and inflows will play important roles in controlling the lake's thermal regime (Spigel 2008).

Lake Brunner, like most large New Zealand Lakes, is a deep monomictic lake, meaning the lake mixes from top to bottom only once per year. For the rest of the year the lake is thermally stratified, being warmer at the surface and cooler at depth. Mixing from top to bottom (also called turnover) usually occurs during mid-winter (typically May-June) when inputs of solar energy are lowest and winter storms allow for deep wind-driven mixing of lake surface waters. The lake will remain largely un-stratified (or isothermal, i.e., the same temperature from top to bottom) over the winter (Figure 4.2). During spring, surface waters of the lake are then heated by the sun, thereby thermally stratifying the lake forming a thermocline (a decrease in temperature with depth). In early spring the thermocline is shallower, but by mid-summer the thermocline usually extends to 40 m depth in Lake Brunner.

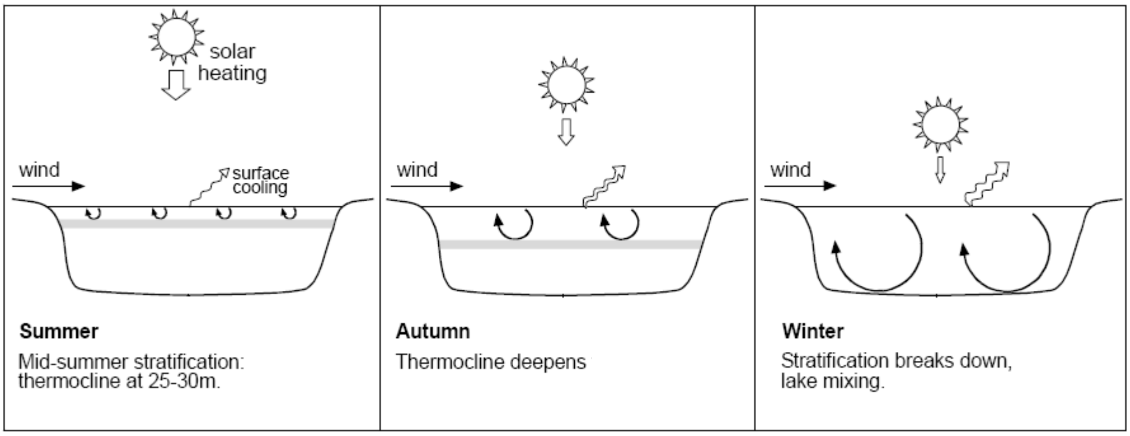


Figure 4.1 Lake stratification and mixing is dependent on the interactions of the sun's energy and wind energy and on the net effect of heating and cooling. The sun tends to heat the lake and increase stratification, the wind tends to mix the lake and break down stratification (courtesy of Kelly and Howard-Williams, 2003).

This pattern of stratification and mixing has important implications for water quality in lakes, predominantly because the thermocline prevents mixing of near surface waters (called the epilimnion) with deep bottom waters (called the hypolimnion). Because of this, waters below the thermocline are essentially isolated from the surface of the lake, where gas exchange with the atmosphere and oxygen-generating processes such as photosynthesis occur. This means that oxygen consuming processes that occur in the bottom-waters of the lake are isolated from oxygen being supplied to the lake at its surface, and can only utilise the available oxygen that was recirculated to the hypolimnion at the time of the last winter turnover. Organic matter such as phytoplankton and river inputs generally sink through the water column into the hypolimnion, where it is decomposed by bacteria and other microbes, thereby consuming oxygen in the hypolimnion. If, on an annual basis, the amount of oxygen consumed by microbes in the hypolimnion exceeds the initial supply at spring turnover, oxygen could be depleted to levels unfit for sensitive aquatic life such as trout. If oxygen is further depleted to near zero at the lake bottom (called anoxia), chemical transformations at the sediment-water interface can result in the liberation of sediment-bound nutrients into the water column, a process known as "internal loading". In the Rotorua Lakes, anoxic conditions have resulted in the equivalent of the annual nutrient loadings from all river inflows being internally loaded from sediments in a matter of a few days. Furthermore, once these processes begin in a lake, positive feedback mechanisms tend to accelerate them, either perpetuating or worsening the water quality in the lake.

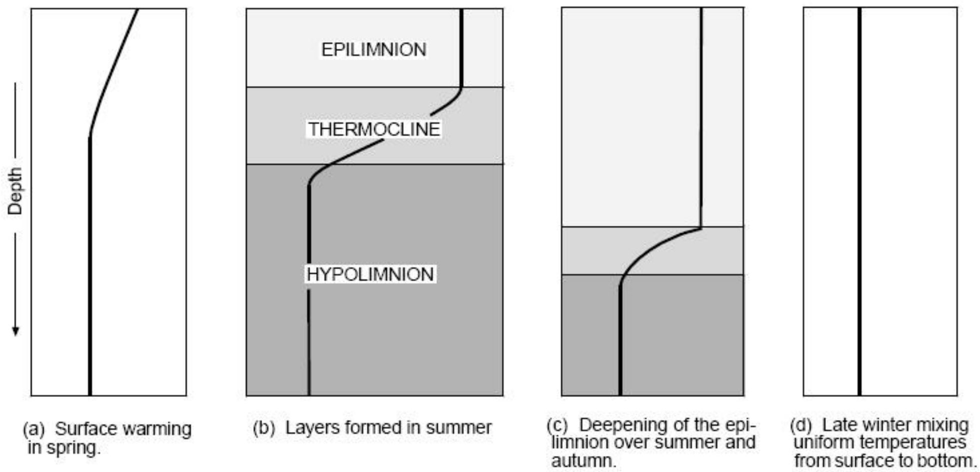


Figure 4.2 The mixing cycle of the water of Lake Brunner. Each panel represents water temperature with depth in the lake for a particular season: (a) spring, (b) summer, (c) late summer/autumn, (d) late winter. Water temperature is represented by the thick black line in each panel with temperature increasing from left to right in each panel (courtesy of Kelly and Howard-Williams, 2003).

It is predicted that phosphorus is the most important nutrient (or limiting nutrient) in the lake based on TN:TP ratios >20:1. The median TN:TP ratio was ~ 34:1 in both the 1990's and 2000's. TN:TP ratios differed between seasons, being highest in winter and lowest in summer, with similar ratios in autumn and spring (Figure 5.11.8). Ratios Most aquatic plants such as phytoplankton maintain TN:TP ratios of roughly 16:1, or what is termed the Redfield ratio, and as this ratio changes the nutrient in lower supply (in this case P) becomes limiting to phytoplankton growth. While faecal coliforms and sediment have short term and localised affects on lake water quality, nutrients entering the lake from tributaries are the major concern.

4.2 Seasonal patterns in Lake Brunner water quality parameters

Lake Brunner undergoes seasonal cycles relating primarily to stratification and mixing as previously mentioned. When data collected at the central lake site was grouped by month seasonal patterns were apparent for some parameters (Section 5.11). Clarity, as measured by secchi disk, was poorest during summer and highest in late winter/early spring. Strongly seasonal patterns were apparent in nitrate concentrations, which were lowest in summer increasing to a peak at the end of winter, then heading down as the weather warmed. While not as strong, total nitrogen (TN) displayed a similar pattern to nitrate, but dissolved organic nitrogen (DON) was lowest in winter. Levels of chlorophyll a were lowest in winter leading to higher water clarity. Chlorophyll a was negatively correlated with secchi disk clarity ($p<0.05$), hence higher phytoplankton biomass was largely responsible for poorer water clarity. There was no obvious seasonal pattern in total phosphorus (TP), but dissolved reactive phosphorus (DRP) seemed to drop in late summer and peaking in winter.

4.3 Trends in lake water quality

The central lake sampling station has the longest dataset of any site in the catchment. This has allowed for statistical analysis of the data to investigate potential trends for water quality parameters while accounting for seasonal patterns. Sampling has been more recent at Cashmere and Iveagh Bay. More data will be required to analyse these sites in the same way although some basic observations can be made from the data we have collected at these sites so far.

4.3.1 Central lake sampling site

Analyses of all data from 1992 and August 2007 using the Seasonal Kendall test indicate that statistically significant trends have occurred for some water quality parameters measured at the central lake monitoring station (Table 4.4) (Scarsbrook unpubl. data 2008). TN and TP concentrations have shown a general increase since monitoring started in 1992 (Figure 4.3). Phytoplankton biomass (measured as chlorophyll a) has trended upwards, which was mirrored by a decrease in visual clarity as measured by the secchi disk depth (Figure 4.3). Visual clarity ranged between 3.1 and 4.4 m during the 2007-08 monitoring season, and was lower on average (3.75 m) than in 2006-2007 where the average was 4.37 m. When the same analysis was conducted for the same parameters, but for a shorter, more recent time period (2001-2007), the statistically significant trends were an increase in chlorophyll a, consistent with analysis of the longer record, and a decrease in nitrate. Interestingly, no nitrate trend was apparent via 1992-2007 analysis.

Table 4.4 Seasonal Kendall test for water quality data collected at Lake Brunner's central monitoring site. Up/down arrows indicate statistically significant increasing or decreasing trends. Red indicates an undesirable trend and blue indicates a good trend.

Variable	Data record	Median	Significance P-value	Trend direction	Rate of change (%) per year
Secchi depth (clarity in meters)	1992 to 2007	5.73	0.000	↘	-2.3
Chlorophyll a (ug/L)	1992 to 2007	1.2	0.000	↗	5.4
TN (ug/L)	1992 to 2007	179.75	0.013	↗	1.6
NO_x – N (ug/L)	1992 to 2007	83.5	1.0	-	0.0
TON (ug/L)	1992 to 2007	72.6	0.496	-	0.8
TP(ug/L)*	1992 to 2007	5.15	0.008	↗	2.4
DRP (ug/L)	1992 to 2007	0.5	0.078	-	4.9
Secchi depth (clarity in meters)	2001 to 2007	5.08	0.197	-	-4.0
Chlorophyll a (ug/L)	2001 to 2007	1.2	0.03	↗	11.3
TN (ug/L)	2001 to 2007	200	1.0	-	0.0
NO_x – N (ug/L)	2001 to 2007	88.6	0.044	↘	-5.7
TON (ug/L)	2001 to 2007	74	0.371	-	-4.2
TP(ug/L)*	2001 to 2007	6	0.371	-	-3.2
DRP (ug/L)	2001 to 2007	119.33	0.314	-	-0.1

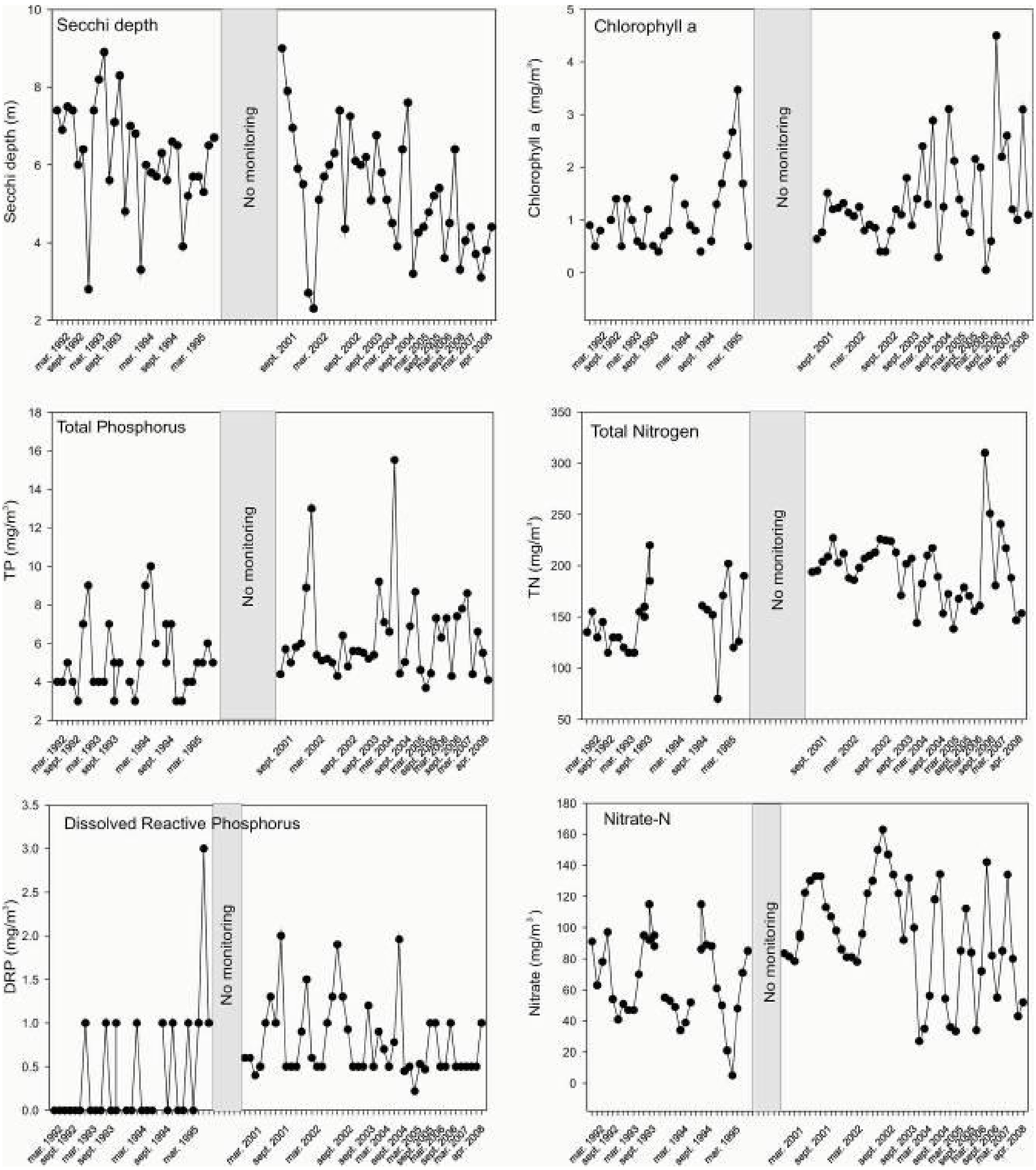


Figure 4.3 *Data for Secchi depth (clarity), chlorophyll a, total phosphorus, total nitrogen, dissolved reactive phosphorus, and nitrate from Lake Brunner's mid-lake station sampled (1992-2008) using a 20 m integrated tube sampler (note that scale of X-axis reflects the closer frequency of sampling in 2001-2002). From Chague-Goff (2008).*

4.3.2 Cashmere and Iveagh Bay stations

Nutrient concentration data consistently show that water quality has been poorest in Cashmere Bay, in comparison to conditions at the mid-lake station and Iveagh Bay (see Figures 5.12.1 to 5.12.3). Oxygen depletion has occurred near the lake bed in Cashmere Bay, which has lead to higher ammoniacal nitrogen levels compared to those for nitrate (Figure 5.12.2). TN and TP were higher near the lake bed compared with the surface. Chlorophyll a appeared to be increasing, and clarity (secchi depth) decreasing in Cashmere Bay. It appears that localised conditions are contributing to poorer water quality around this portion of the lake, and it is uncertain as to the degree to which water quality in Cashmere Bay might affect water quality in neighbouring Iveagh Bay, or the rest of the lake.

At Iveagh Bay nutrient concentrations were similar at both surface and bottom depths. Unlike Cashmere, ammoniacal nitrogen levels were low near the bed of Iveagh Bay. TN and nitrate may be increasing but further sampling and time are required to prove this. Chlorophyll a concentrations have varied inconclusively but clarity (secchi depth) seems to have deteriorated.

4.4 Nutrient levels in lake tributaries

Rutherford *et al*. (2008) utilised existing Brunner tributary monitoring data to develop a model predicting flow and nutrient delivery to the lake. Information from this work has been incorporated into the following sections. For further detail refer to Rutherford *et al.* (2008).

4.4.1 Lake and tributary flow

Average lake outflow for the period 1st August 1989 to 2nd November 2007 was 61.5 m^3/s. The average contribution to the outflow from net rainfall on the lake was estimated at 3.6 m^3/s. Thus inflow to the lake from tributary rivers averaged 57.9 m^3/s over the period considered. The three main tributaries – Crooked, Hohonu and Orangipuku – contribute 69% of the total lake inflow but do not contribute inflow in proportion to their catchments area. For example, the Orangipuku River gains significant flow inputs from spring sources.

4.4.2 Tributary nutrients

In forested catchments (e.g., the Carew) TN is largely in the form of dissolved organic nitrogen (DON) (c. 100 mg N/m^3) with low DIN concentrations (c. 10 mg/m^3). DON from forested areas generally has low bioavailability to plants. In the farmed catchments DON varies from 10 to 100 mg/m^3. DON from dairying catchments may well be un-oxidised urea (Dr R.J. Wilcock, pers. comm., data from the Inchbonnie catchment study) and hence be 'available' to aquatic plants, since it is readily mineralised to ammonia and then nitrified. In the Crooked and Orangipuku catchments, which are most intensively farmed, DIN concentrations commonly exceed 100 mg N/m^3.

TP comprises roughly equal proportions of DRP, dissolved organic phosphorus (DOP) and particulate phosphorus (PP). Phosphorus concentrations were low in forested catchments (e.g., the Carew) and high in the farmed catchments (e.g., the Orangipuku and Crooked) as expected. In Pigeon Creek (a tributary of the Orangipuku) DRP was 61% of TP, which is high but not unusual for a dairy stream (Dr R.J. Wilcock, pers. comm.)

DIN and DRP are immediately bioavailable to plants in the lake. A proportion of particulate nitrogen (PN) and PP is potentially bioavailable, although they must first be mineralised and broken down to DIN and DRP by bacteri and fungi. DON from forested catchments and DOP are unlikely to stimulate plant growth in the lake because of low bioavailability (Hall et al. 2005). However, the colour of these organic compounds may affect light levels in the lake. DON from dairying catchments may be derived from urea and hence be bioavailable, as discussed above.

TP concentrations increase with river flow in most of the tributaries, which is consistent in other catchments (Rutherford *et al.* 2008). The exception is the Carew probably because the catchment is bush-covered which reduces the effects of rain on mobilising phosphorus. In the Poerua TN concentration was not correlated with flow. The Poerua River drains Lake Poerua, which may buffer the effects of rain on nitrogen generation and transport. The correlation between TN concentration and flow is also weak in the Crooked River. The Poerua River drains into the Crooked and this may affect the flow relationship. However, the Poerua River contributes only 16% of the mean flow and so one would not expect it to unduly influence nutrients in the Crooked. The high variability in the Crooked TN data may disguise a flow relationship. It is not clear why.

The duration of sampling and data variability should be considered when interpreting nutrient data over time collected in the major tributaries of Lake Brunner. In the Orangipuku River phosphorus appeared to have remained stable, while nitrogen may have increased (Figure 5.12.4). Whilst nutrient concentrations were low in the Hohonu River, they appear to have increased (Figure 5.12.5). Nutrient levels in the Crooked River were more variable. This is a large catchment, including Lake Poerua. Other than high nutrients recorded during two early sampling rounds, no pattern was apparent (Figure 5.12.6). The Arnold River, near the lake outlet, had similar TN and TP concentrations as the lake, albeit slightly higher (Figure 5.12.1). This may have resulted from nutrient associated with the Moana municipal sewage treatment plant, which has undergone upgrades over the sampling period.

4.4.3 Land use

Land cover and use data for the catchment was extracted from the Land Cover Database 2 (LCDB2). Of the total catchment 18.9% is classified as high producing exotic pasture (denoted as Pasture 3 by LCDB2), with 74.6% of the catchment designated as undeveloped – forest, scrub, undeveloped grassland, rock or water. Low producing exotic grassland and tussock (Pasture 2 and 1, respectively) make up the remaining land cover (Table 4.5).

The Orangipuku is the most intensively developed catchment and this is reflected in it having the highest TN concentrations (Figure 5.12.1). The Orangipuku had the highest TN concentrations but not the highest TP concentrations. Based on LCDB2 35% of the Orangipuku catchment area is high producing exotic grassland while the Crooked/Poerua and Hohonu contain 18% and 10% of this land type, respectively.

4.4.4 Nutrient yields

TP and TN specific yields were highest in the Orangipuku (0.93 kg P/ha/yr and 21 kg N/ha/yr). This was consistent with it being the most intensively farmed catchment with 35% of the catchment being high producing exotic grassland. TN/TP ratios were significantly lower in the Crooked/Poerua compared with the Orangipuku and Hohonu. The reasons for the difference are not clear but may include differences in soil type and the effect of Lake Poerua.

4.4.5 Relationship between yield and land use

Modelling (Rutherford *et al*. 2008) produced a TN yield for Pasture3 of 50.4 kg N/ha/yr. This value matches closely the yield of 50 kg N/ha/yr for a typical New Zealand dairy farm as predicted by the Overseer model. The TP yield for Pasture3 [Brunner area] of 2.4 kg P/ha/yr is higher than the typical yield of 1 kg P/ha/yr found elsewhere in New Zealand (R.J. Wilcock, NIWA, pers. comm.). Alternatively, if the Orangipuku is 35% dairy pasture and has yields of 0.93 kg TP/ha/yr and 21 kg TN /ha/yr, and we assume the non-farmed yields are 0.2 for TP and 5 for TN, then the dairy components are 2.3 kg TP /ha/yr and 51 kg TN /ha/yr. Average specific yields for the whole catchment were estimated at 11.3 kg N/ha/yr and 0.54 kg P/ha/yr.

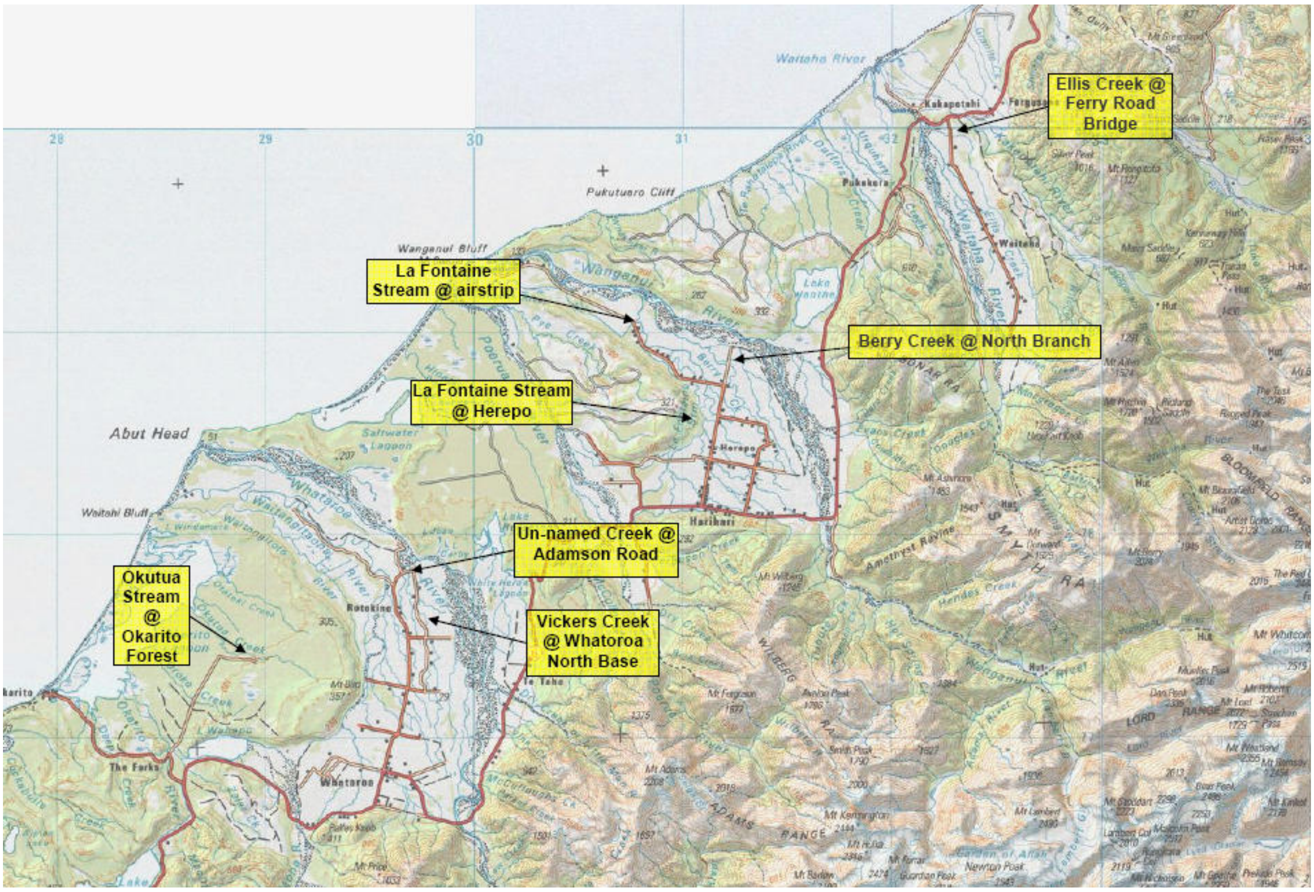
Table 4.5 Catchment nutrient yields estimated from daily flow and concentration predictions.

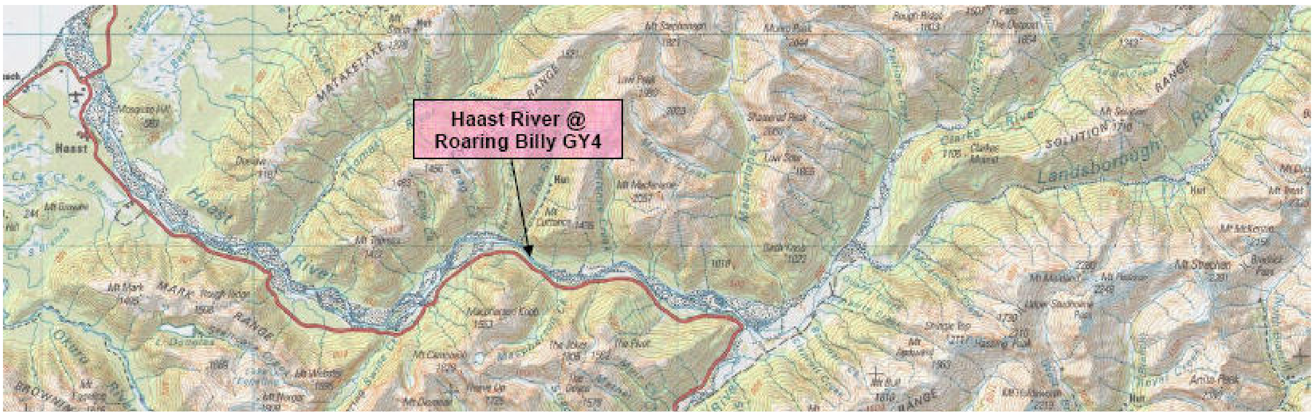
	Crooked	**Hohonu**	**Orangipuku**	**Crooked**	**Hohonu**	**Orangipuku**
Area km^2	243	45.6	45.7	243	45.6	45.7
%Forest	62%	81%	57%	62%	81%	57%
%Pasture1	9%	2%	1%	9%	2%	1%
%Pasture2	1%	0%	0%	1%	0%	0%
%Pasture3	18%	10%	35%	18%	10%	35%
%Scrub	7%	6%	6%	7%	6%	6%
%Other	3%	2%	1%	3%	2%	1%
	TP yield			**TN yield**		
Tonne/yr	14	0.86	4.2	180	21	98
kg/ha/yr	0.59	0.19	0.93	7.4	4.7	21
	TN/TP ratio					
	13:1	25:1	23:1			

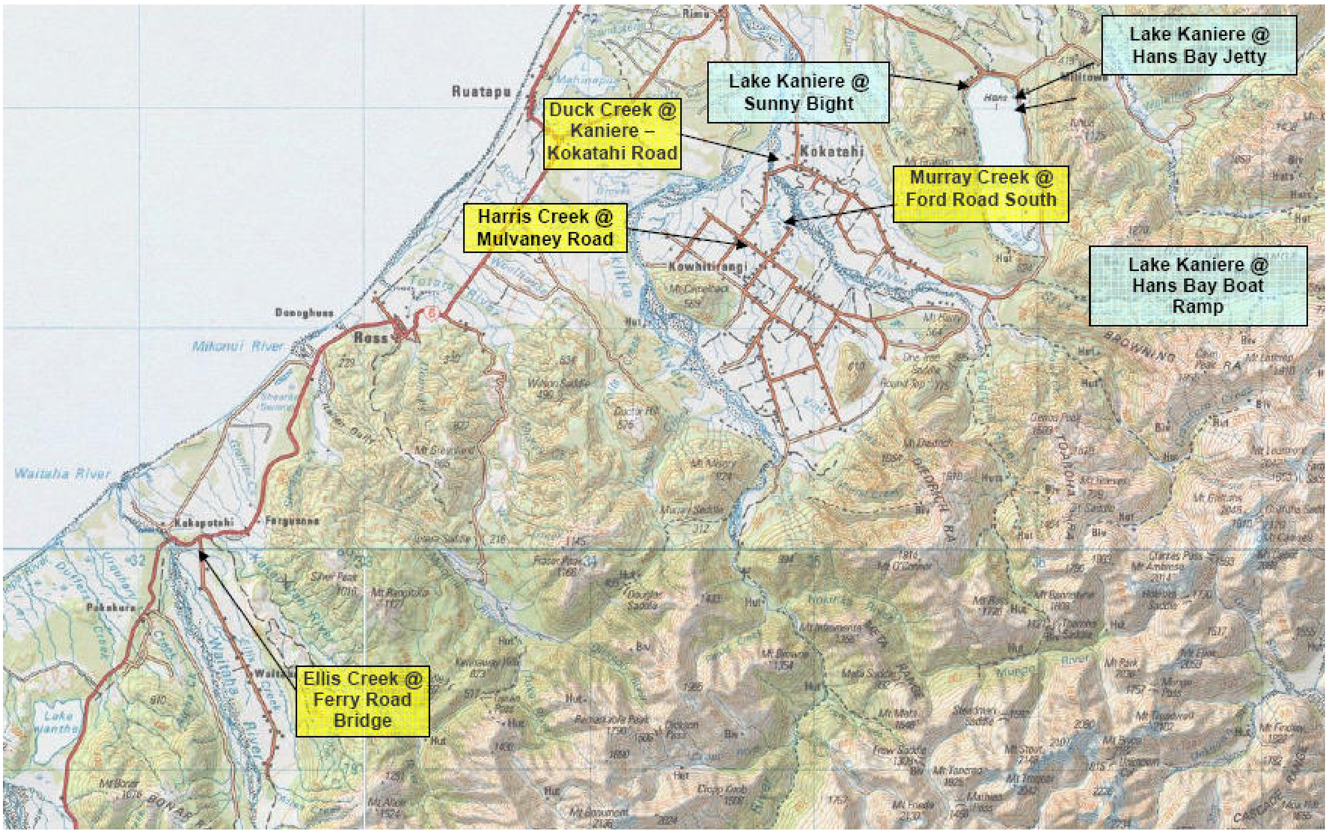
5 Appendices

5.1 Location of surface water quality monitoring sites

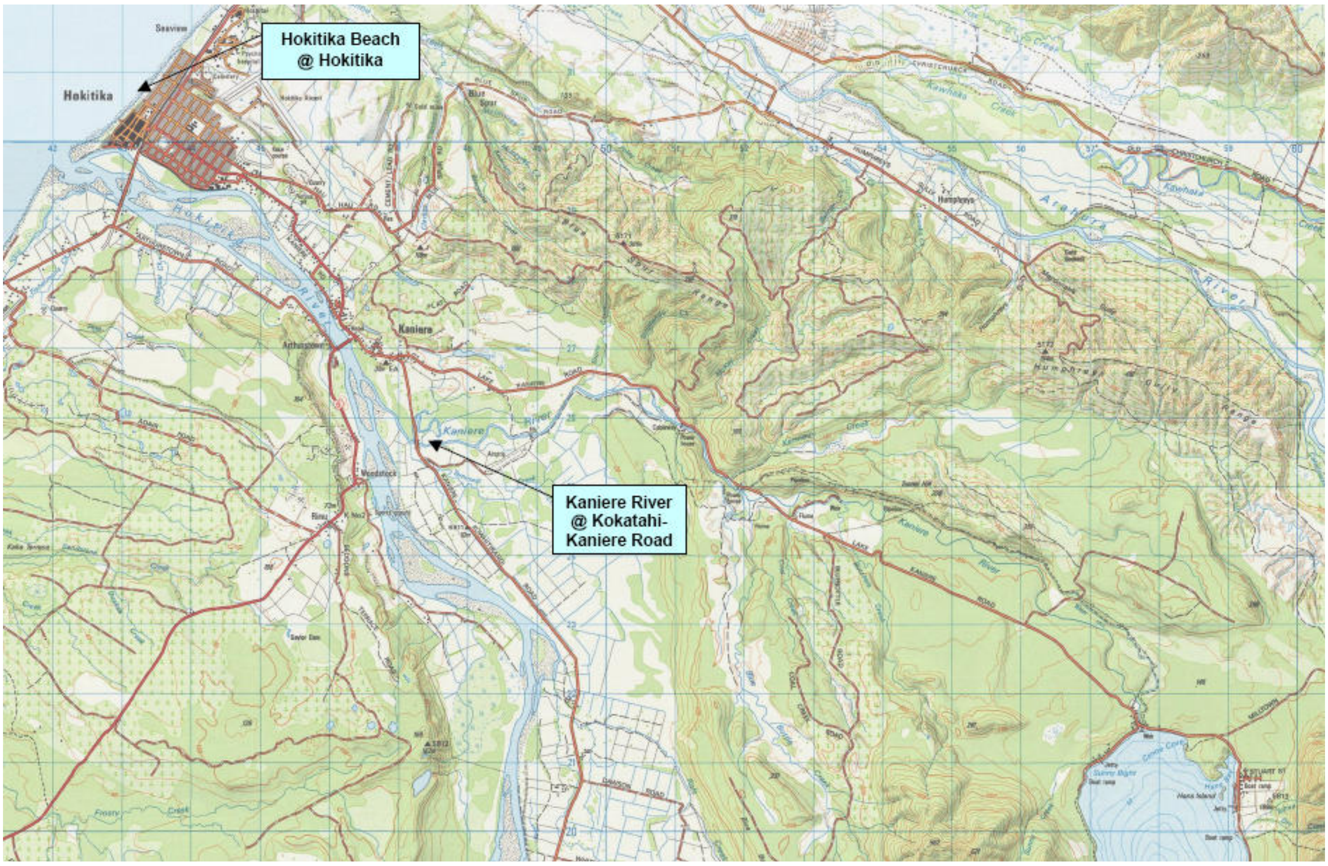
The following maps show the location of surface water quality monitoring sites in the West Coast Region. Yellow boxes indicate WCRC surface water quality monitoring sites; blue boxes indicate WCRC contact recreation water quality monitoring sites; and pink boxes indicate NIWA surface water quality monitoring sites.



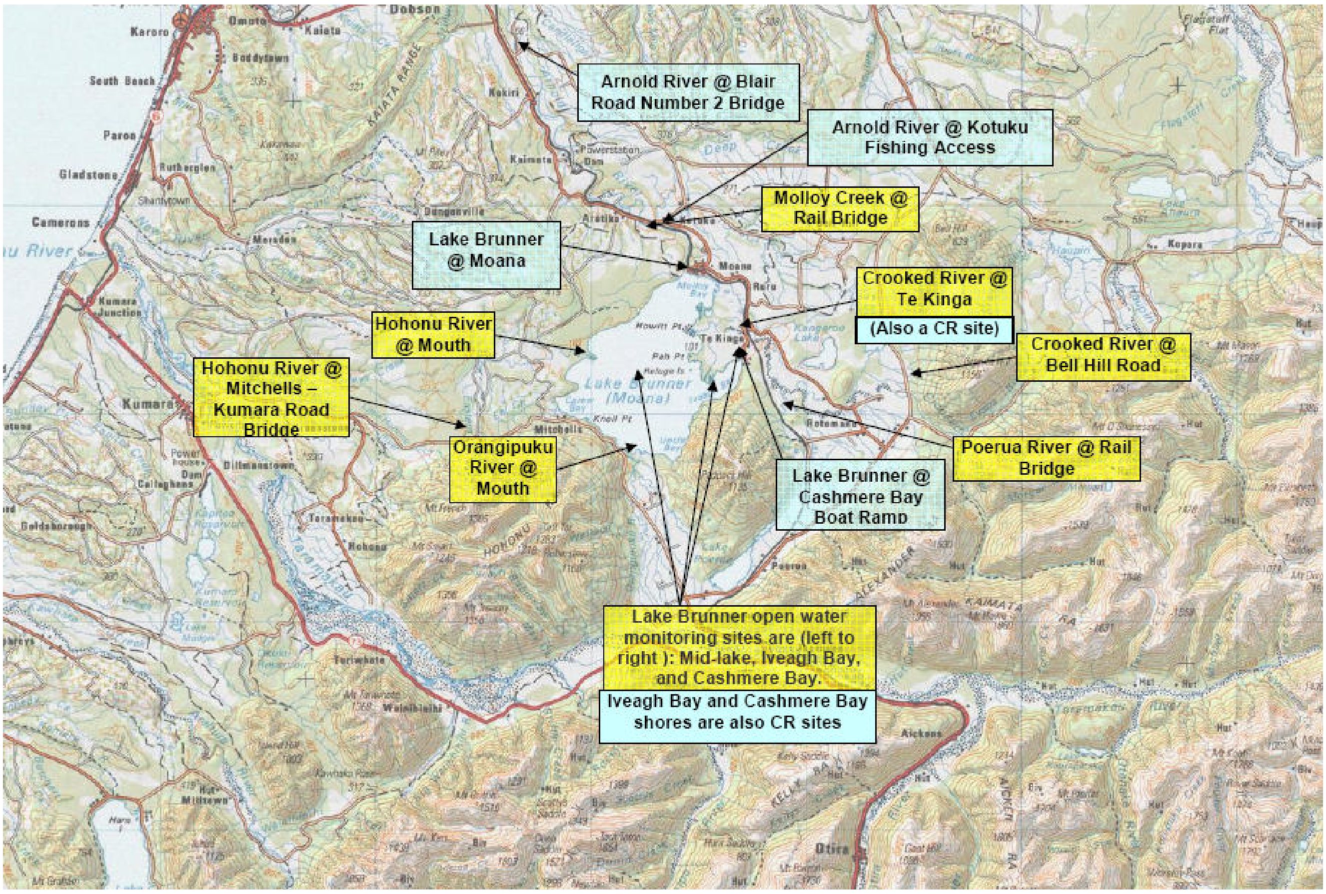




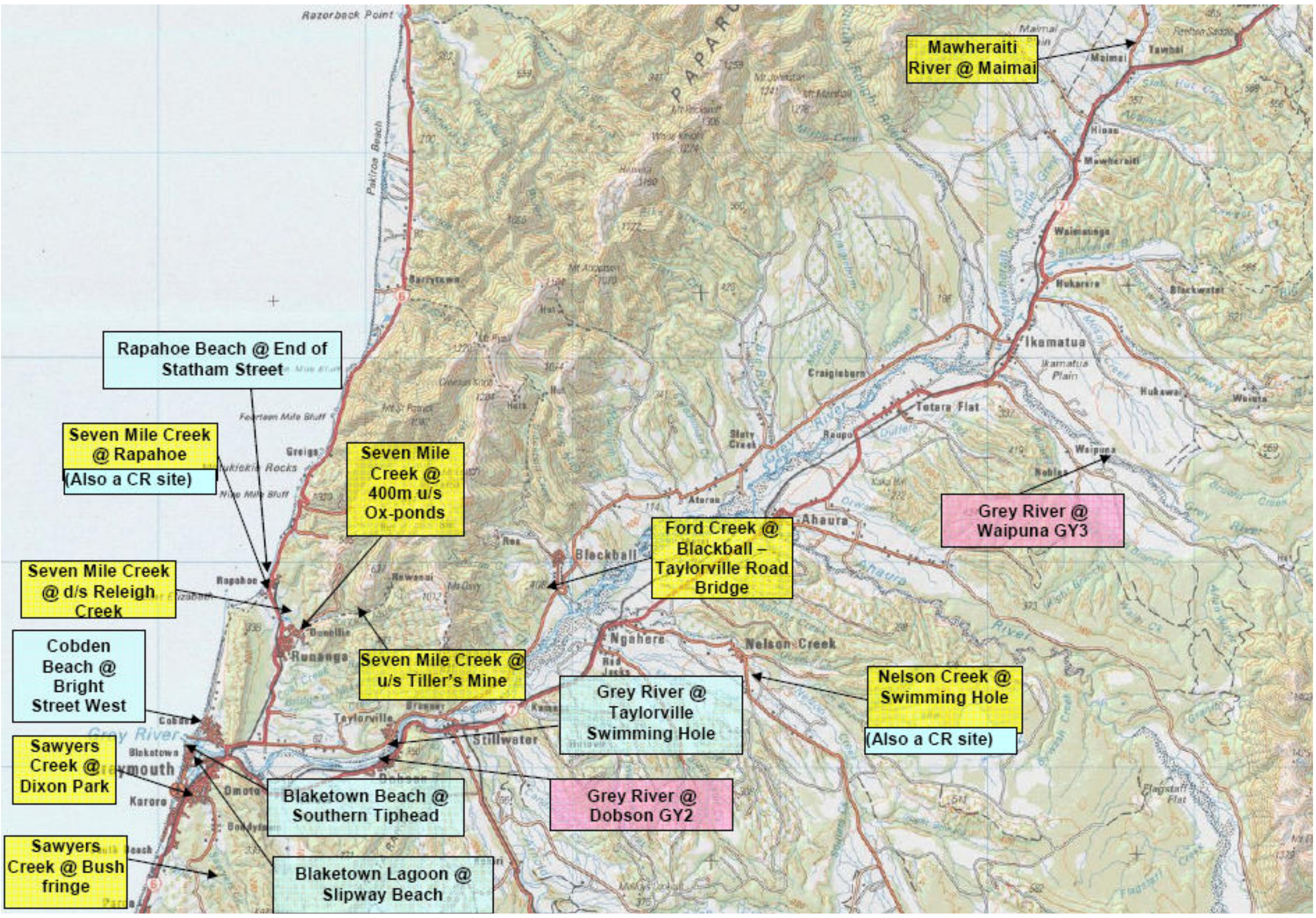
Lake Kaniere @ Hans Bay Jetty
Lake Kaniere @ Sunny Bight
Duck Creek @ Kaniere – Kokatahi Road
Murray Creek @ Ford Road South
Harris Creek @ Mulvaney Road
Lake Kaniere @ Hans Bay Boat Ramp
Ellis Creek @ Ferry Road Bridge
Ruatapu
Kokatahi
Ross
Mikonui River
Waitaha River
Kakapotahi



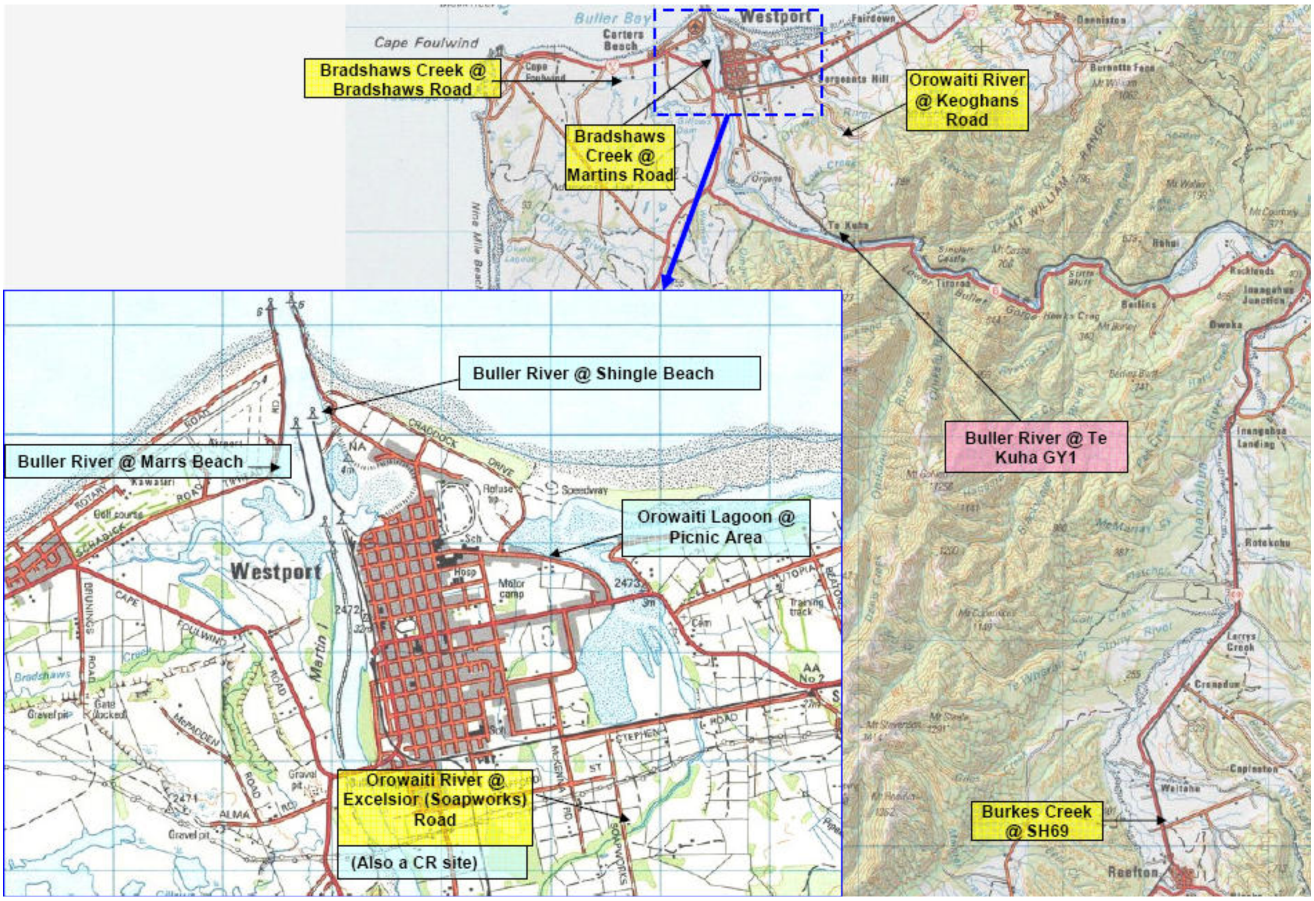
Hokitika Beach @ Hokitika
Hokitika
Kaniere River @ Kokatahi-Kaniere Road

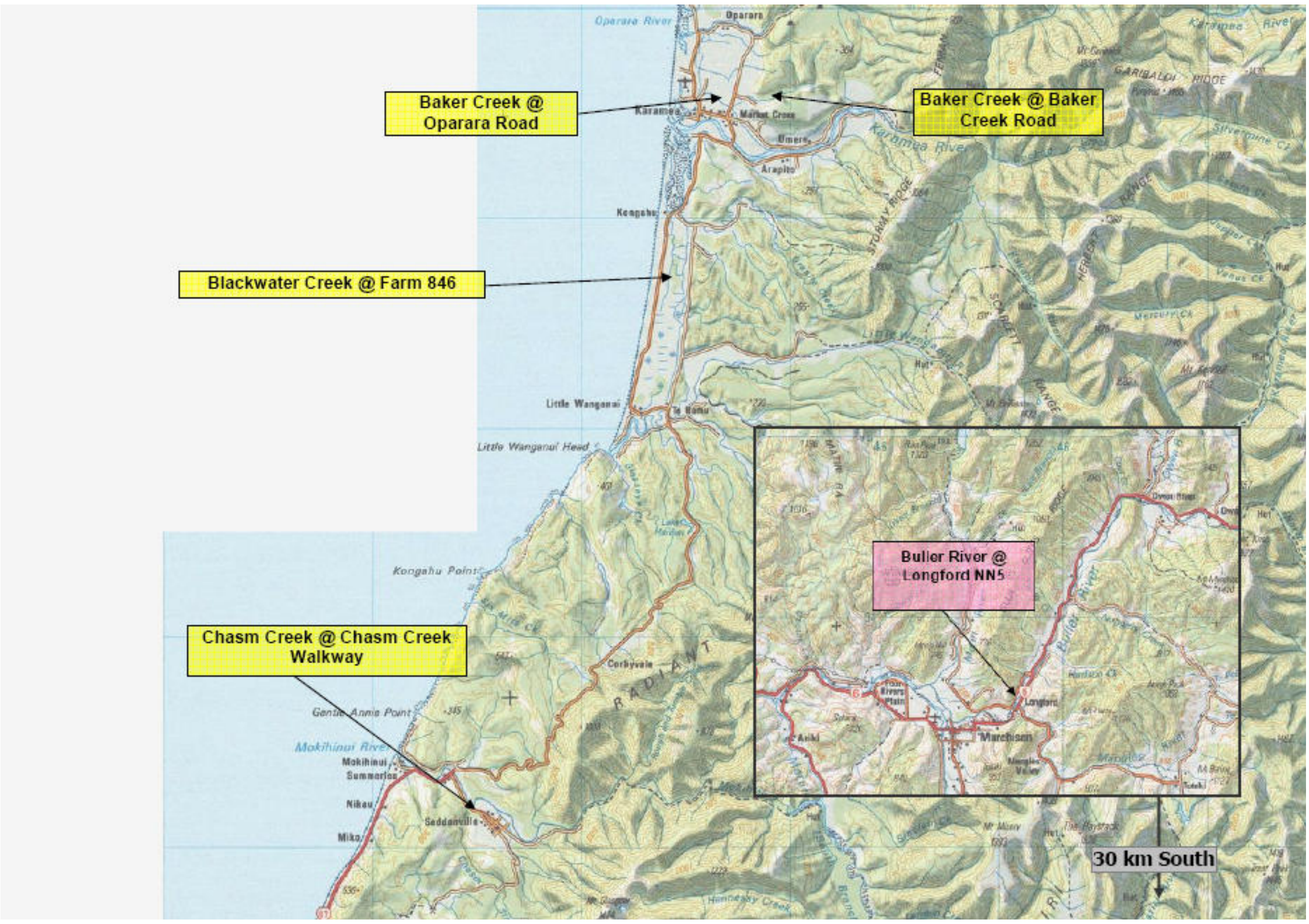


Arnold River @ Blair Road Number 2 Bridge
Arnold River @ Kotuku Fishing Access
Molloy Creek @ Rail Bridge
Lake Brunner @ Moana
Crooked River @ Te Kinga
(Also a CR site)
Hohonu River @ Mouth
Crooked River @ Bell Hill Road
Hohonu River @ Mitchells – Kumara Road Bridge
Orangipuku River @ Mouth
Poerua River @ Rail Bridge
Lake Brunner @ Cashmere Bay Boat Ramp
Lake Brunner open water monitoring sites are (left to right): Mid-lake, Iveagh Bay, and Cashmere Bay.
Iveagh Bay and Cashmere Bay shores are also CR sites



Mawheraiti River @ Maimai
Rapahoe Beach @ End of Statham Street
Seven Mile Creek @ Rapahoe
(Also a CR site)
Seven Mile Creek @ 400m u/s Ox-ponds
Grey River @ Waipuna GY3
Ford Creek @ Blackball – Taylorville Road Bridge
Seven Mile Creek @ d/s Releigh Creek
Cobden Beach @ Bright Street West
Seven Mile Creek @ u/s Tiller's Mine
Grey River @ Taylorville Swimming Hole
Nelson Creek @ Swimming Hole
(Also a CR site)
Sawyers Creek @ Dixon Park
Blaketown Beach @ Southern Tiphead
Grey River @ Dobson GY2
Sawyers Creek @ Bush fringe
Blaketown Lagoon @ Slipway Beach


Bradshaws Creek @ Bradshaws Road
Bradshaws Creek @ Martins Road
Orowaiti River @ Keoghans Road
Westport
Buller River @ Shingle Beach
Buller River @ Marrs Beach
Orowaiti Lagoon @ Picnic Area
Buller River @ Te Kuha GY1
Orowaiti River @ Excelsior (Soapworks) Road
(Also a CR site)
Burkes Creek @ SH69


Baker Creek @ Oparara Road
Baker Creek @ Baker Creek Road
Blackwater Creek @ Farm 846
Buller River @ Longford NN5
Chasm Creek @ Chasm Creek Walkway
30 km South

5.2 List of sites, variables, and sampling frequencies

Area		Site	Grid Ref		Continuous flow	Gauge per visit by WCRC	Freq.	Summer			Autumn			Winter		
			Easting	Northing				Peri	Macro	Extra	Peri	Macro	Extra	Peri	Macro	Extra
Grey Valley		Molloy Ck@Rail line	2383580	5849140	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Grey Valley		Nelson Ck@Swimming hole	2388200	5865900	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Grey Valley		Ford Ck @ Blackball - Taylorville Rd	2379300	5868700	no	yes	1/4	-	-	SO4 (f/c & NH) & other	4x6	Yes	SO4 (f/c & NH) & other	-	-	SO4 (f/c & NH) & other
Reefton		Burkes Ck @ SH69 Reefton	2414750	5901500	no	yes	1/4	-	-	SO4 (f/c & NH) & other	4x5	Yes	SO4 (f/c & NH) & other	-	-	SO4 (f/c & NH) & other
Reefton		Mawheraiti Rv @ SH7 Maimai	2404200	5889000	no	yes	1/4	-	-	NHx & E. coli & F/C	4x5	Yes	NHx & E. coli & F/C	-	-	NHx & E. coli & F/C
Greymouth		Sawyers Ck @ Dixon Park	2362415	5859530	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Greymouth		Sawyers Ck@Bush Fringe	2363270	5855790	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Greymouth		Seven Mile Ck @ 400m u/s Dunollie ox ponds	2366400	5867100	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Greymouth		Seven Mile Ck @ d/s Raleigh Ck	2366030	5867500	no	yes	1/4	-	-	NHx & E. coli & F/C	4x5	Yes	NHx & E. coli & F/C	-	-	NHx & E. coli & F/C
Greymouth		Seven Mile Ck @ u/s Tillers	2368704	5867509	no	surrogate	1 yr	-	-	SENZ data	4x5	Yes	SO4 (f/c & NH) & other	-	-	SENZ data
Greymouth		Seven Mile Ck @ SH6 Rapahoe	2365300	5868600	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Hokitika		Duck Ck @ Kokatahi-Kowhitirangi Rd	2349145	5817525	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Hokitika		Harris Ck @ Mulvaney Rd	2347500	5815265	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Hokitika		Murray Ck @ Ford Rd South	2349000	5814560	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Westport		Bradshaws Ck @ Bradshaws Rd	2388996	5937484	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Westport		Bradshaws@Martins Rd	2392150	5938120	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Westport		Orowaiti Rv @ Excelsior Rd	2395700	5936400	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Westport		Orowaiti Rv @ Keoghans Rd	2398700	5936700	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Waitaha		Ellis Ck@Ferry Bridge	2322740	5799670	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Whanganui		Berry Ck@N Branch (Wanganui flat Rd)	2312100	5788400	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Whanganui		La Fontaine@Airstrip	2307720	5790620	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Whanganui		La Fontaine@Heropo fishing access	2310380	5784650	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Whataroa		Okutua Rv @ Rd Br N Okarito forest	2289610	5773870	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Whataroa		Un-named Ck @ Adamson Rd	2296900	5778180	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Whataroa		Vickers Ck @ North Base Rd (Whataroa Base)	2297220	5776320	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
North Buller		Baker Ck @ Baker Ck Rd	2438400	5995500	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
North Buller		Baker Ck @ Oparara Rd	2437070	5995260	no	yes	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
North Buller		Page Stm @ Chasm Ck walkway	2424800	5961700	no	surrogate	1/4	-	-	SO4	4x5	Yes	SO4	-	-	SO4
North Buller		Blackwater Ck @ Farm 846	2434380	5988440	no	surrogate	1/4	-	-	NHx & F/C & other	4x5	Yes	NHx & F/C & other	-	-	NHx & F/C & other
Grey Valley	NIWA	Grey Rv @ Dobson NIWA	2370100	5860200	yes	no	1/12	-	-	Flow, DO%, temp, clarity, BOD, colour (340&440 nm), NO3, NHx, TN, DRP, TP, *E. coli*						Macro's once a year NIWA
Grey Valley	NIWA	Grey Rv @ SH7 Ikamatua NIWA	2400500	5879200	yes	no	1/12	-	-	Flow, DO%, temp, clarity, BOD, colour (340&440 nm), NO3, NHx, TN, DRP, TP, *E. coli*						Macro's once a year NIWA
Haast	NIWA	Haast Rv NIWA	2212820	5689640	yes	no	1/12	-	-	Flow, DO%, temp, clarity, BOD, colour (340&440 nm), NO3, NHx, TN, DRP, TP, *E. coli*						Macro's once a year NIWA
Buller	NIWA	Buller @ Te Kuha NIWA	2402450	5929590	yes	no	1/12	-	-	Flow, DO%, temp, clarity, BOD, colour (340&440 nm), NO3, NHx, TN, DRP, TP, *E. coli*						Macro's once a year NIWA
		Site	Grid Ref		Continuous	Gauge	Freq.	Feb			April		June	August		October
								Peri		Extra (no macro)	macro's at all sites		No macro	No macro		No macro
Brunner		Arnold Rv @ Blairs Rd	2376470	5857090	no	no	1/6	no		NHx & F/C & other	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Arnold Rv @ Kotuku Fish Access	2383500	5848900	yes	no	1/6	no		Nuts & F/C & other	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Crooked Rv @ Rotomanu-Bell Hill Rd	2394900	5840950	no	no	1/6	4x5		Nuts & F/C & other	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Crooked Rv @ Te Kinga / mouth	2386700	5844015	no	WCRC	1/6	4x5		NIWA does the above	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Hohonu Rv @ Mouth	2379580	5842970	no	WCRC	1/6	no		NIWA does the above	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Hohonu Rv @ Mitchells - Kumara Rd Br	2374970	5838940	no	no	1/6	4x5		Nuts & F/C & other	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Orangipuku Rv @ Mouth	2382070	5837750	no	WCRC	1/6	no		NIWA does the above	As for Feb		As for Feb	As for Feb		As for Feb
Brunner		Poerua River @ Rail Bridge	2381800	5838700	no	yes	1/6	4x5		Nuts & F/C & other	As for Feb		As for Feb	As for Feb		As for Feb

Continuous flow: The presence of a flow recording station that continuously records flow data for that particular river
Gauge per visit: Whether water flow is gauged during a water quality site visit. Flow rate influences many water quality variables and this information is used for calibration
Frequency: How many times a year the site is monitored. 1/4 means four times; once normally at the start of each season.
Measurements of water quality:

Periphyton (= Peri): This is the slime that covers rocks and is made up algae, cyanobacteria and diatoms. Four transects, each collecting five random stones across the channel, are collected. Percentage cover of different types of periphyton are assess

Macroinvertebrates (= macro): Like periphyton, macroinvertebrates can be indicative of longer term water and habitat quality regimes, even though they are measured at a single point in time. Numbers and types of bugs say a lot about conditions in the s

Other: electrical conductivity, pH, turbidity, temperature, and dissolved oxygen. Collected everytime, everywhere. Also clarity, and qualitative assessment of deposited and re-suspendable sediment, riparian condition.

NHx = ammoniacal nitrogen (NH_3 + NH_4^+); **E. coli** = a common faecal coliform; **F/C** = total faecal coliform; **SO4** = sulphate. Associated with acid mine drainage.

Nuts = Total nutrients. This is: Particulate phosphorus PP, dissolved inorganic phosphorus DRP, total dissolved phosphorus TDP, particulate nitrogen PN, total dissolved nitrogen TDN, Nitrate NO3, ammoniacal nitrogen NHx. The other nutrient fractions

Site	Depth	pH	Conductivity	Temperature	DO	Turbidity	Flow gauging/data	Black disk	Secchi disk	E coli and FC	Nutrients *1	Chlorophyll a	TSS	Turbidity (lab)	Colour * 2
	Profiles measured using YSI 6600 Data sonde														
Lake															
Iveagh Bay	0 - 30 m							✓	✓		Van Dorn 4 m & 25 m	✓			
Cashmere Bay GYBC	0 - 12 m							✓	✓		Van Dorn 4 m & 10 m	✓			
Centre of Lake GYBI	0 - 100 m					0 - 60 m		✓	✓		Van Dorn *3	✓			
Centre of Lake GYBS											Tube *4	✓	✓	✓	✓
Tributaries															
Crooked R @ Bell Hill Rd		✓	✓	✓	✓	✓		✓		✓	✓				
Crooked R @ Mouth		✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	
Poerua R @ Rail Bridge		✓	✓	✓	✓	✓	✓	✓		✓	✓				
Orangipuku R @ Mouth		✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	
Hohonu R @ Mitchells - Kumara Rd Br		✓	✓	✓	✓	✓		✓		✓	✓				
Hohonu R @ Mouth		✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	
Arnold R @ Kotuku Fishing Access		✓	✓	✓	✓	✓		✓		✓	✓				

*[1] All nutrients are = TDP, TDN, DRP, NO3, NH4, PN, PP (DIN, TON, TOP, TN, TP are calcualted from others)

*[2] Colour 340 nm 440 nm 740 nm

*[3] Van Dorn samples taken at 10, 20, 40, 70 , and 95 metres - preferably in April and October.

*[4] Bi-monthly tube sample: 25 m long 20 mm diameter plastic weighted tube, lowered through the water column, then sealed and retrieved, collecting a 0 - 25 m deep composite water sample

Year	Month	Sampling trip	Deep water?	Van Dorn		
2007	November	Sampling	yes	10, 20, 40, 70, 95 m		
2007	December					
2007	January					
2008	February	Sampling				
2008	March					
2008	April	Sampling	yes	10, 20, 40, 70, 95 m		
2008	May					
2008	June	Sampling				
2008	July					
2008	August	Sampling				
2008	September					
2008	October	Sampling	yes	10, 20, 40, 70, 95 m		
2008	November					
2008	December	Sampling				
2009	January					
2009	February	Sampling				
2009	March					
2009	April	Sampling	yes	10, 20, 40, 70, 95 m		
2009	May					
2009	June	Sampling				
2009	July					
2009	August	Sampling				
2009	September					
2009	October	Sampling	yes	10, 20, 40, 70, 95 m		
2009	November					
2009	December	Sampling				
2010	January					

Note: December, February, April, June, August, October sampling regime preferred, so that we can collect the deep samples with the Van Dorn at the mid lake station in the spring (October), once the thermal stratification has become established and is stable, and autumn, before the thermostratification begins to break down and the thermocline deepens. With end points, you can compute the VHOD rate (volumetric hypolimnetic oxygen depletion rate).

Coordinates	
GYBS	2382561, 5840026
GYBI	2386295, 5841869
GYBC	2386834, 5842727
Orangipuku mouth	2381700, 5838270
Hohonu Mouth	2379820, 5842730
Crooked Mouth	2384360, 5844180

5.3 Data analytical methods

5.3.1 Relationships between water quality and land use

Two techniques were used to estimate land use in the catchment above each monitoring. The first used REC land use categories that designate land use according to which land use is dominant in the catchment (refer to Section 5.5 for more details on REC). Indigenous forest (IF) and pasture (P) were the two main land use categories for SWQMP sites. The other technique, LCDB2 (Land Cover Database 2), determines the proportion of land use types in a catchment. REC categories were used extensively in the earlier WCRC Surface Water Quality report (Horrox 2006).

An overall site average rank was calculated, providing a high level summary of water quality at each SWQMP site, which was then related to land use. SWQMP sites were ranked by median values for each of seven water quality variables (i.e., DO%, temperature, turbidity, *E. coli*, NH_4-N, pH and conductivity), with ranking from low to high water quality for each water quality variable. The mean of these medians was calculated to determine an overall site ranking. Note that all parameters were given equal weighting when developing an overall rank.

A two-sample t-test was used to test for a statistically significant difference in mean water quality rank between indigenous forest and pasture sites. A Mann-Whitney U test was used to test for significant differences between IF and P sites when sites were grouped together according their REC land use category (either IF or P). The percentage of 'natural' land cover for each site, according to LCDB2, was correlated against the range of medians among sites for each water quality variable, using Spearman rank correlation. Spearman rank correlation is a non-parametric measure of correlation – that is, it assesses how well an arbitrary monotonic function could describe the relationship between two variables, without making any assumptions about the frequency distribution of the variables.

5.3.2 Comparison to water quality guidelines

Percentage bar graphs have been used to illustrate how some of the key parameters measured at WCRC SWQMP sites compared to the respective guidelines for those parameters. A guide to the interpretation of these figures is provided in Section 5.6 with more detail on these guidelines provided in Section 5.4.

5.3.3 Impact/reference sites: Longitudinal patterns over time

A number of rivers in the region are sampled at two or more locations. This consists of an upstream 'reference site' and downstream site impacted to a greater extent by one or more anthropogenic pressures. Only data for the most frequently sampled variables (i.e., DO%, temperature, turbidity, *E. coli*, NH_4-N, pH and conductivity) was presented in these figures. Data presented are annual median values. Data are presented for five rivers, which were those showing the greatest longitudinal changes in overall water quality rank.

5.3.4 Contact recreation

Contact Recreation suitability is currently based on faecal indicator bacterial information collected at a range of sites located between Hokitika and Westport that include marine, estuarine and fresh waters. Results from all samples collected in a year were combined and analysed according to a) single sample guidelines for bathing suitability, and b) a seasonal (annual) regional median compared to *E. coli* and Enterrococci guidelines for annual single site medians. While the latter guideline's intended purpose is for use with single sites, it still provides a useful reference point for our regional seasonal medians. The sampling season runs from the beginning of November through to the end of March. For most sites, monitoring began in the summer of 1999 – 2000, except for the Lake Kaniere @ Sunny Bight and Orowaiti Creek @ Excelsior Rd sites, where monitoring began more recently in the summer of 2001 – 2002. Two other exceptions are Blaketown Beach @ South Tiphead and Blaketown Lagoon @ Slipway Beach, which were initiated in the summer of 1998 – 1999.

5.3.5 Trend analysis

All trend analyses in this report were done using the trend analysis software package (Time Trends) developed by NIWA (Ian Jowett) using Envirolink funding.

Monthly water quality data from five NIWA National River Water Quality Network (NRWQN) sites in the West Coast region were analysed for trends in individual parameters using Seasonal Kendall tests on raw and flow-adjusted data. Flow adjustment was carried out using LOWESS smoothing (30% span). The Sen Slope Estimator (SSE) was used to represent the magnitude and direction of trends in data. Values of the SSE were relativised by dividing through by the raw data median (RSSE), allowing for direct comparison between sites.

The first step in producing summary figures for WCRC SWQMP sites was to compute annual median values at each site for all variables with sufficient length of record. Summary figures were then compiled with values from each site (i.e., annual median) used as the replicate data to calculate 25th, 50th (median) and 75th percentile values for the region in each year. This is similar to the approach taken by Scarsbrook (2006) in national SoE reporting.

Seasonal Kendall tests for trends were carried out on data from WCRC sites for the period 1998-2007. Sites needed to have greater than 40 sampling occasions (i.e., potentially quarterly samples over 10 years).

5.3.6 Lake Brunner catchment

As previously stated, all Seasonal Kendall trend analyses in this report were done using the trend analysis software package (Time Trends) developed by NIWA (Ian Jowett) using Envirolink funding. It was determined that a bi-monthly step was the most appropriate form of seasonal grouping for central lake data analysed using Time Trends. Other methods relevant to Section 4 are detailed in Rutherford *et al.* (2008), and Spigel (2008).

Insufficient data was available at the time this report was compiled to analyse tributary data using Seasonal Kendall trend analyses, but all data for the three main lake tributaries, where they enter the lake, has been provided in graphical form. A ten sample moving average trend line has been fitted to these figures.

5.4 Physical and chemical parameters

5.4.1 pH

At a given temperature, the intensity of the acidic or basic character of a solution is indicated by the pH or hydrogen ion activity (APHA 1992). Most natural waters fall within the pH range of 6.5 to 8.0 (ANZECC 2000), and in the absence of contaminants, most waters maintain a pH value that varies only a few tenths of a pH unit. Recommended trigger limits for pH of New Zealand upland and lowland rivers are in the pH range of 7.2 to 8.0. A more appropriate means of setting pH limits involves using the 20th and 80th percentiles, calculated from seasonal medians in a reference site (ANZECC 2000). It is recommended that changes of more than 0.5 units from the natural seasonal maximum and minimum be investigated (ANZECC 1992). However, there are many streams and rivers on the West Coast that have naturally low pH (as low as pH 4), which may originate from humic acids or come from young sedimentary geologies with a pyrite component.

Some plants and animals are adapted to naturally lower pH (refer Collier et al. 1990). The key difference between streams with naturally low pH and those that are such as a result of acid rock drainage are the nature of compounds causing the acidity and the typically higher concentrations of metals found in the latter. The toxicity alone of these metals may prove detrimental to a streams ecological health and be exacerbated further when combined with low pH, but evidence of increased toxicity is not conclusive from New Zealand studies. As well as toxicity, high concentrations of metal can give rise to precipitates that negatively effect macroinvertebrate habitat and food quality, and subsequently, food webs.

Overall, it seems clear that invertebrate diversity is negatively impacted by pH and elevated metal concentrations below pH 4.5. We have chosen a minimum level of pH 5.5, based on studies of West Coast streams (e.g. Collier et al. 1990; Rowe 1991), as a general criterion for measuring exceedences in section 3.2, applicable to sites with anthropogenic acid generation, as a buffer to allow for more sensitive taxa and potential chronic effects of metal toxicity on certain species. It also considers that while many West Coast streams have lower pH, many others are within the range specified by ANZECC (2000) guidelines. Higher than 'average' pH can occur where a catchment contains limestone geology, although not common, parts of the West Coast have elevated pH for this reason. These higher pH's are not toxic, although higher pH will increase the ratio of toxic un-ionised to ionised ammonium ions. Two pH ranges are used as a reference in this report: 6.5 – 8.0 (ANZECC 2000), and 5.0 – 9.0 (CCREM 1987).

Daily pH levels can be influenced by photosynthesis and respiration, particularly where plant and algae are abundant. A small amount of CO_2 in water is hydrated to form carbonic acid. This can lead to a lowering of the pH in waters that have low buffering capacity. Therefore, when ample light is present and photosynthesis is consuming large amounts of CO_2, the pH can increase. This obviously coincides with an increase in dissolved oxygen, often to supersaturated levels, i.e. >100%. In the same plant-filled streams, during early morning when it is still dark, plant respiration has consumed much of the dissolved oxygen, creating an abundance of CO_2 and lower pH relative to mid-day levels.

5.4.2 Temperature

Temperature is fundamental to the rate of biological and chemical processes in a water body. For many micro-organisms, metabolism doubles with each rise of 10 °C, but tolerance of temperature extremes for different species is generally quite specific.

Aquatic biota are strongly influenced by water temperature in terms of their growth, reproduction, and survival. The biota of Westland streams and rivers contain elements that are valued for their recreational opportunities (brown trout, whitebait) and national endemism (various native fish). Increased water temperatures may affect these taxa directly, for example via oxygen removal, and indirectly via aquatic food chains. The key components of river ecosystems (algae, plant, macroinvertebrates and fish) are all affected by temperature. Introduced sport fish (trout and salmon species) are very susceptible to high temperatures and their success in New Zealand has largely been attributed to cool summer water temperatures, and winter temperatures generally high enough to allow for some food (i.e. invertebrate prey) production (Viner 1987).

As temperature varies widely both spatially and temporally in aquatic systems, it is difficult to assign low risk trigger values for temperature. It is, however, recommended that temperatures should not be varied beyond the 20^{th} and 80^{th} percentiles of natural ecosystem temperature distribution (ANZECC 2000).

Algae and plant growth in New Zealand rivers are most strongly affected by a combination of nutrient supply and disturbance regime, however temperature has also been identified as an important factor in determining periphyton biomass and community structure. Higher temperatures favour high biomass accrual and the dominance of erect, stalked and filamentous algae (often synonymous with nuisance algal growths). Such effects are also strongly influenced by disturbance (i.e., floods), with low disturbance favouring increased biomass of algae and plants.

In general, algae and plants are much more resilient to high temperatures than invertebrates and some elements of the algal community exhibit high growth rates at temperatures as high as 45 °C. Lethal temperatures for algae and plants are likely to be much higher than would occur in lowland rivers. The effects of increases in water temperature on algae and plant growth are likely to be predominantly positive, presuming that nutrients are not limiting and the system is not subject to major disturbance. Therefore, no standards are recommended for protecting plants and algae.

There is relatively detailed information available on the effects of water temperature on aquatic macroinvertebrates. Water temperature can affect abundance, growth, metabolism, reproduction, and activity levels of aquatic insects. A detailed analysis of 88 New Zealand rivers (Quinn and Hickey 1990) identified water temperature as one of the important variables affecting species distribution. Stoneflies (Plecoptera) were largely confined to rivers between 13 and 19 °C, and mayflies (Ephemeroptera) were less common in rivers with maximum temperatures of > 21.5 °C (Quinn and Hickey 1990).

Laboratory studies of the effects of water temperature on invertebrate taxa have also identified mayflies (Ephemeroptera) and especially stoneflies (Plecoptera) as being particularly sensitive to high water temperatures. The common mayfly (*Deleatidium* spp.) is a common invertebrate species in many West Coast Rivers with a LT_{50} (the temperature at which 50 % of individuals will die) of 22.6 °C. There is the potential at high temperatures for *Deleatidium* to be replaced by the grazing snail *Potamopyrgus antipodarum*, which has a much higher LT_{50} (31.0 °C). Potamopyrgus can be considered a less desirable taxa, as it is a less attractive prey item for trout and native fish. Some recent research has suggested that *Deleatidium* may be able to survive short periods of high temperatures, providing they have experienced a summer acclimation period (Cox and Rutherford 2000).

Fish are often strongly affected by temperature, with effects of temperature on mortality, growth and reproductive behaviour all described from New Zealand or elsewhere. Some of these effects are direct, with water temperature affecting behaviour, egg maturation, growth and mortality. Other effects are subtler; increased water temperatures can increase rates of disease, reduce resistance to pollutants, and reduce competitive abilities. Approximate preferred temperatures of some main New Zealand fish groups, in degrees celsius, include: just above 25 for short fin eels and just below 25 for long fins; around 20 for many bully species; and below 20 for trout and galaxid species. Greater detail is provided in Richardson et al. (1994).

5.4.3 Biochemical oxygen demand and dissolved oxygen

In order to characterise the potential for a body of water to lose oxygen, Biochemical Oxygen Demand (BOD) is often measured. The BOD of water may be defined as the amount of oxygen required for aerobic microorganisms to oxidise organic matter to a stable inorganic form.

Unpolluted waters typically have BOD_5 (5 day biochemical oxygen demand) values of 2 mg/L or less, whereas receiving waters of waste may have values up to 10 mg/L or more, particularly near a point of a wastewater discharge. Raw sewage has a BOD_5 of about 600 mg/L, whereas treated sewage effluents have BOD_5 values ranging from 20 to 100 mg/L depending on the level of treatment applied.

Aquatic heterotrophic bacteria and fungi (the main components of undesirable feathery, cotton-wool-like growths commonly referred to as "sewage fungus") grow in response to readily degradable organic compounds, such as short-chain organic acids, sugars, and alcohol, which are sometimes found in wastewater discharges (e.g., dairy shed, piggery, meat works, and cheese factory effluents). In doing so, they consume oxygen from the water and can detract from the aesthetic appeal of a water. Sewage fungus should not be visible to the naked eye as obvious plumes or mats. The MfE (1992) guideline suggests BOD_5 of <5 mg/L to avoid growth of nuisance bacterial slime.

An adequate supply of dissolved oxygen (DO) is essential to the metabolism of all aerobic organisms and for the maintenance of purification processes in aquatic systems. DO levels are most often reduced in aquatic ecosystems directly by the addition of organic material and indirectly through the addition of plant nutrients (ANZECC 2000).

The total amount of oxygen that can be dissolved in a water body is dependent upon temperature and salinity. By measuring the DO content, the effects of oxidisable wastes (e.g., human and animal faeces, dead algae) on receiving waters may be assessed. DO levels also indicate the capacity of a natural body of water for maintaining aquatic life. The DO depletion in nutrient enriched waters may be offset during the day by algal photosynthesis. As photosynthesis requires light, a high DO concentration may build up during the day but depletion will occur during the night due to respiration of the aquatic plants.

Low concentrations of dissolved oxygen adversely affect the functioning and survival of biological communities and below 2 mg/L may lead to the death of most fish.

Water quality criteria for dissolved oxygen generally state that DO concentrations should not be permitted to fall below 80% saturation for water quality classes AE (aquatic ecosystems), F (fisheries), FS (fish spawning), and SG (gathering or cultivation of shellfish for human consumption), as specified in the Third Schedule of the RMA 1991. The West Coast Water Management Plan classifies all freshwater bodies as AE (Aquatic Ecosystem) except those identified for bathing. ANZECC (1992) guidelines suggest a DO threshold of >6.5 mg/L, or a reduction to no more than 80% saturation.

5.4.4 Suspended sediment, turbidity & clarity

Sediments suspended in the water column are often referred to as suspended solids. "Turbidity" is an optical property of water where suspended and some dissolved materials cause light to be scattered and absorbed rather than be transmitted in straight lines. Clarity refers to the "transparency" of water.

Turbidity and suspended solid sampling have been used traditionally as methods for determining the degree of impact and sediment loading in waters. Assessing 'visual water clarity', measured using either 'Secchi' (for vertical water clarity) or 'black' disks (for horizontal water clarity) is recommended for determining the visual and ecological effects of turbidity (MfE 1994). The greater the viewing distance, the greater the water clarity. For most rivers, concentration of suspended solids is positively correlated with turbidity, and both suspended solids and turbidity are inversely correlated with visual clarity. In other words, as the visual clarity decreases, suspended solid concentration and associated turbidity increase.

In rivers, excessive concentrations of suspended sediment can affect chemical and physical water characteristics, plants, algae, invertebrates, and fish, as well as human aesthetic, recreational, and spiritual values, as described below. Sediment influxes can physically alter rivers and lakes by creating excessive turbidity and changing the nature of the bed. Coarser graded particles fill in the interstices between stones and cobbles, while finer graded particles smother or "blanket" the bed.

Sediment-laden water affects benthic macroinvertebrates by five primary mechanisms. These are:

- reduction of light penetration;
- abrasion;
- absorbed toxicants;
- changes in substrate character; and
- reduction in food quality.

Increased water turbidity, caused by suspended sediments, can affect benthic algae and macrophyte growth by reducing light penetration through the water column. This can reduce the "euphotic depth" of water (the depth at which irradiance, the penetration of diffuse light from the sun into water, is reduced to 1 % of the surface value, a point below which most aquatic plants can not grow for the lack of light). Altering the natural euphotic depth of a river or lake can result in a shift in plant and algal communities that in turn, can affect the composition of the benthic invertebrate and fish communities. As well as reducing algal growth by reducing light penetration, fine sediments can smother algae and plants when they settle out.

Reduction of light penetration reduces periphyton production, which may result in a limiting food supply for the invertebrates (as stated above). Abrasion can act directly on benthic invertebrates by physical contact and, indirectly, by abrading periphyton.

Elevated levels of sediment in rivers and lakes affect fish, both directly and indirectly. Direct effects usually occur when concentrations of suspended solids are high. These include avoidance of turbid water by some fish, lower growth rates, impairment of growth in fish that use vision during feeding, and clogging of gills resulting in death. Indirect effects include reduction in the invertebrate food source (by mechanisms discussed above), avoidance by adult fish of silted gravels for spawning, and high egg mortality due to reduced oxygen levels in gravel fouled by silt deposition.

Turbidity, caused by suspended solids affecting the colour and clarity of water, may also have special significance to humans. Under New Zealand law, discharges of contaminants to water are not supposed to cause conspicuous changes in water colour and clarity (Resource Management Act 1991, Section 70). Most people accept that the visual clarity of running water decreases as the flow increases (Davis-Colley 1990). However, increases in turbidity that occur during low or normal flows are generally regarded as unacceptable.

As discussed above, decreased water quality, due to increased concentrations of suspended solids, can affect freshwater aquatic organisms and human values in a number of ways. In order to protect these attributes, guidelines have been developed by the Ministry for the Environment (MfE 1994). These numerical guidelines were developed to aid the interpretation of the narrative guideline found within the RMA (1991) that implies that discharges should not cause conspicuous changes in colour or clarity (Section 107). MfE guidelines of relevance to water clarity are:

Visual clarity change

For Class A waters where visual clarity is an important characteristic of the water body, the visual clarity should not be changed by more than 20 % (visual clarity is measured with a black disk). For more general waters the visual clarity should not be changed by more than 33 % to 50 % depending on the site conditions.

Significant adverse effects on aquatic life

The protection of visual clarity (as recommended above) will usually also protect aquatic life. Settlement of solids onto the beds of water bodies should be minimised, but guidelines for this have not been recommended. For lowland New Zealand Rivers ANZECC (2000) recommends clarity trigger levels of 0.8 m, and turbidity levels of 5.6 NTU.

Water managed for contact recreation.

Visual clarity affects bather preferences. Potential hazards should be visible in bathing waters and thus it is recommended that in such waters the horizontal sighting range of a 200 mm black disk should exceed 1.6 m (MfE 1994). Smith et al. (1991) recommend that total suspended solids should not exceed 4 mg/L, and turbidity should not exceed 2 NTU, and should be applied to base flow samples only. This also applies to the ANZECC (2000) default trigger value for lowland river water clarity of 0.8 m, which is referenced from unmodified or slightly disturbed ecosystems. Some WCRC samples were collected during periods when flows may have been insufficiently low for effective use of these latter guidelines i.e. higher flows normally correspond with increased mobilisation of suspended sediment and a subsequent decrease in visual clarity.

5.4.5 Conductivity

The concentration of dissolved solids in solution is generally determined by salinity or conductivity measurements. Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence, and relative concentrations, and on the temperature during measurement (APHA 1992).

Anions (including bicarbonates, carbonates, chlorides, sulphates, phosphates, and often nitrates) occur in combination with such metallic cations as calcium, sodium, potassium, magnesium, and iron, to form ionisable salts. Because of the high availability and solubility of carbon dioxide, carbonates are usually the most abundant salts in fresh water.

Total dissolved solids (in mg/l) may be obtained by multiplying the conductance (in m*S*/m) by a factor, which is commonly between 0.55 and 0.75. The lower these measurement are, the more pure the water.

Certain dissolved mineral salts serve as nutrients for plants, while other salts may limit metabolism through osmotic effects. The conductivity of a liquid increases in relation to the concentration of dissolved ionised substances and, therefore, provides an indirect measure of the concentration of dissolved salts in a water sample. Conductivity monitoring is often used as a surrogate measure of nutrient enrichment in rivers.

Conductivity can be greatly affected by geology with streams in limestone catchments often having conductivities > 300 µ*S*/cm. There are no guidelines for conductivity levels in water (ANZECC 2000) but it is suggested that guidelines for south-eastern Australian coastal rivers may be applicable where geology is not a significant factor (i.e. 125-300 µ*S*/cm).

5.4.6 Plant nutrients: nitrogen and phosphorus

Nutrient monitoring in relation to nuisance aquatic plant and algal growths usually focuses on nitrogen and phosphorus. Dissolved inorganic nutrient concentrations are most relevant for predicting periphyton and macrophyte biomass in flowing waters. However, total nutrient concentrations are also relevant in rivers because particulate material can settle out in calm areas and become biologically available to plants via mineralisation (MfE 1992).

Aquatic plant and algal growths are important in rivers and streams as they provide food for both invertebrate and vertebrate life forms that live in, or are associated with, the water. However, if algal growth becomes excessive, due to an oversupply of nutrients (particularly nitrogen and phosphorus), the quality of the river or lake ecosystem deteriorates.

In most catchments where human impacts have been minimised, phosphorus and sometimes nitrogen are generally in short supply. As human activities intensify, the supply of both elements increases, leading to over-enrichment with the associated threat of eutrophication. The severity of eutrophication in a water body is also strongly controlled by the flushing rate. Rapidly flushed areas can tolerate higher levels of nutrient inflows than stagnant areas. Careful monitoring of phosphorus and nitrogen levels, along with flushing rates will, therefore, give a good indication of the susceptibility to eutrophication of a particular water body.

For New Zealand lowland rivers the trigger value for total nitrogen (TN) is 0.614 mg/L, and for total phosphorus (TP) 0.033 mg/L (ANZECC 2000).

In some circumstances it may be more useful to consider dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP), as these are the forms that are readily assimilated by living organisms. DIN is made up of a combination of soluble oxides of nitrogen (nitrites/nitrates (NO_x) and ammoniacal nitrogen (NH_x-N). Trigger values for NO_x are 0.444 mg/L, and 0.010 mg/L for DRP (ANZECC 2000). The upper limit for DIN (MfE 1992) is 0.10 mg/L.

5.4.7 Ammoniacal nitrogen, ammonia, and ammonium

Ammonia is a common constituent of aquatic environments. It is present both as a natural breakdown product of nitrogenous organic matter and as a contaminant from wastewater discharges and run-off.

Ammoniacal nitrogen is the combination of ammonium ions (or ionised ammonia) (NH_4^+), and [un-ionised] ammonia (NH_3). The prevalence of these two forms is dependent on the pH, temperature, and salinity of the water. Concentrations are usually expressed either as total ammonia (or ammoniacal nitrogen, the sum of NH_3 and NH_4^+), or as concentration of the un-ionised NH_3 only. NH_3 is the main poisonous component for aquatic organisms, so when ammoniacal nitrogen is quoted, the pH and temperature are also relevant in determining toxicity (Figure 5.4.1).

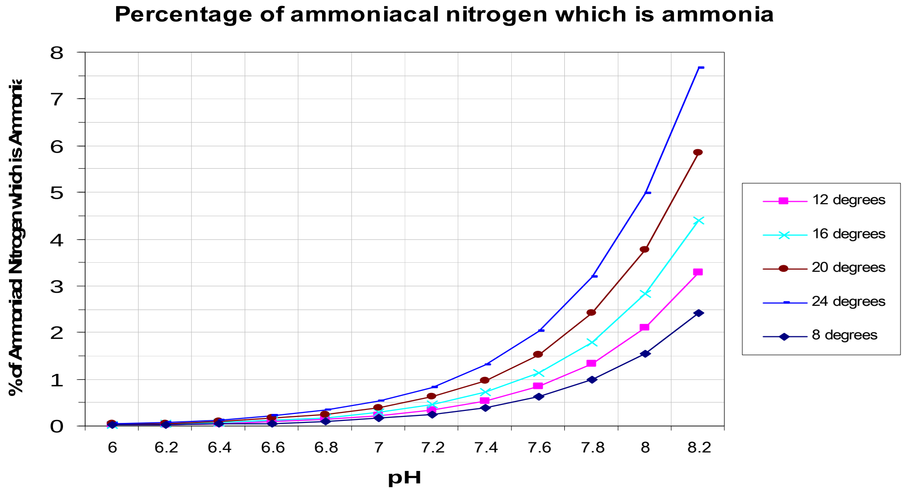


Figure 5.4.1 Percentage of ammoniacal nitrogen which is ammonia depending on the water pH and temperature.

Most of the trigger values for toxicants in the 2000 ANZECC guidelines have been derived using data from single-species toxicity tests on a range of test species, because these formed the bulk of the concentration–response information. 'High reliability' trigger values were calculated from chronic 'no observable effect concentration' (NOEC) data. However the majority of trigger values were 'moderate reliability' trigger values, derived from short-term acute toxicity data (from tests ≤ 96 hour duration) by applying acute-to-chronic conversion factors.

An ammoniacal nitrogen value of 0.9 mg/L (at pH 8, 20 ℃), has been suggested as a high reliability (95%) trigger value for freshwater (ANZECC 2000). This trigger value varies with pH and temperature (refer Table 5.4.1). It is rare for waterways on the West Coast to go above pH 8.5, although it has occurred occasionally at a few sites (Figure 5.7.12). Based on an upper limit of pH 8.5, an ammoniacal nitrogen guideline of 0.4 mg/L has been selected as a benchmark for analysis in this report (Table 5.4.1).

Table 5.4.1 2000 ANZECC freshwater trigger values for ammoniacal nitrogen at different pH (temperature not taken into account).

pH	Freshwater trigger value (mg/L ammoniacal nitrogen-N)	pH	Freshwater trigger value (mg/L ammoniacal nitrogen-N)
6.5	2.46	7.8	1.18
6.6	2.43	7.9	1.03
6.7	2.38	8.0	0.90
6.8	2.33	8.1	0.78
6.9	2.26	8.2	0.66
7.0	2.18	8.3	0.56
7.1	2.09	8.4	0.48
7.2	1.99	8.5	0.40
7.3	1.88	8.6	0.34
7.4	1.75	8.7	0.29
7.5	1.61	8.8	0.24
7.6	1.47	8.9	0.21
7.7	1.32	9.0	0.18

5.4.8 Faecal microbiological indicators

Microbiological criteria are important because humans (particularly children) can contact various diseases from microbes in water: from drinking it, swimming in it, or eating shellfish harvested from it. The categories of microbes that can cause disease (pathogens) are well documented (e.g. McNeill 1985). Examples of water-borne diseases include: salmonella, gastroenteritis, hepatitis, and giardia.

To contain the risk of contracting such water-borne diseases various criteria have been derived from studies in which the density of suitable "indicator" organisms is correlated with disease risk. An acceptable value of this risk is then selected. Unfortunately, the relationship of the disease risk to the density of the "indicator" organisms is not clear.

Numerical standards are applied to New Zealand waters to protect them for recreational water use and for the gathering of shellfish for consumption. Typically, faecal coliforms and Enterococci are the groups of bacteria used as indicators of public health concern.

The main water quality parameters used for monitoring WCRC sites are faecal coliforms/*Escherichia coli* and Enterococci. The later is used only at sites that have tidal influence or are located in marine waters. *E. coli* and Enterococci seasonal medians were plotted for all WCRC contact recreation sites (Section 5.9). Individual values have been plotted for *E. coli* with values separated by the following criteria: circle = acceptable (< 260 *E. coli*/100 ml), triangle = alert (260 – 550 *E. coli* 100 ml), and square = action (> 550 *E. coli* 100ml) values in accordance with MfE (2003) contact recreation guidelines for individual values. For medians, the Department of Health (1992) guidelines for contact recreation waters recommend a season median of 126 E.coli/100 ml, with ANZECC (2000) stipulating a median of 150 faecal coliform cfu/100 ml and 35 Enterococci/100 ml as a safe limit.

The older MfE (1999) secondary contact guideline was used as a benchmark for comparing faecal coliforms among SOE monitoring sites (1000 cfu/100 ml median from a minimum of five samples taken at regular intervals not exceeding one month has been use). This was easier to apply to the SOE monitoring site data than the 2003 MfE contact recreation guidelines, and was the same figure as that used for 1999 ANZECC stock drinking water quality guidelines also applied here. The ANZECC 1992 guidelines specify for stock drinking a faecal coliform limit of 1000 cfu/100 ml, where as the limit for stock drinking in the ANZECC 2000 guidelines is 100 cfu/100 ml.

Guidelines for shellfish gathering recommend that the mean faecal coliform content shall not exceed 14 cfu/100 ml and not more than 10 % should exceed 43 cfu/100 ml (MfE 2003).

5.4.9 Sulphate

Sulphate is found in most natural waters as a result of the dissolution of sulphate-bearing minerals in soils and rocks. Mine wastewaters, tannery wastes and other industrial discharges often contain high concentrations of sulphate. Under anoxic conditions bacteria in water can reduce sulphate to sulfide, which results in the release of hydrogen sulfide, causing an unpleasant taste and odour and increasing the potential for corrosion of pipes and fittings.

Sulphate is used as an indicator by the WCRC to monitor the effects of mining, current and historic, on water chemistry. The main environmental implications associated with sulphate are for consumption by stock and humans. Sulphate is an essential element for animal nutrition. It is not a highly toxic substance, but excessive concentrations of sulphate in water typically cause diarrhoea, especially if a change from low to high sulphate water occurs quickly. Animals generally avoid water containing high sulphate concentrations in favour of water containing lower concentrations. No adverse effects to stock are expected if the concentration of sulphate in drinking water does not exceed 1000 mg/L. Adverse effects may occur at sulphate concentrations between 1000 and 2000 mg/L, especially in young or lactating animals or in dry, hot weather when water intake is high. These effects may be temporary and may cease once stock become accustomed to the water. Levels of sulphate greater than 2000 mg/L may cause chronic or acute health problems in stock. The USEPA recommended maximum guideline for sulphate as a secondary contaminant in human drinking water is currently 250 mg/L, based on aesthetic effects (i.e., taste and odour).

5.4.10 Periphyton

Periphyton is the slime coating stones, wood, weeds or any other stable surface in streams and rivers. The community is composed predominantly of algae, cyanobacteria (formerly "blue-green algae") and diatoms (Biggs 2000). Periphyton occurs in a variety of thicknesses and forms depending on conditions.

Periphyton is the “foodstuff” of aquatic grazing animals, mainly macroinvertebrates, which are, in turn, fed upon by fish. Without periphyton many waterways would be barren of life. Periphyton also plays a role in the maintenance of water quality, the community removing nitrogen, phosphorous and unwanted organic contaminants (Biggs 2000). During periods of low flows and high nutrient levels, however, periphyton communities may proliferate to the extent that aesthetics, biodiversity and other in stream parameters are compromised.

Periphyton is assessed by the WCRC once during autumn and once during spring using an approach similar to the Rapid Assessment Method 2 (RAM 2) (Biggs & Kilroy 2000). Four transects across the stream are used, each with five points where a stone is selected and the percentage cover of each category of periphyton is visually estimated for each stone. Categories are differentiated by colour and thickness, and are likely to represent certain groups of periphyton. Categories have an assigned score, and the combination of these can be used to calculate an enrichment indicator. A *low* score indicates *high* periphyton abundance. The New Zealand periphyton guideline (Biggs 2000) suggests biomass limits of 60 % cover of >3 mm thick diatoms/cyanobacteria and 30 % cover of >2 cm filamentous algae, to maintain contact recreation and aesthetic values. The same standard of 30 % cover of >2 cm filamentous algae is also promoted to maintain trout habitat and angling values. When computed into a RAM2 enrichment score, these thresholds equate to a score of between four and six. For analysis in this report a threshold of five has been chosen. Thus, enrichment scores of five or less are deemed likely to indicate periphyton biomass beyond that recommended by the guideline.

5.4.11 Macroinvertebrates

Freshwater benthic macroinvertebrates are bottom-dwelling animals that have no backbone and are, simply speaking, large enough to be seen with the naked eye. In the case of macroinvertebrates collected by the WCRC for monitoring, they are of a size at least as large as 500 microns (0.5 mm) as this is the mesh size of the net used to collect them. Macroinvertebrates include insect larvae (e.g. caddisflies, mayflies, and stoneflies), aquatic worms (oligochaetes), aquatic snails, and crustaceans (e.g., amphipods, isopods and freshwater crayfish). Macroinvertebrates utilise a variety of food sources depending on the species.

Numbers of individual macroinvertebrate taxa collected in samples are enumerated according to categories (Table 5.4.2)

Table 5.4.2 Values used for conversion of ranked abundances to numeric abundances for macroinvertebrate data. Ranks based on Stark (1998).

Rank class	Abundance range	Value used
Rare (R)	1-5	1
Common (C)	5-19	5
Abundant (A)	20-99	20
Very abundant (VA)	100-499	100
Very very abundant (VVA)	> 500	500

Aquatic macroinvertebrates are good indicators of ecological change in freshwater environments. Changes in density (numbers) can indicate changes in productivity of algae (e.g. periphyton), which may suggest increased nutrient inflows. 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.

Taxonomic richness (number of different types of animals); Ephemeroptera, Plecoptera, Trichoptera (EPT) number and percentage (Lenat 1988); the Macroinvertebrate Community Index (MCI) (Stark 1985); and the Quantitative Macroinvertebrate Community Index (QMCI) (Stark 1993), are typical indices that are used to assess macroinvertebrate community health. The MCI uses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream, using the following formula:

$$\mathrm{MCI} = \left(\frac{\sum \text{of taxa scores}}{\text{Number of scoring taxa}} \right) \mathrm{X}\ 20$$

Taxa are scored between 1 and 10, with low scores indicating high tolerance to organic pollution and high scores indicating taxa that will only be found in "pristine rivers" (Stark 1985). A site score is obtained by summing the scores of individual taxa and dividing this total by the number of taxa present at the site, then multiplying by 20. Scores can range from 0 (no species present) to 200, with different scores indicating different pollution status (Table 3.3).

The QMCI (Stark 1993) uses the same approach as the MCI but weights each taxa score on the abundance of the taxa within the community. As for MCI, QMCI scores can be interpreted in the context of national guidelines (Table 3.2.1).

$$\mathrm{QMCI} = \sum \frac{\text{Taxa Score X No. present in that taxa}}{\text{Total No. present}}$$

Table 5.4.3 Interpretation of Macroinvertebrate Community Index values from stony riffles (after Boothroyd & Stark 2000).

Interpretation	**MCI**	**QMCI**
Clean water	>120	>6.00
Doubtful quality	100-119	5.00-5.99
Probable moderate pollution	80-99	4.00-4.99
Poor water quality	<80	<4

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). Consequently, a useful approach is to compare MCI and QMCI scores upstream and downstream of an impact. In such a situation the differences between scores for the index are much more important than the actual scores.

5.5 What is REC?

The River Environment Classification

Water quality patterns in the West Coast Region were investigated using the framework of the River Environment Classification (REC) (Snelder et al. 2003).

The REC characterises river environments at six hierarchical levels, each corresponding to a controlling environmental factor. The factors, in order from largest spatial scale to smallest, are climate, source-of-flow, geology, land cover, network position and valley landform. Each factor is associated with a suite of physical processes that influence water quality, and vary at approximately the same scale. For example, the climate level of the REC is associated with precipitation and thermal regimes that vary at scales of 10^3 – 10^4 km2. Each REC factor is composed of 4 – 8 categories that differentiate all New Zealand rivers. Categories at each classification level and their abbreviations [relevant to the West Coast] are shown in Table 5.5.1 The number of possible classes at any level is equal to the number of categories at that level multiplied by the number of classes at the preceding level. For example, the source of flow level has 24 possible classes (6 climate classes × 4 source-of-flow classes). At the geology level there are 144 possible classes, and 1152 at the land-cover level (from Larned et al. 2005).

Typical use of the REC involves grouping REC classes from each level e.g. climate/source-of-flow/geology/land-cover/network position/valley landform. However, WCRC sites were analysed mainly via individual controlling environmental factors because there was not in most cases sufficient replication for sites to be compared based on combined REC levels. Not all classes occurring in New Zealand are represented in the WCRC dataset, and those that are, are listed in Table 5.5.1. Map distributions of source of flow, geology, and land cover are shown in Figure 5.5.2 to 5.5.3

Table 5.5.1 REC classes found in the West Coast region. Classes are hierarchical starting at the top in the order of: climate/source-of-flow/geology/land-cover/network position/valley landform. Those in bold are represented in the WCRC SOE monitoring dataset.

Class	Definition
Climate:	
CX	Cool, extremely wet (mean annual temp. < 12, rainfall > 1000mm)
CW	Cool, wet (mean annual temp. < 12, rainfall > 500, < 1000 mm)
CD	Cool, dry (mean annual temp. < 12, rainfall < 500mm)
WW	Warm, wet (mean annual temp. > 12, rainfall > 500, < 1000 mm)
Source of flow:	
L	Low elevation (> 50 % of annual precipitation occurs < 400m ASL)
H	Hill (> 50 % of annual precipitation occurs between 400 and 1000m ASL)
M	Mountain (> 50 % of annual precipitation occurs > 1000m ASL)
Lk	Lake sourced
S	Spring
Gl	Glacial
Geology:	
Al	Alluvial and sand
HS	Hard sedimentary
SS	Soft sedimentary
Pl	Plutonic
St	Schist
M	Miscellaneous
Landcover	
IF	Indigenous forest
P	Pastoral
T	Tussock
S	Scrub
EF	Exotic forest
W	Wetland
U	Urban
Stream order:	
HO	High order (> 4)
MO	Mid order (3-4)
LO	Low Order (< 3)
Valley landform:	
HG	High gradient (slope > 0.04)
MG	Medium gradient (slope 0.02-0.04)
LG	Low gradient (slope < 0.02)

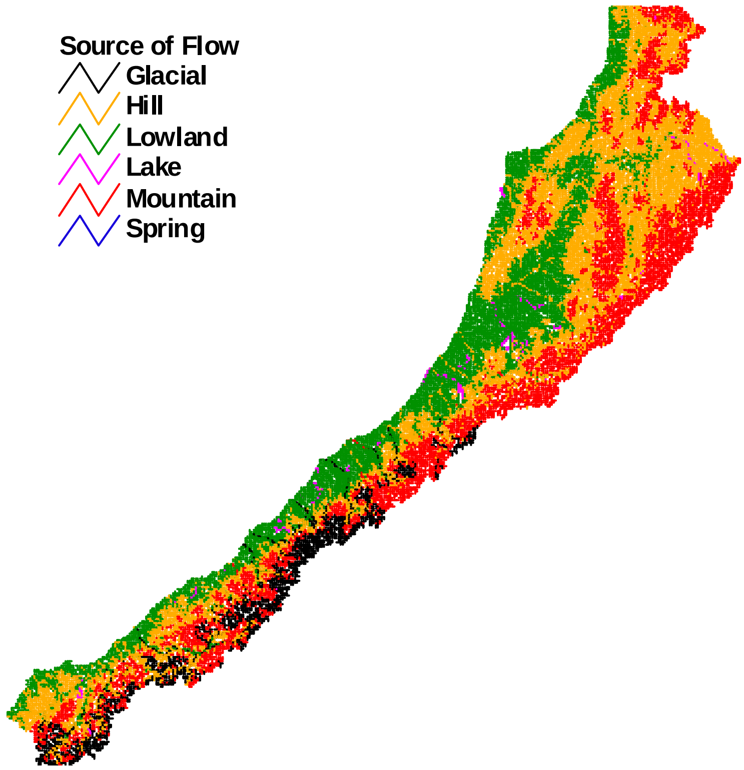


Figure 5.5.2. Map of the West Coast region showing source of flow according to REC.

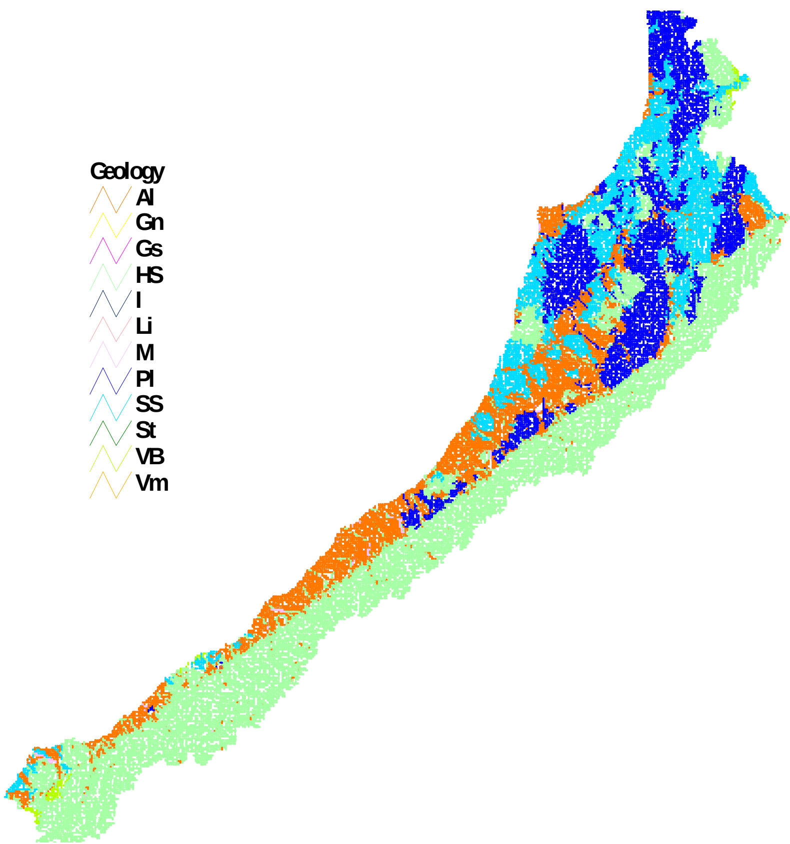
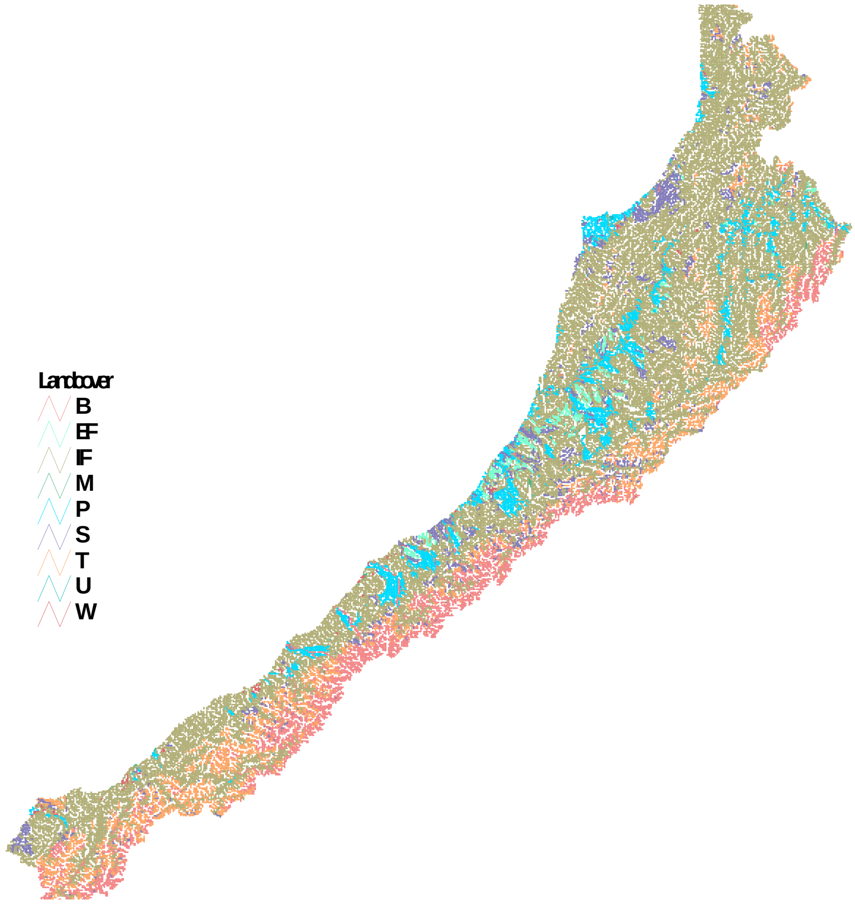


Figure 5.5.3 Map of the West Coast region showing geology class according to REC. From the key, only Al (alluvial), HS (hard sedimentary), M (metamorphic), Pl (plutonic), and SS (soft sedmentary), are present on the map.



Figures 5.5.4 Map of the West Coast region showing land cover type according to REC.

5.6 Percentage bar graphs: How they work

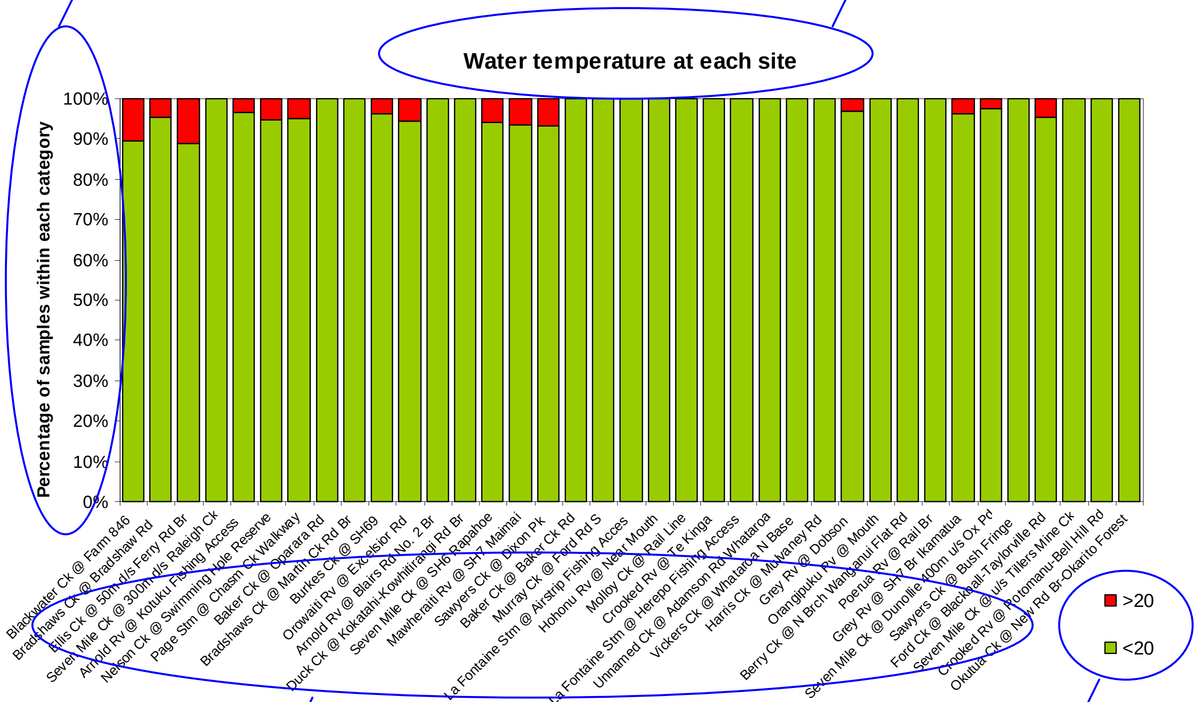
These are located in Section 2.4. Below is an example with some additional information to assist with their interpretation.

This indicates the percentage of samples that are within the categories indicated in the graph legend at the bottom right of each graph.

Note that the number of samples making up the 100% may differ between sites.

Lists the variable (in this case water temperature), and points out that a bar is presented for each site.

Note that all the available data for this site collected over time has been use for each site.

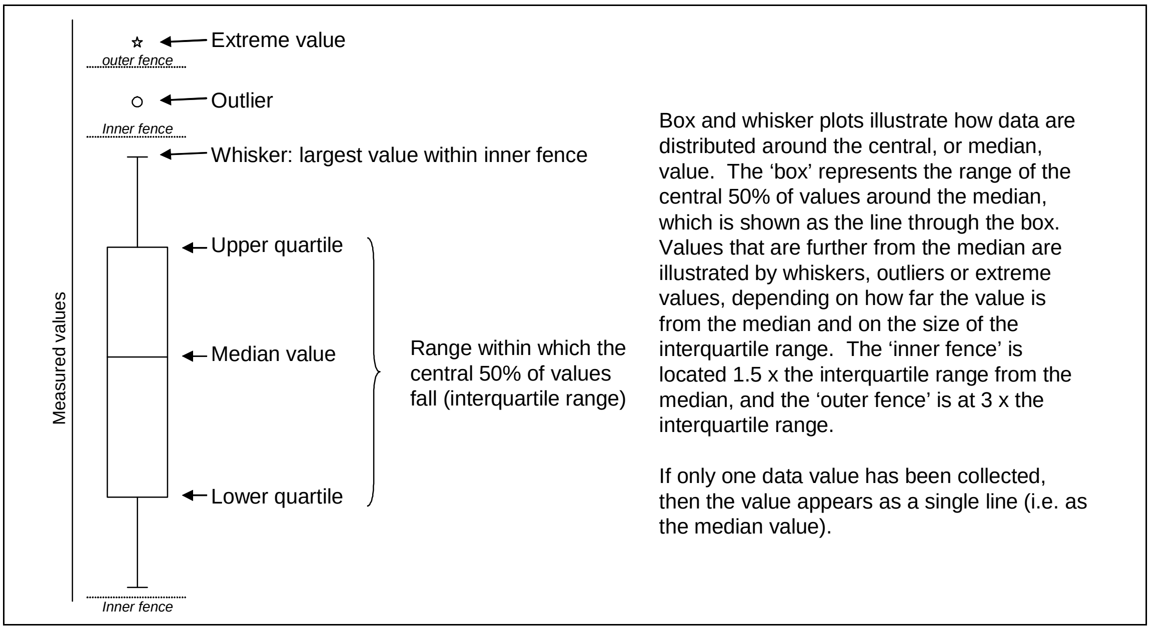


The bottom X axis lists what each bar represents. In this case it is each WCRC SWQMP site. All the data on record has been incorporated into each bar, and the amount of data might vary between sites. This is why a proportion has been used to standardise sites and make comparison easier. **Sites are ordered left to right based on lowest to highest site median for that parameter**.

The legend indicates what the categories are for that parameter, and what colour they are. Categories have been selected according to relevant guidelines for that parameter.

We know from this graph, representing temperature, that Blackwater Ck @ Farm 846 had the highest median temperature, and Okutua Stream @ Okarito Forest the lowest median temperature. At Blackwater Ck @ Farm 846, 10% of all samples taken there were above 20 °C, hence 90% of all samples collected there were below 20 °C. This temperature (20 °C) is a common threshold considered relevant for many fish species intolerant of higher temperatures. Note that it is possible for a site to have a higher occurrence of samples over 20 °C (e.g. Seven Mile Creek @ Rapahoe), but have a lower median temperature than its neighbour to the left that will always have a higher median (e.g. Duck Creek @ Kokatahi – Kowhitirangi Road).

5.7 Box and whisker plots - WCRC sites



Sites listed in the following box and whisker graphs are listed in alphabetical order so easier comparison can be made between multiple sites on the same water body.

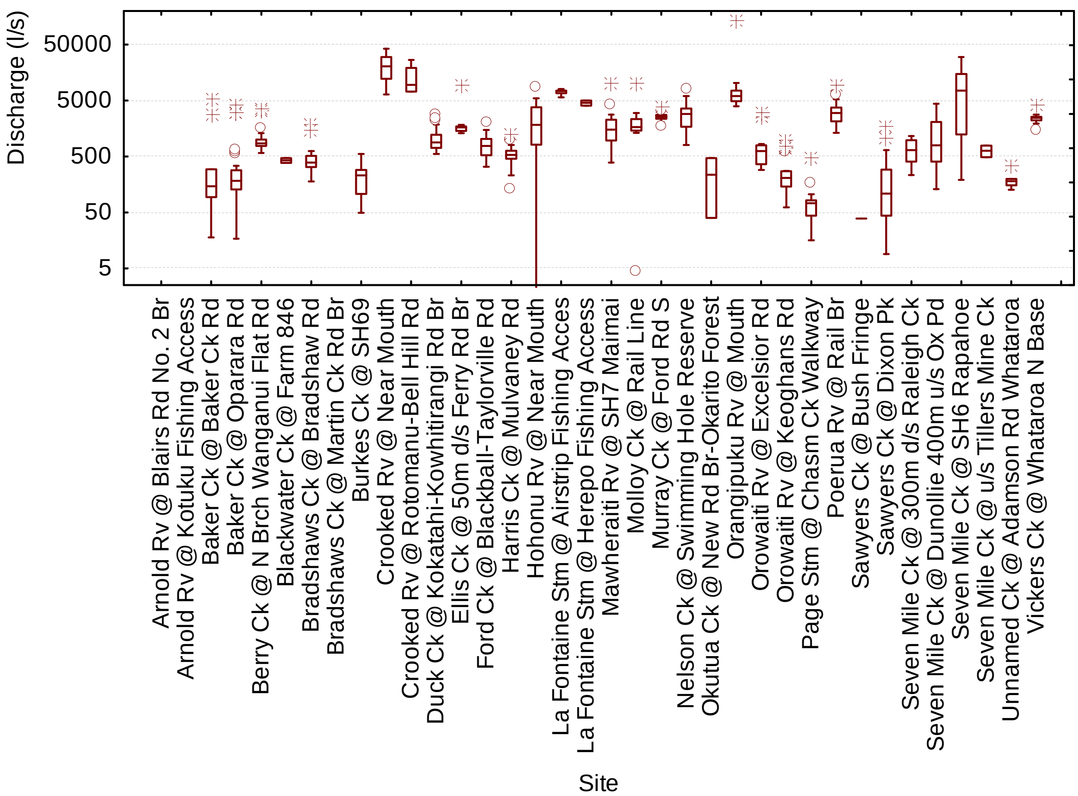


Figure 5.7.1 Box and whisker plot: Flow.

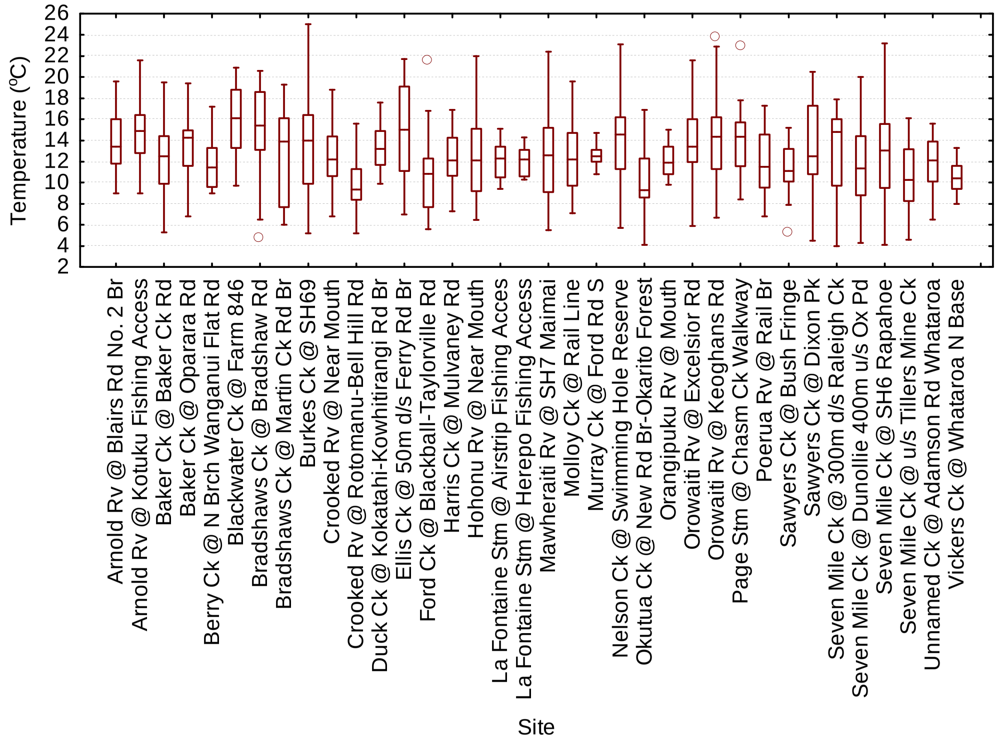


Figure 5.7.2 Box and whisker plot: Temperature.

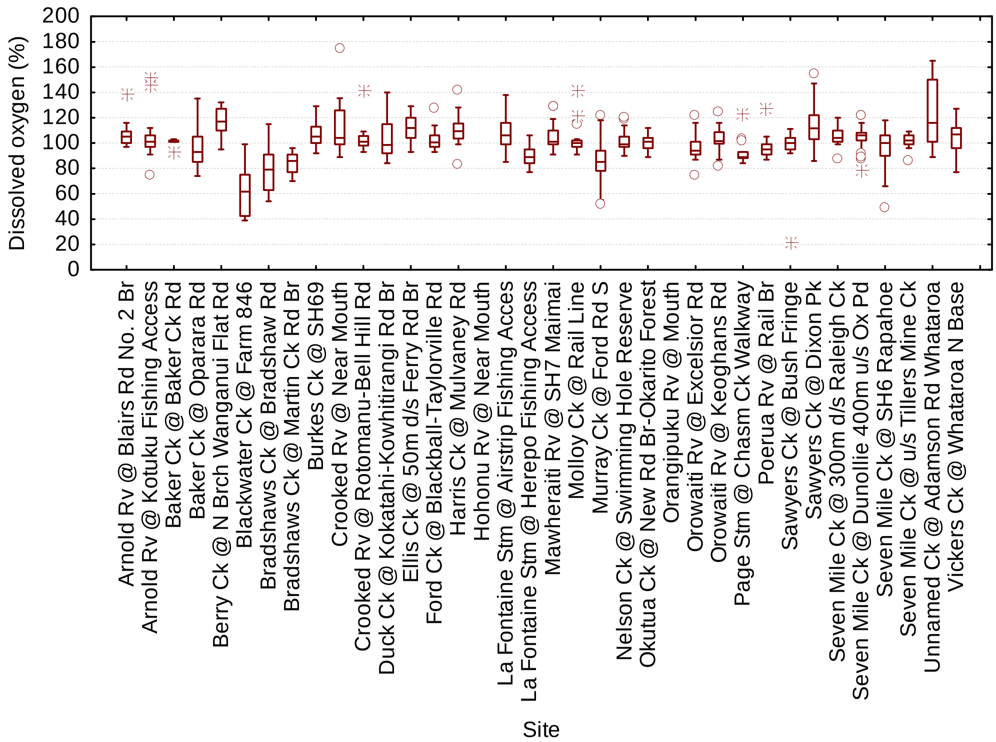


Figure 5.7.3 Box and whisker plot: Dissolved oxygen (% saturation).

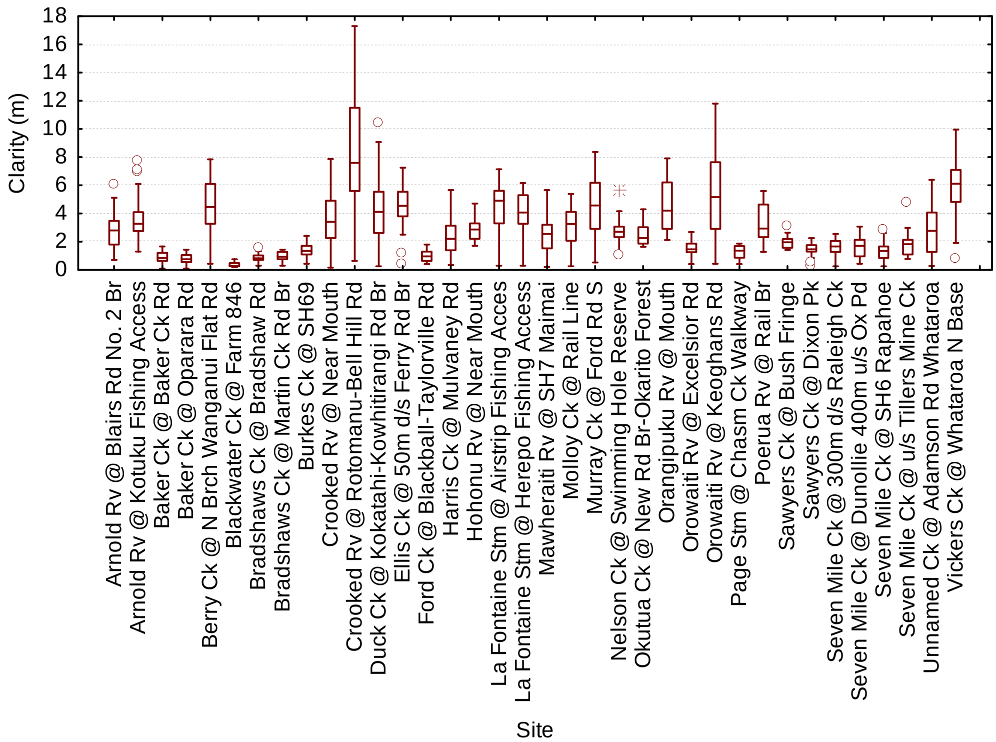


Figure 5.7.4 Box and whisker plot: Clarity.

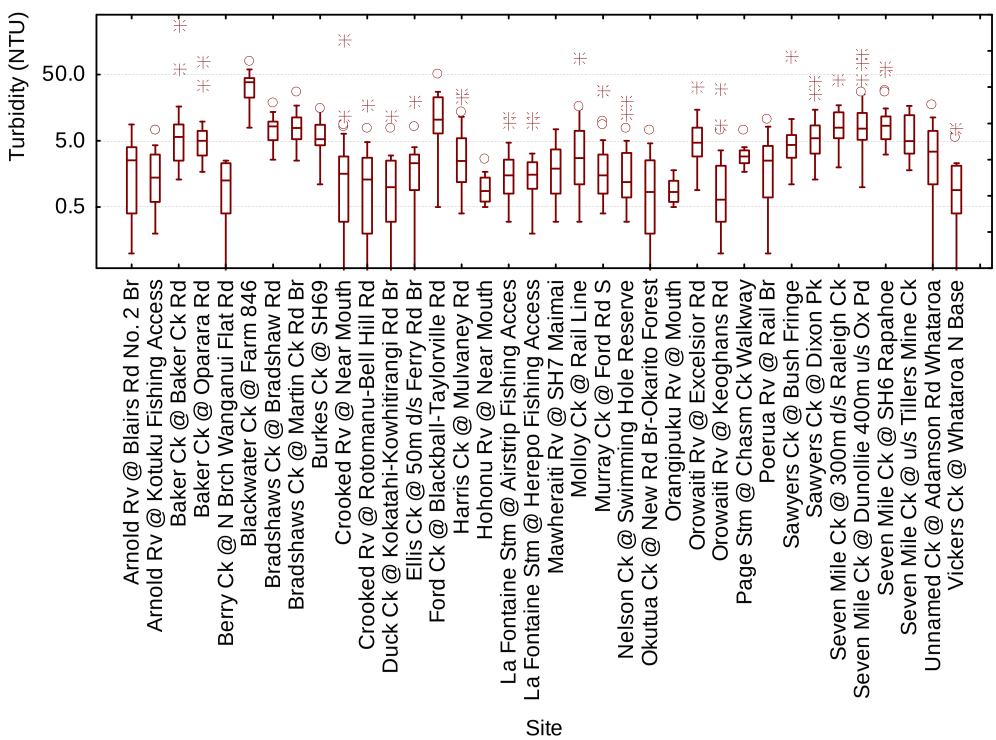


Figure 5.7.5 Box and whisker plot: Turbidity.

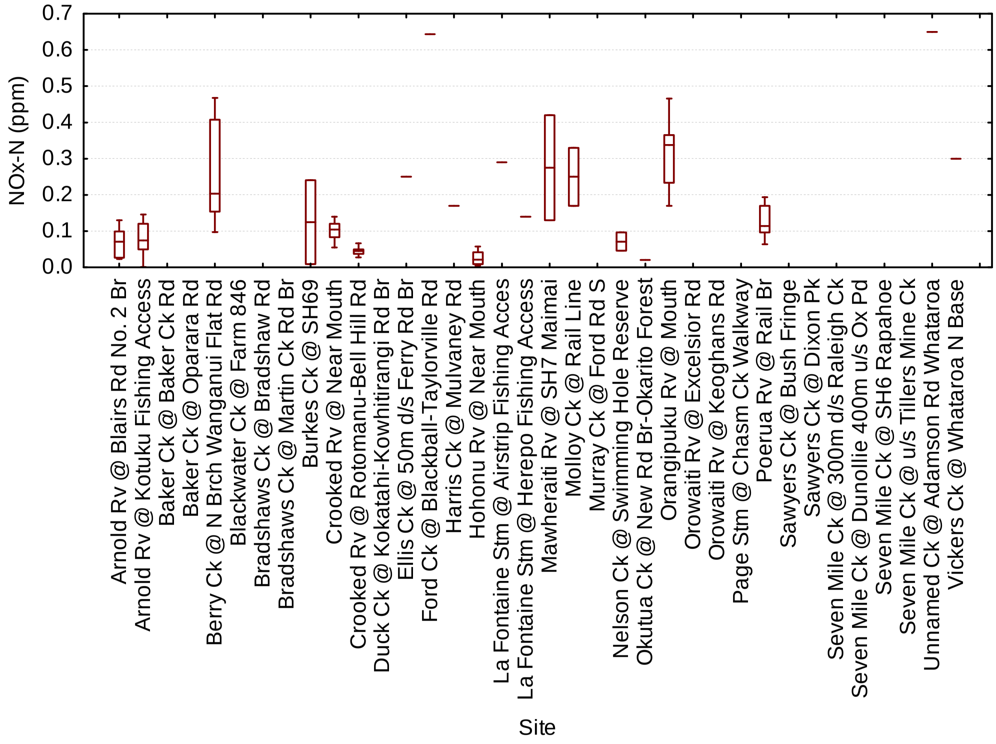


Figure 5.7.6 Box and whisker plot: Nitrate (NOx-N).

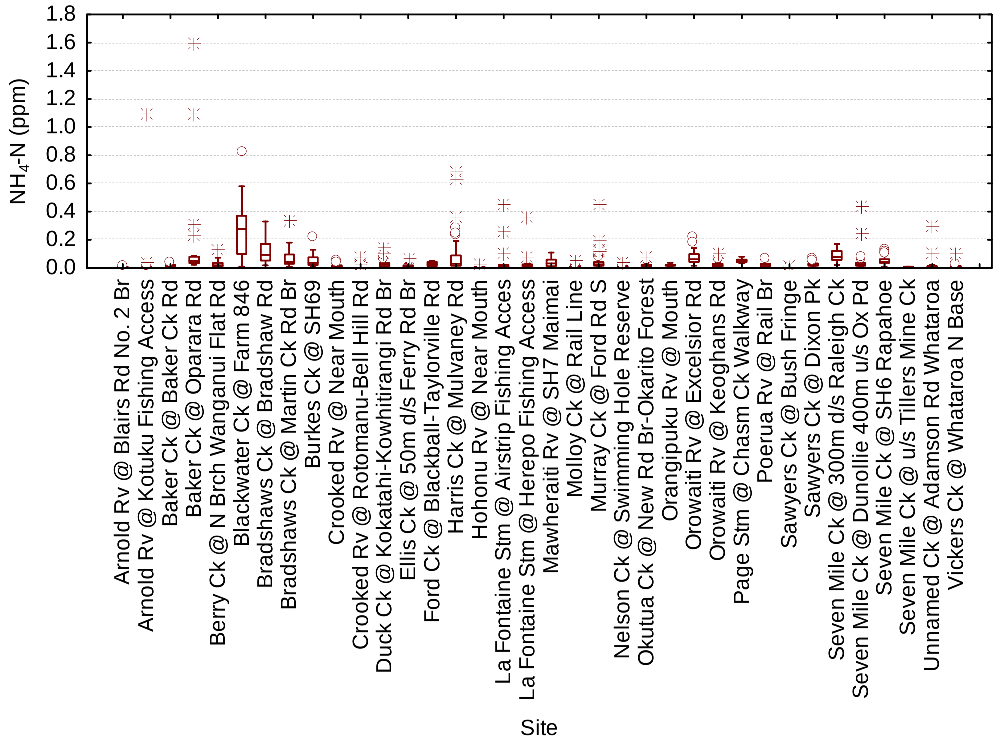


Figure 5.7.7 Box and whisker plot: Ammoniacal nitrogen (NH4-N).

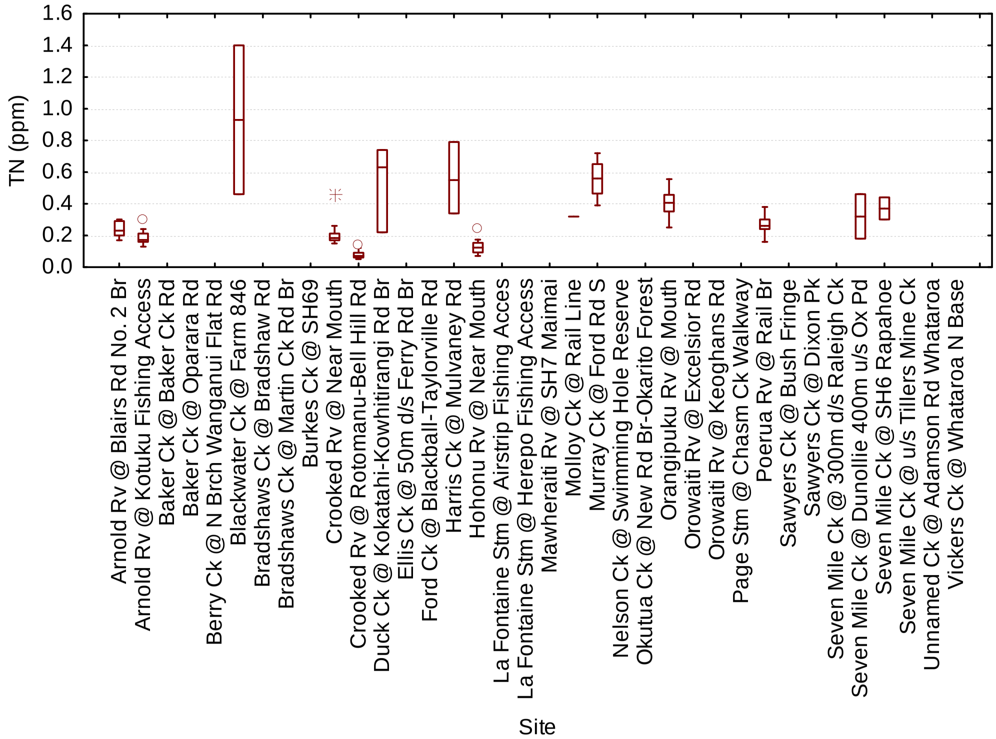


Figure 5.7.8 Box and whisker plot: Total nitrogen (TN).

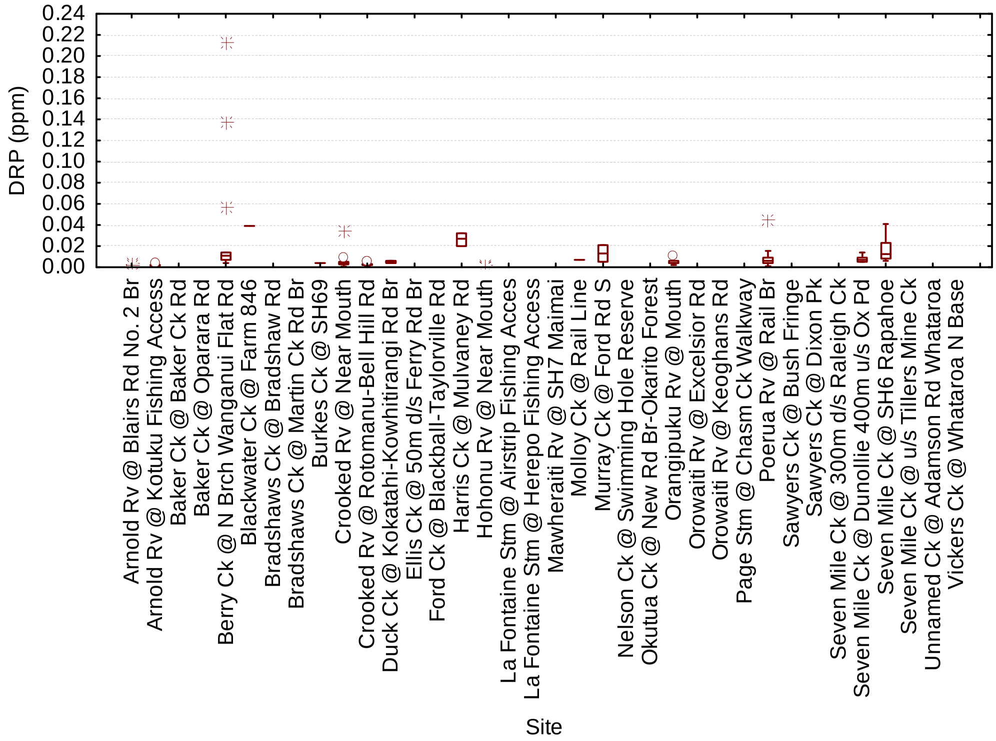


Figure 5.7.9 Box and whisker plot: Dissolved reactive phosphorous (DRP).

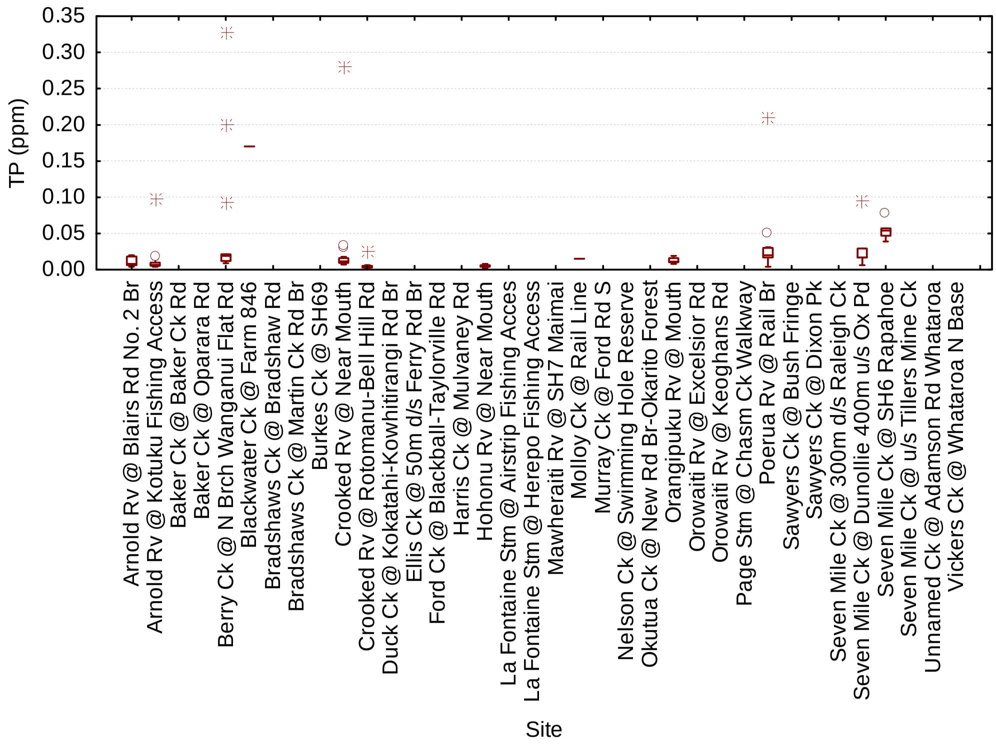


Figure 5.7.10 Box and whisker plot: Total phosphorous (TP).

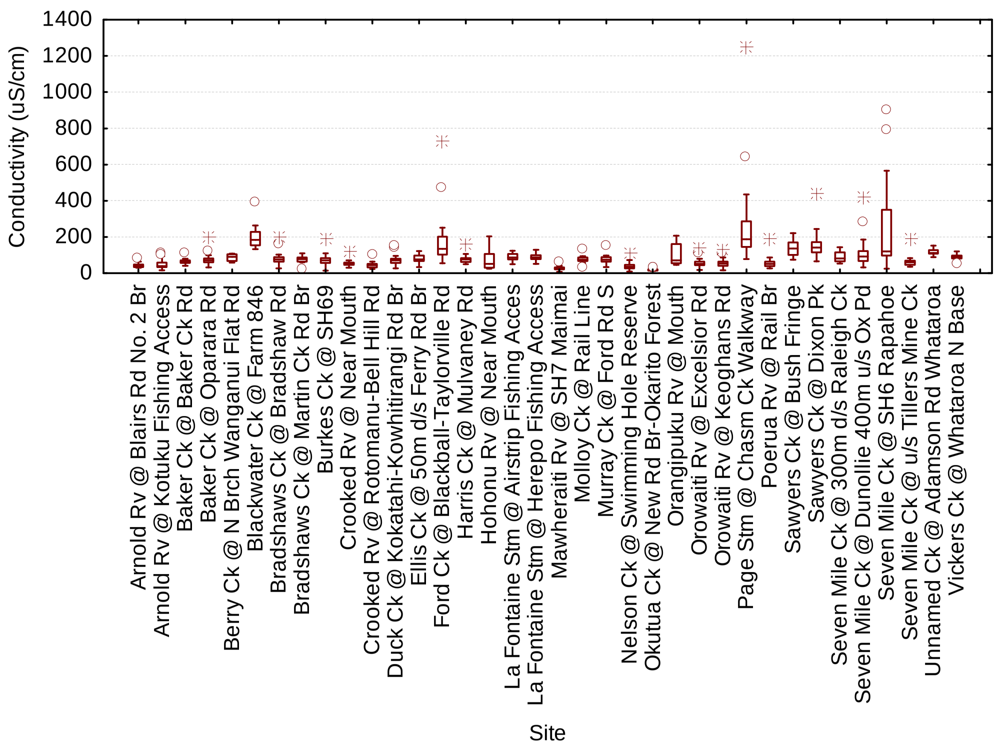


Figure 5.7.11 Box and whisker plot: Conductivity.

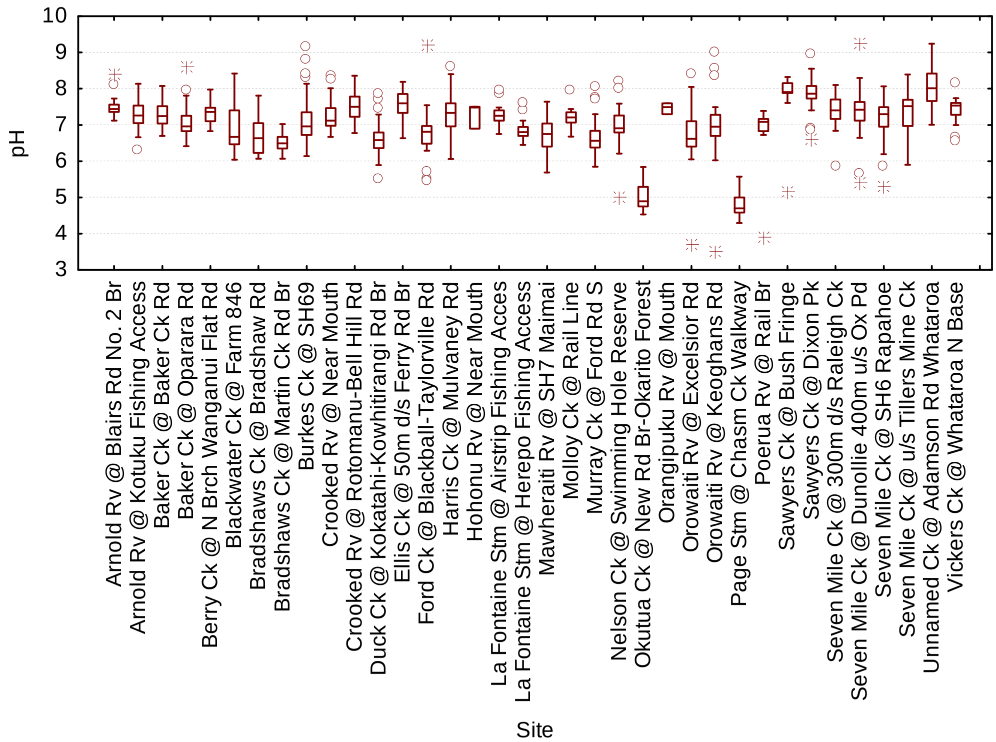


Figure 5.7.12 Box and whisker plot: pH.

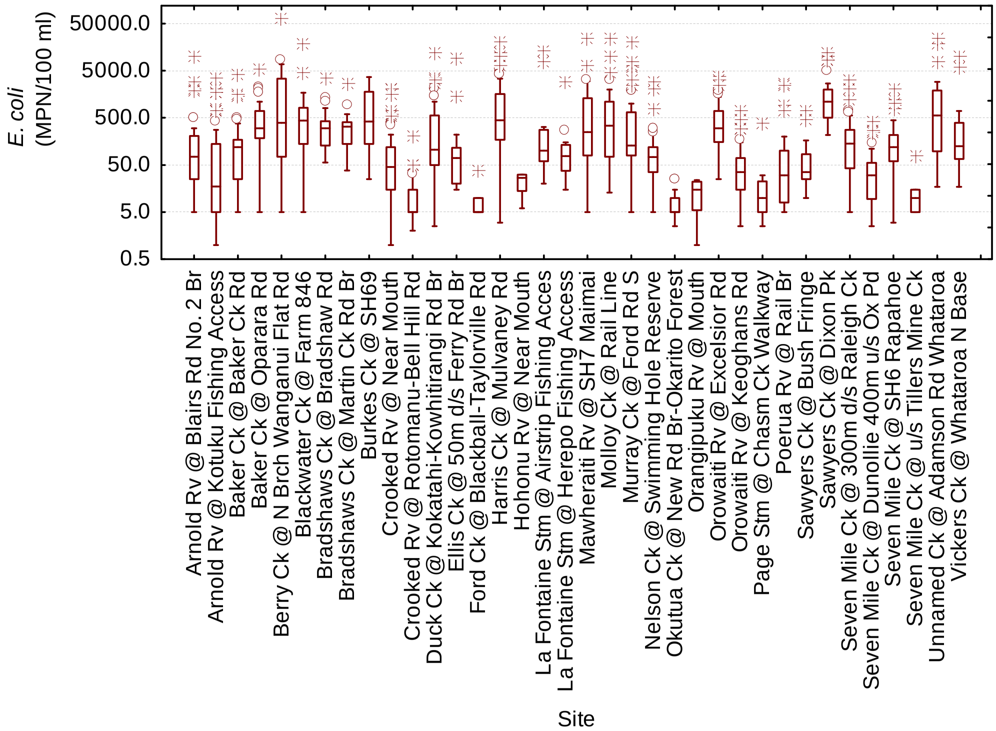


Figure 5.7.13 Box and whisker plot: E.coli.

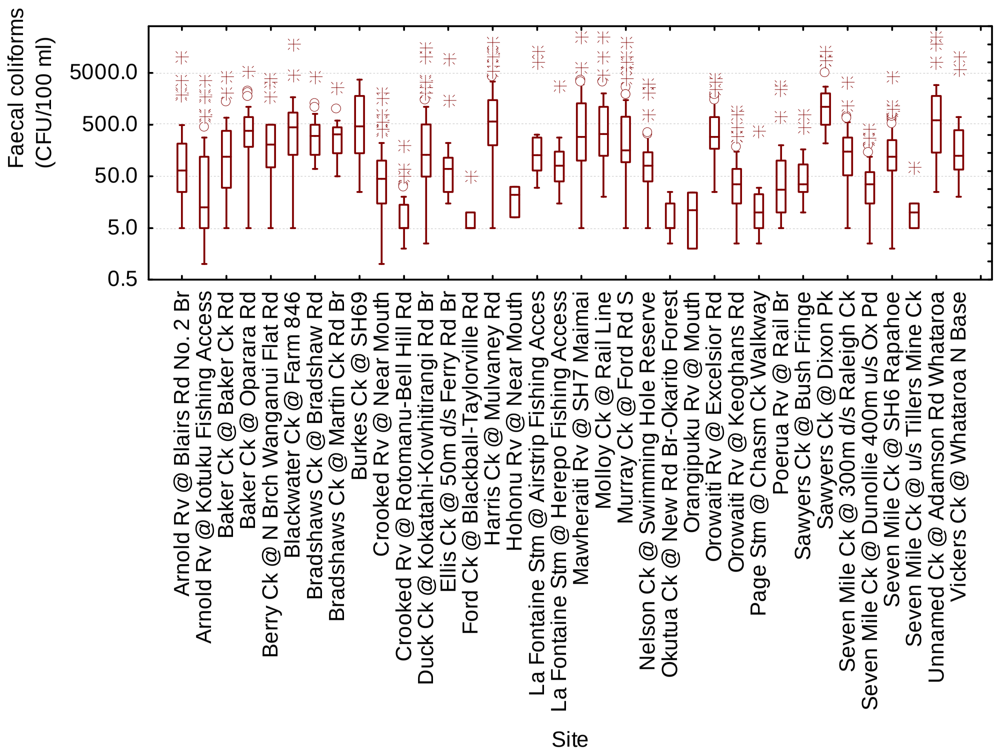


Figure 5.7.14 Box and whisker plot: Faecal coliforms.

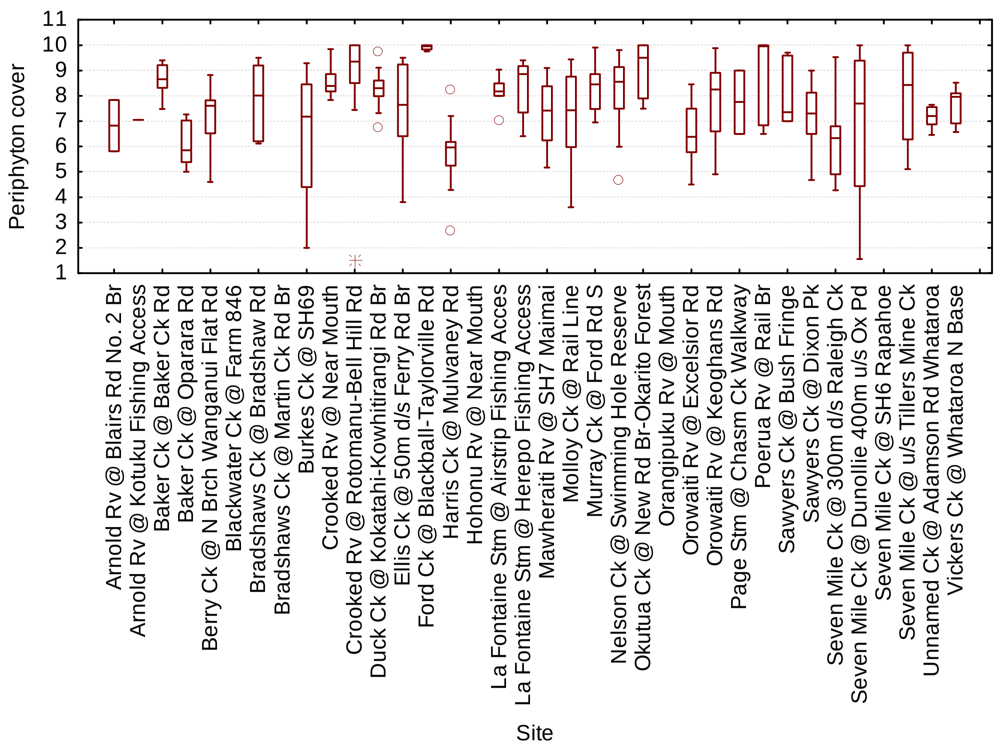


Figure 5.7.15 Box and whisker plot: Periphyton.

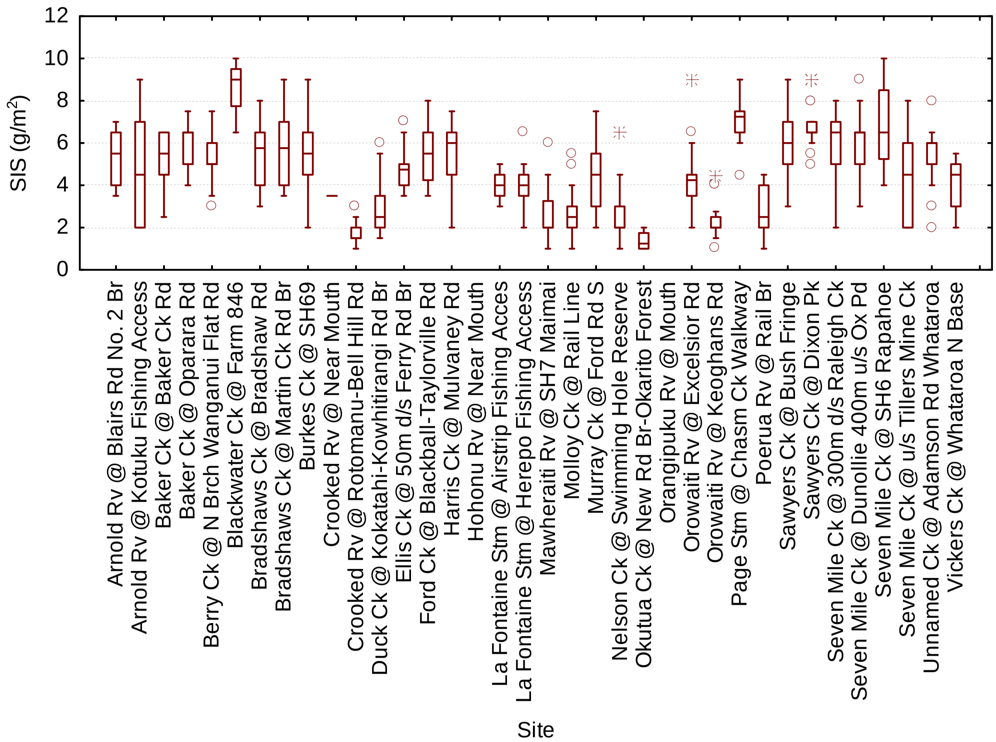


Figure 5.7.16 Box and whisker plot: Re-suspendable sediment (SIS).

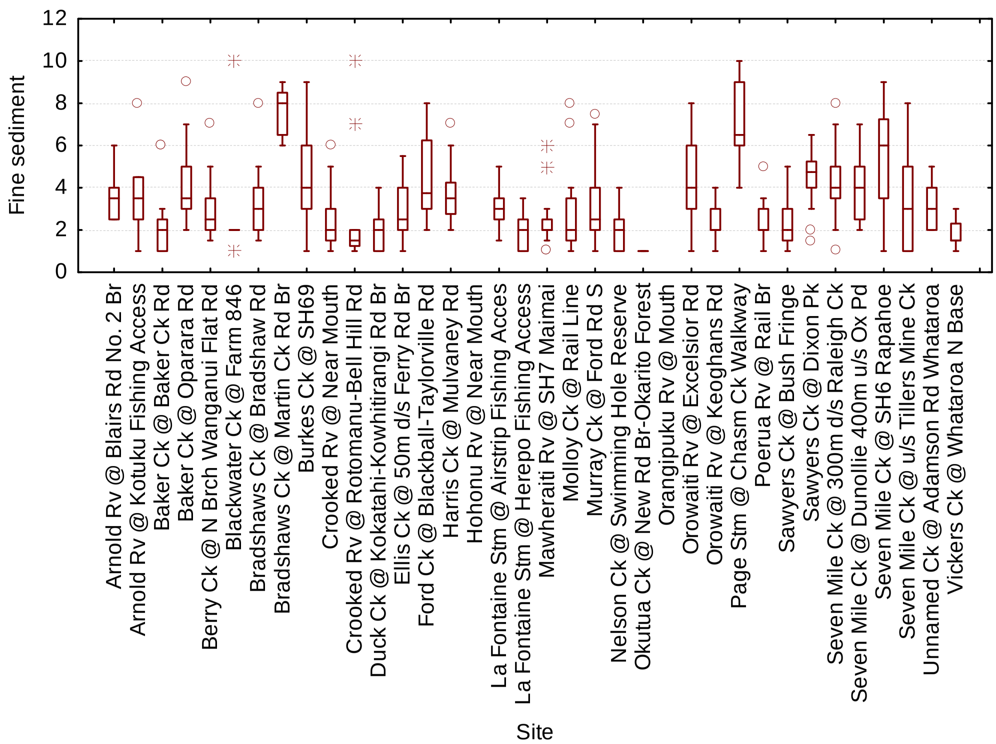


Figure 5.7.17 Box and whisker plot: Fine sediment deposits.

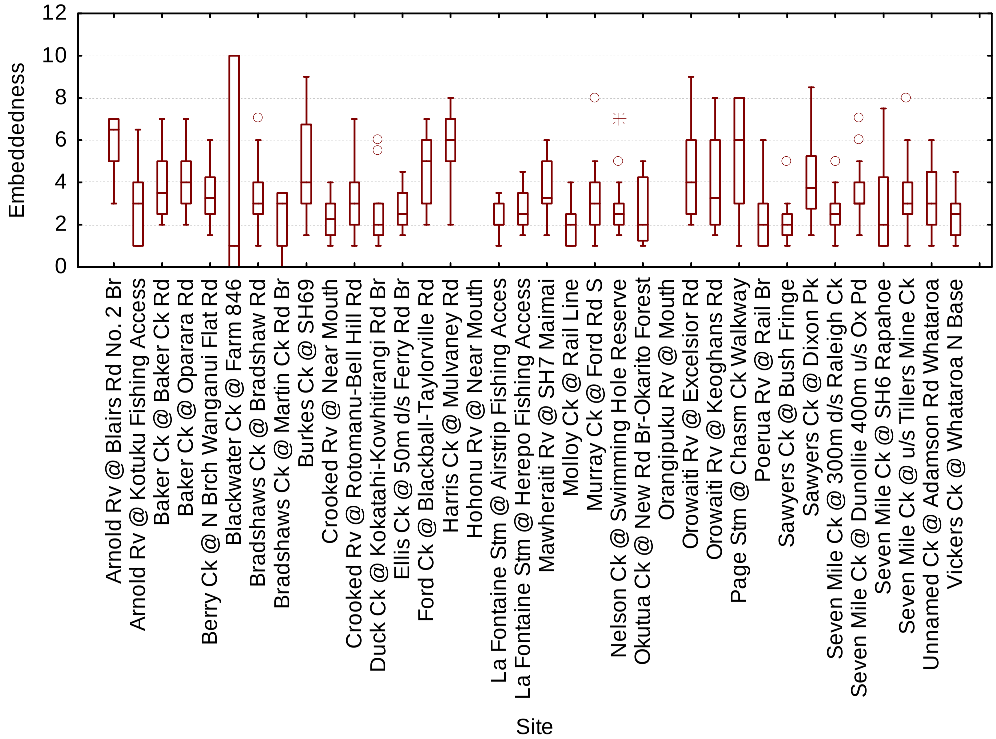


Figure 5.7.18 Box and whisker plot: Substrate embeddedness.

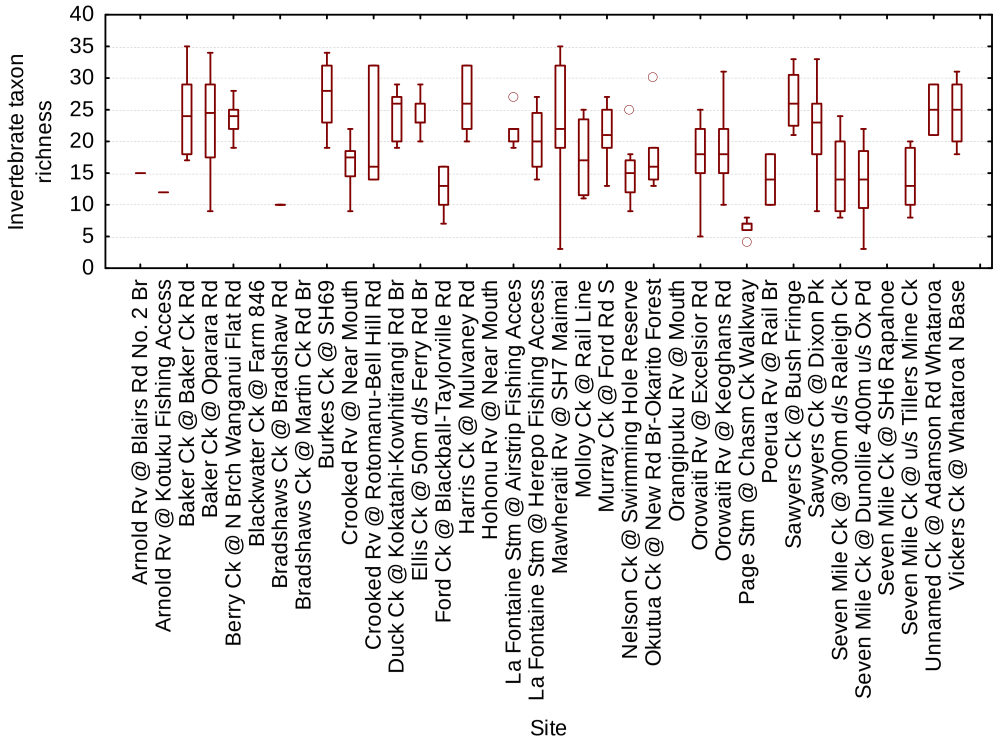


Figure 5.7.19 Box and whisker plot: Invertebrate taxon richness.

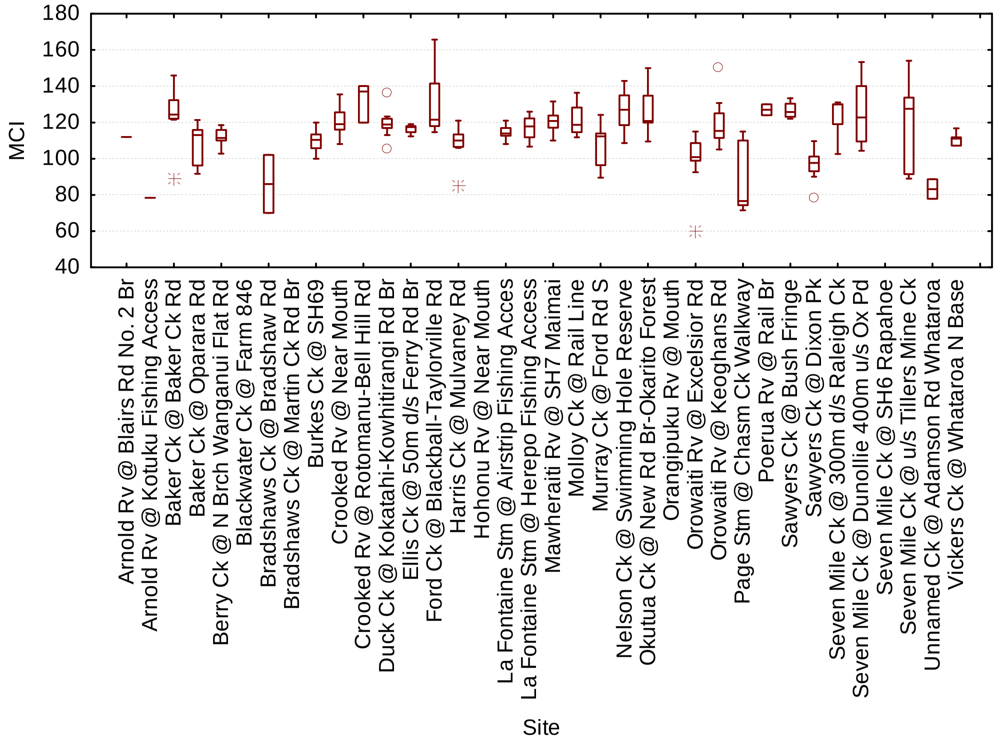


Figure 5.7.20 Box and whisker plot: Macroinvertebrate Community Index (MCI).

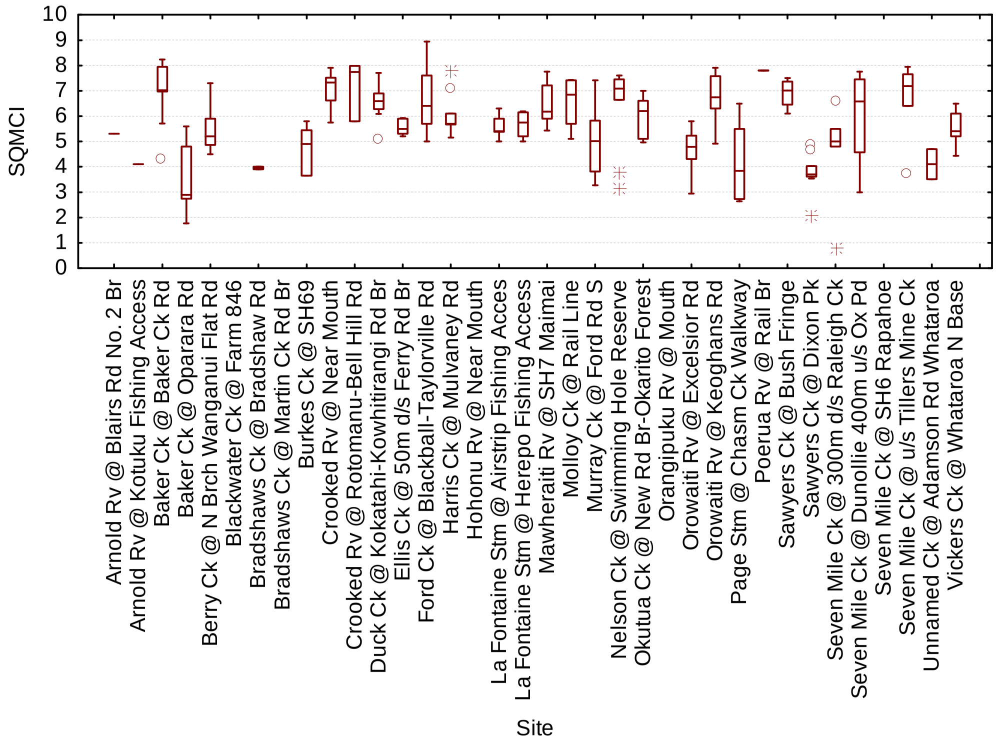


Figure 5.7.21 Box and whisker plot: Semi-Quantitative Macroinvertebrate Community Index (SQMCI).

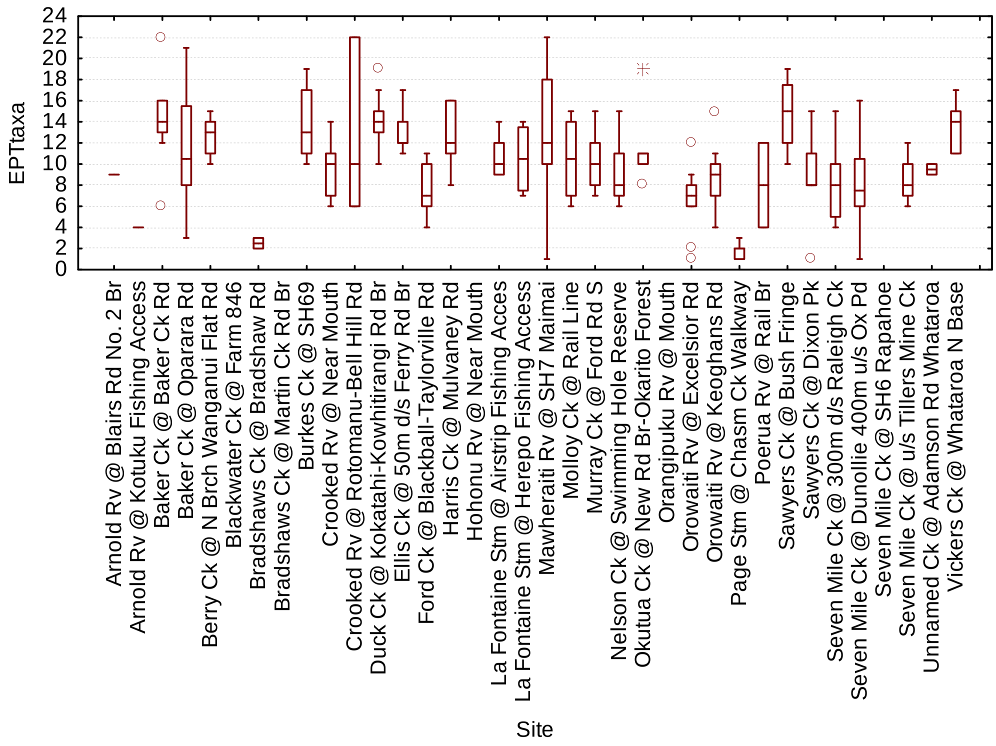


Figure 5.7.22 Box and whisker plot: EPT taxa.

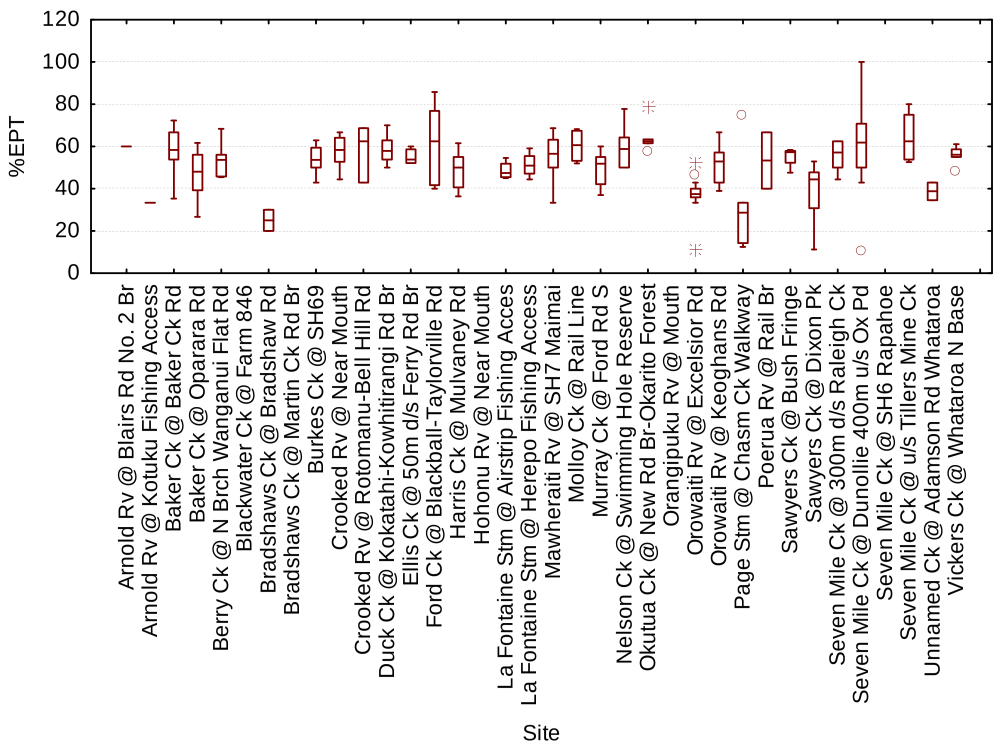


Figure 5.7.23 Box and whisker plot: % EPT.

5.8 Impact/reference sites: Longitudinal patterns over time

A number of rivers in the region are sampled at two or more locations. There is usually an upstream 'reference site' and downstream site impacted by one or more anthropogenic pressures. The figures in this section show temporal patterns at these paired sites. Only data for the most frequently sampled variables is presented (i.e., DO%, temperature, turbidity, *E. coli*, NH_4-N, pH and conductivity). These are the same seven variables used for the water quality ranking presented in Section 2.2. Data points represent annual median values. Data are presented for five rivers, which are those showing the greatest longitudinal changes in overall water quality rank. Note upstream site is in indigenous forest (IF; green) and downstream site is in pasture (P; orange).

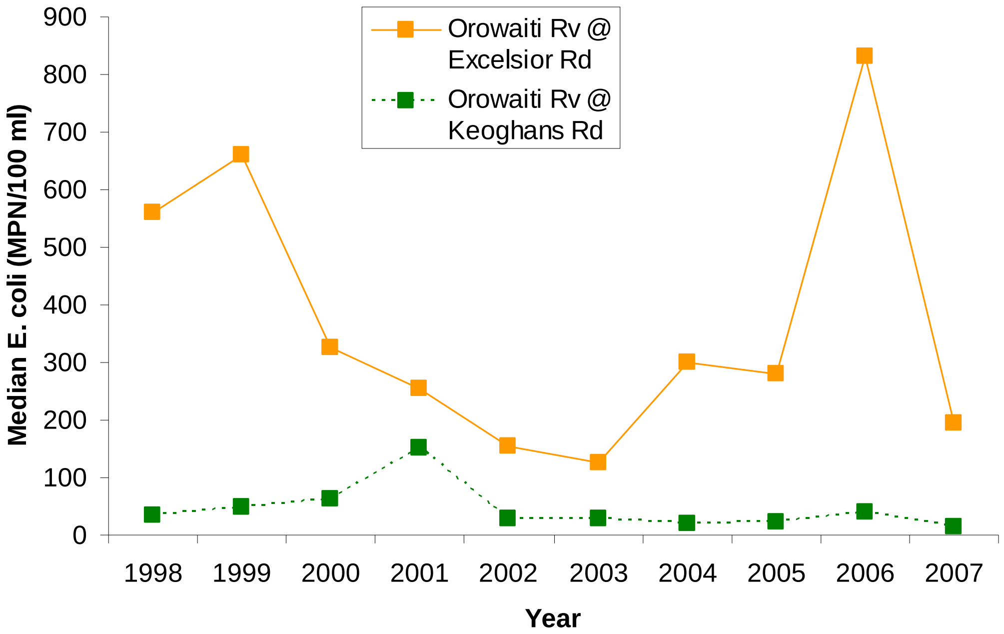


Figure 5.8.1 Orowaiti River – Yearly median E. coli.

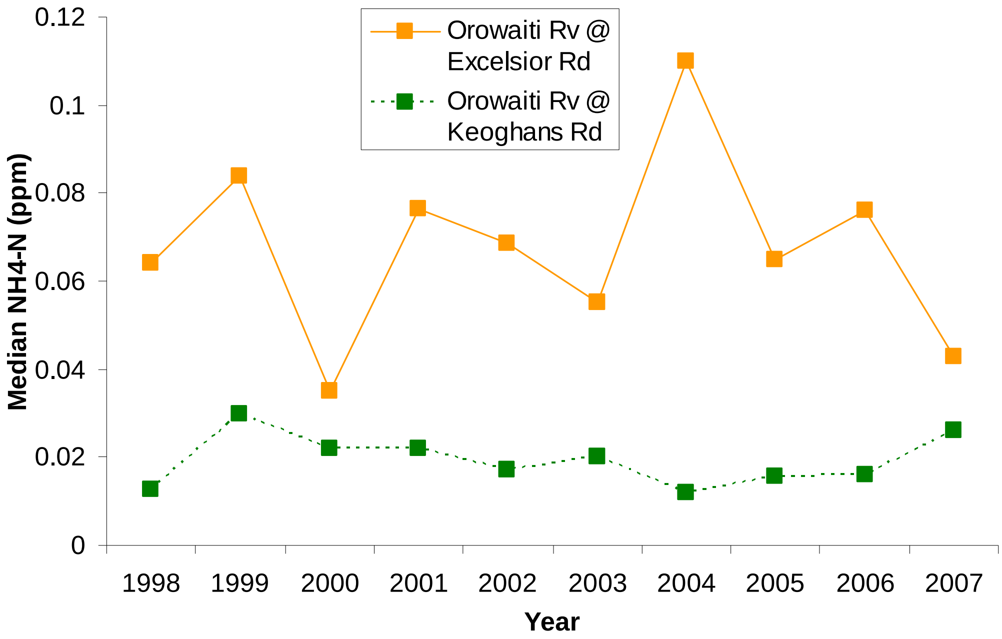


Figure 5.8.2 Orowaiti River – Yearly median ammoniacal nitrogen (NH_4-N).

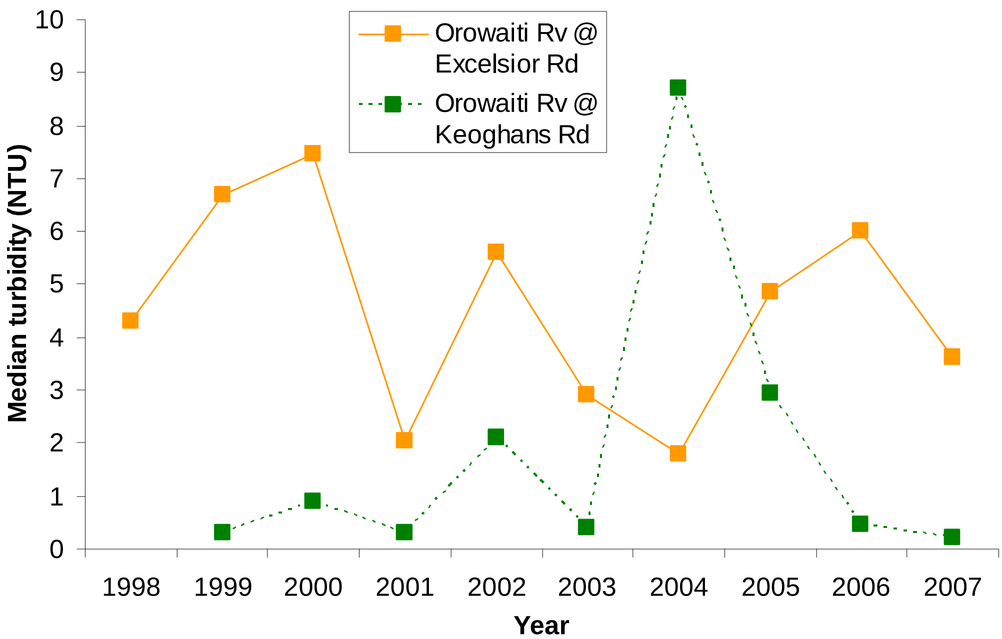


Figure 5.8.3 Orowaiti River – Yearly median turbidity.

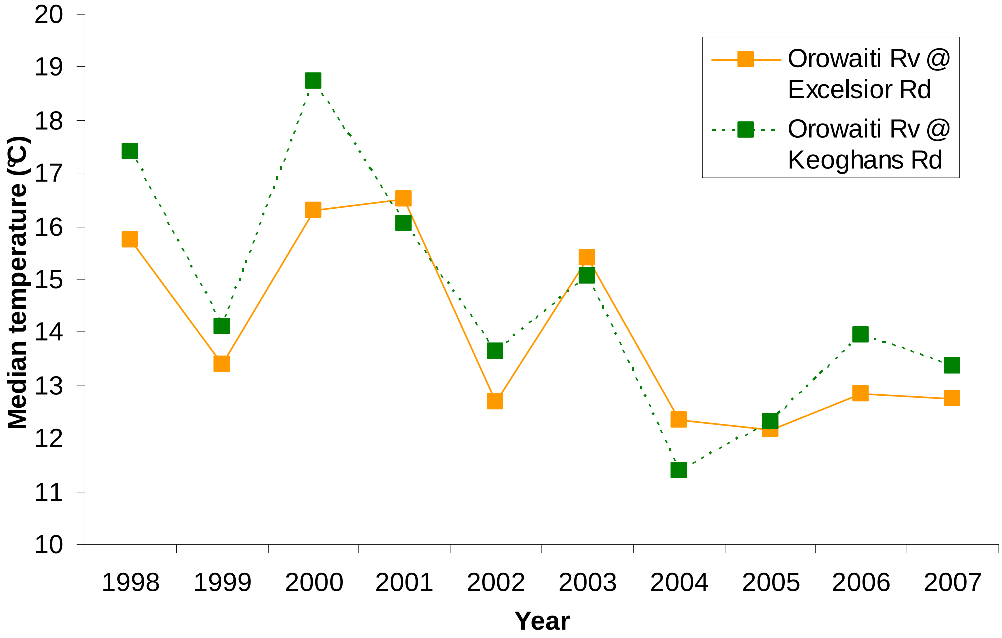


Figure 5.8.4 Orowaiti River – Yearly median temperature.

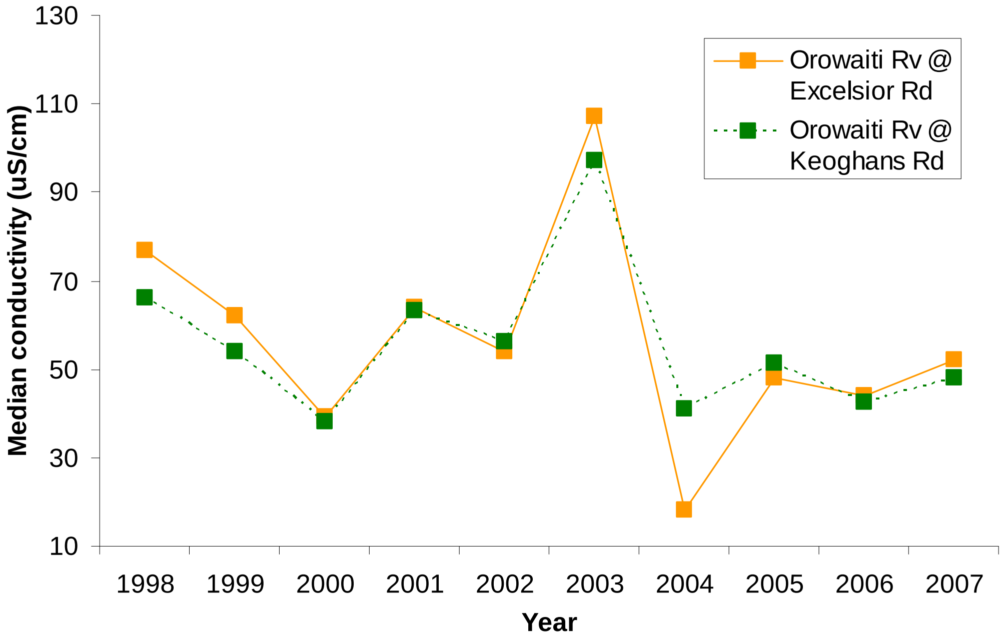


Figure 5.8.5 Orowaiti River – Yearly median conductivity.

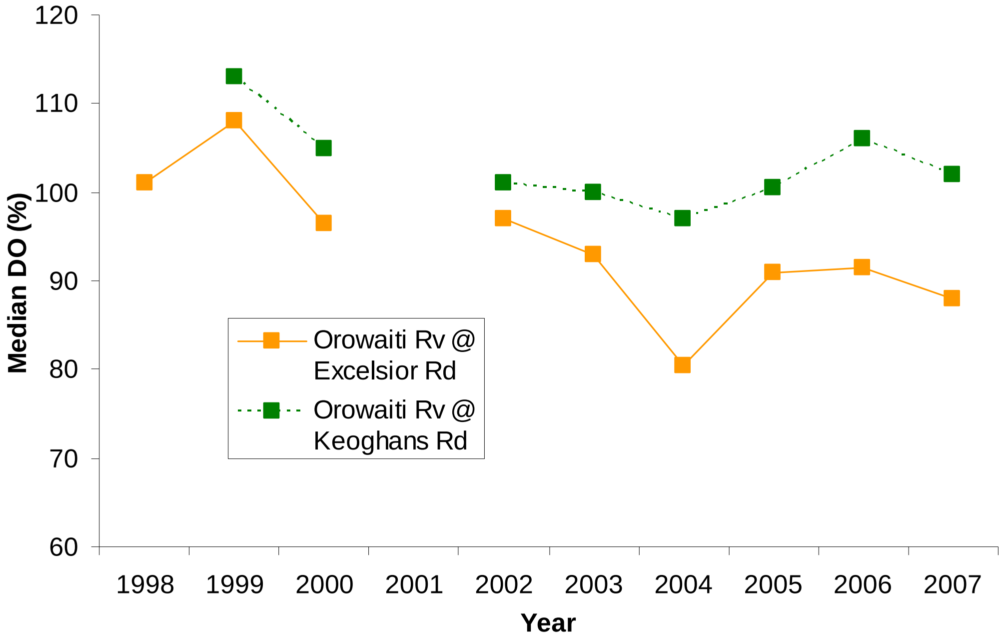


Figure 5.8.6 Orowaiti River – Yearly median percentage dissolved oxygen saturation.

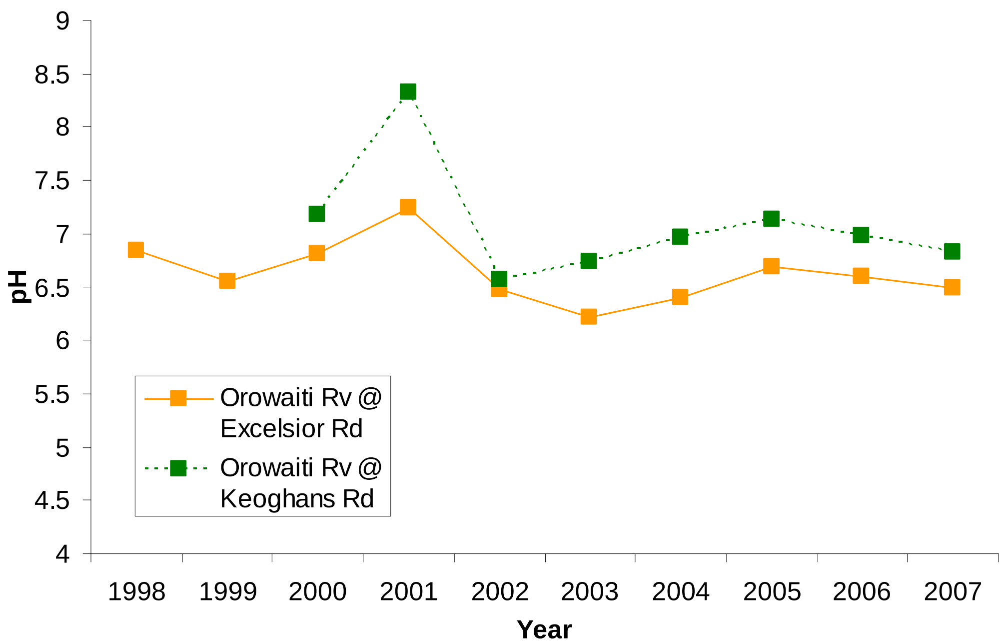


Figure 5.8.7 Orowaiti River – Yearly median pH.

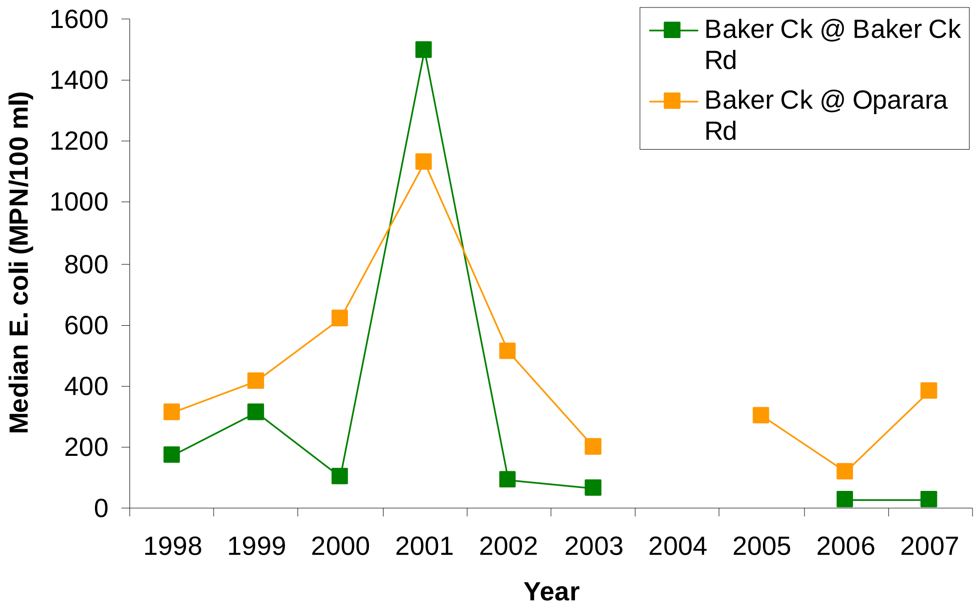


Figure 5.8.8 Baker Creek – Yearly median E. coli. Note upstream site is in indigenous forest (IF; green) and downstream site is in pasture (P; orange).

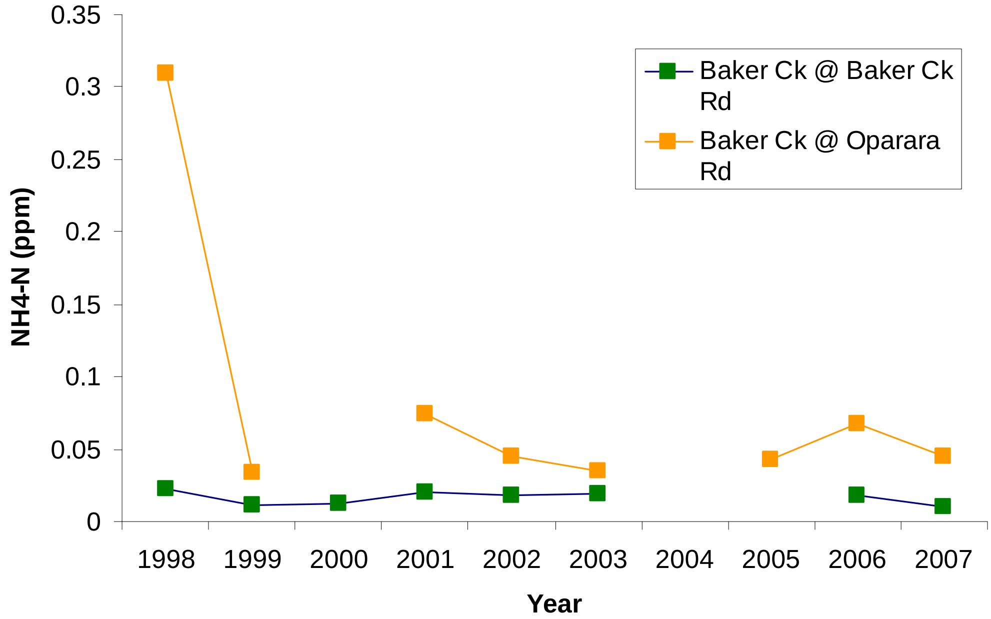


Figure 5.8.9 Baker Creek – Yearly median ammoniacal nitrogen (NH_4-N).

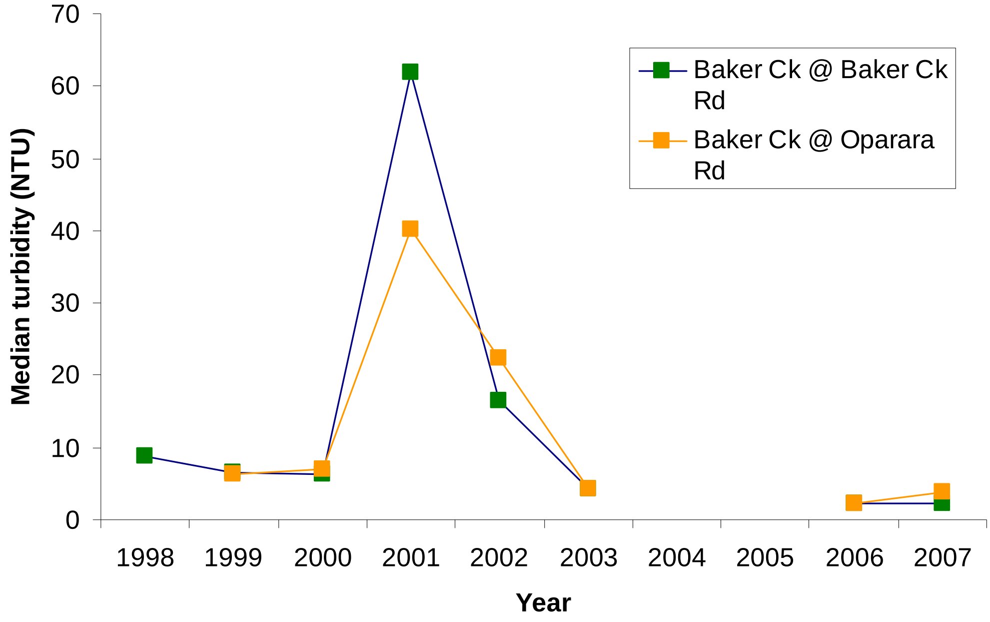


Figure 5.8.10 Baker Creek – Yearly median turbidity.

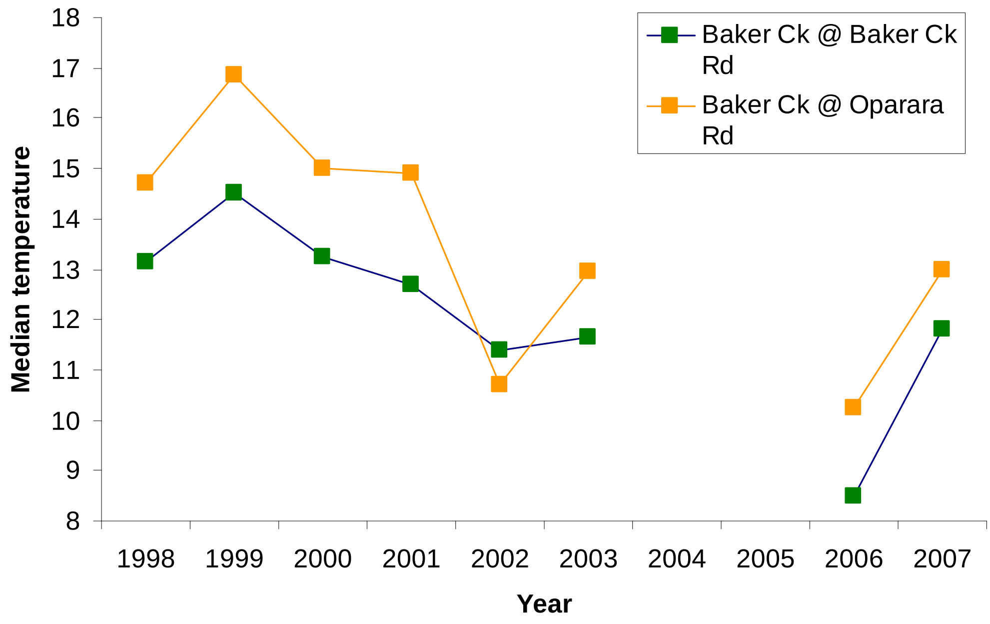


Figure 5.8.11 Baker Creek – Yearly median temperature.

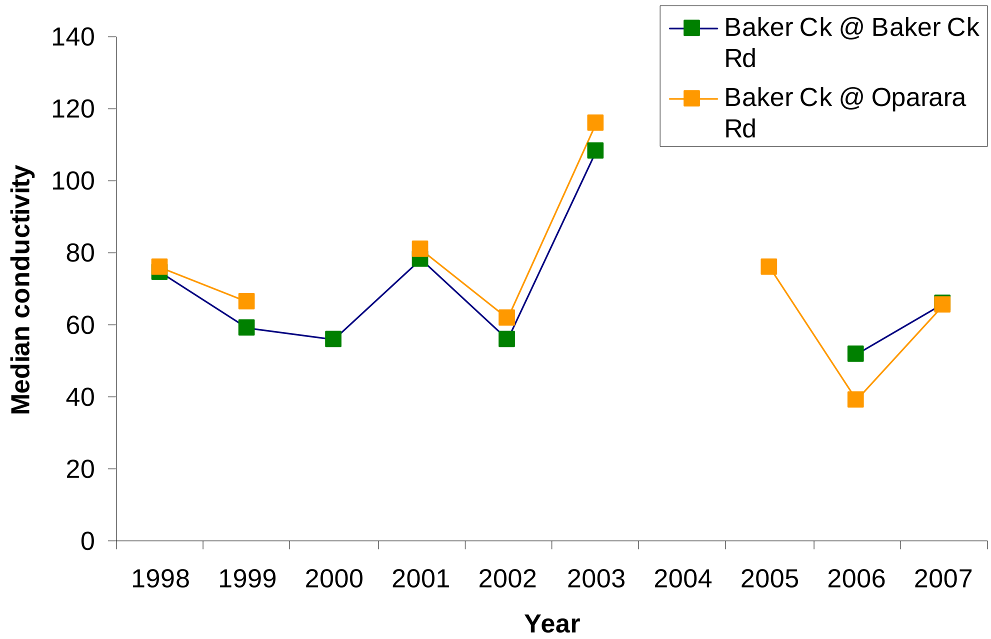


Figure 5.8.12 Baker Creek – Yearly median conductivity (measured in uS/cm).

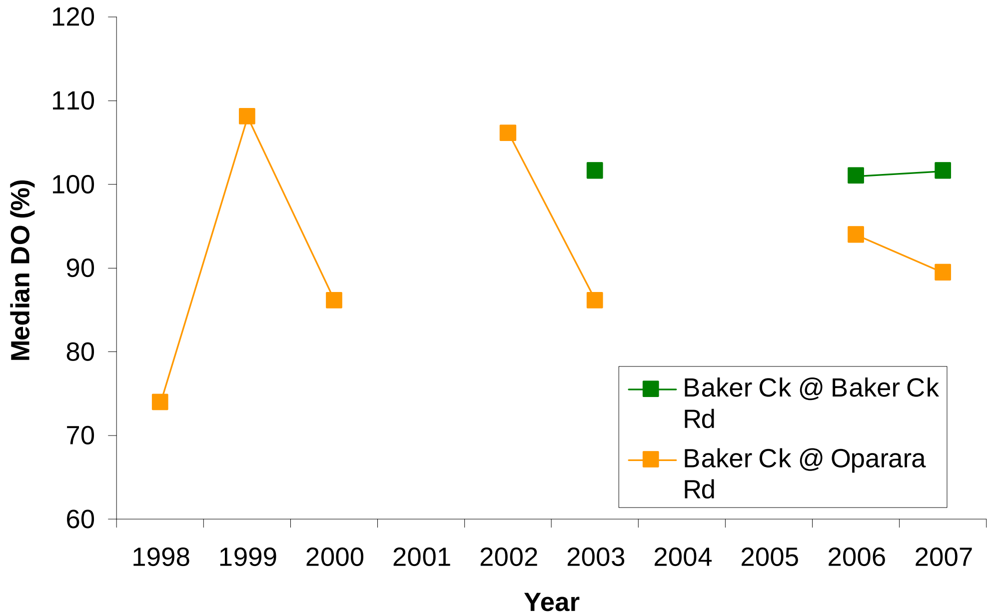


Figure 5.8.13 Baker Creek – Yearly median percentage dissolved saturation.

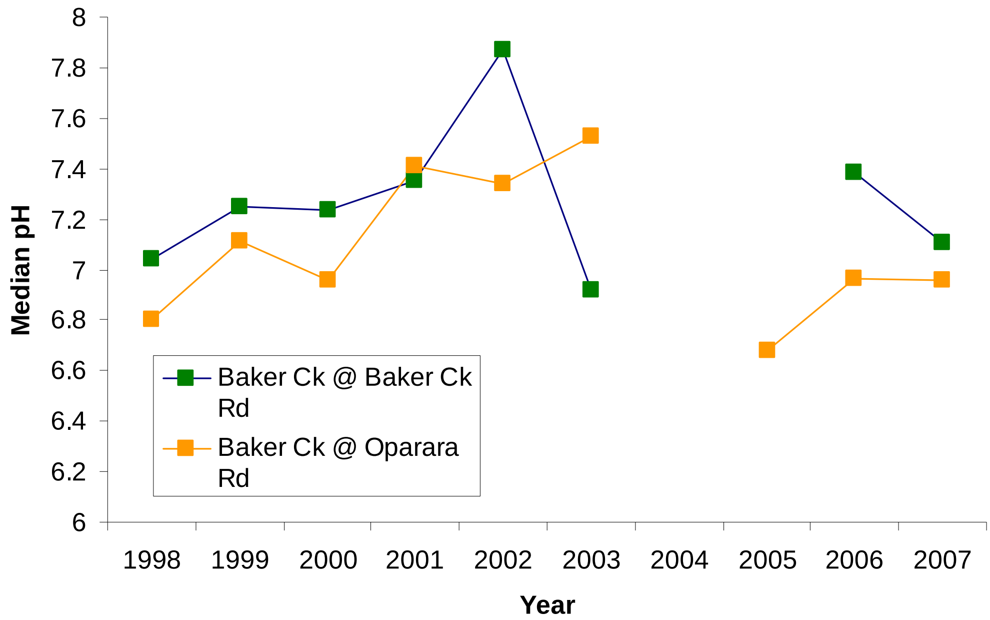


Figure 5.8.14 Baker Creek – Yearly median pH.

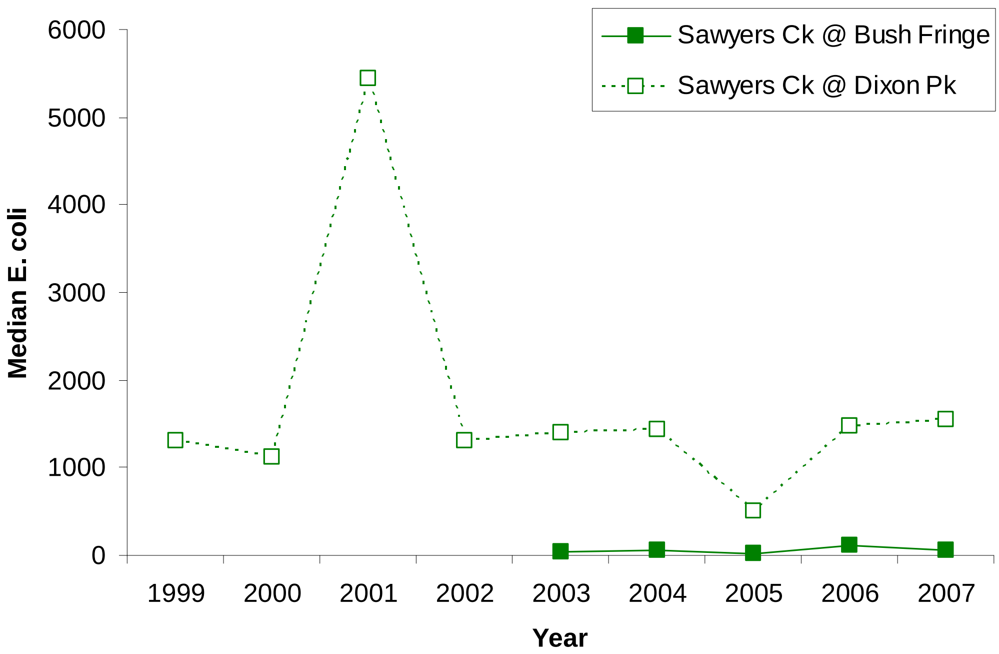


Figure 5.8.15 Sawyers Creek – Yearly median E. coli/100 ml.

Note both sites are in indigenous forest (IF; green), so the upstream site is shown in solid colour and the downstream site in dashed line and open box.

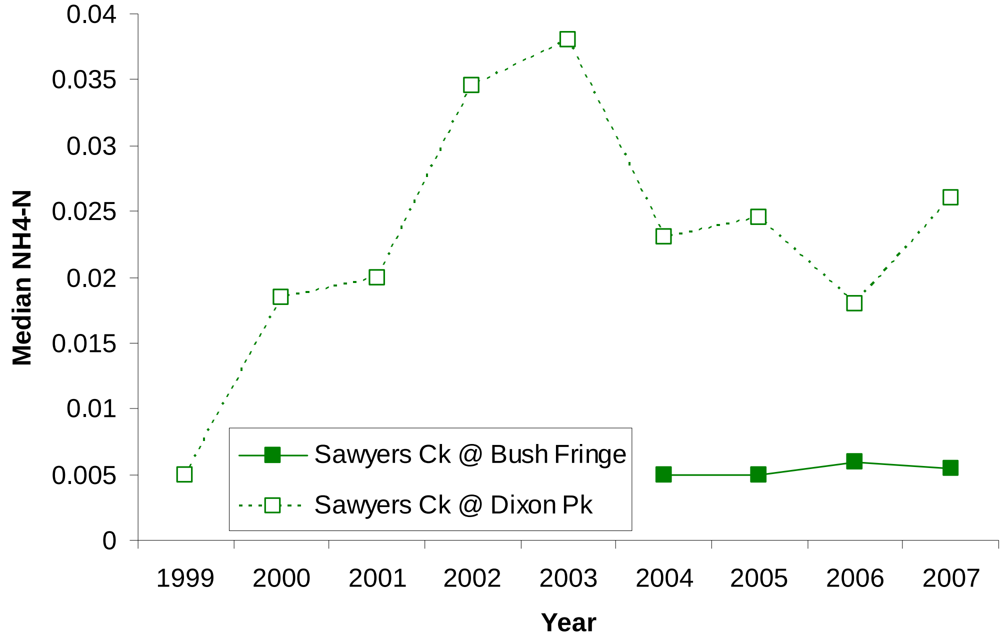


Figure 5.8.16 Sawyers Creek – Yearly median ammoniacal nitrogen (NH_4-N) (measured in ppm).

Figure 5.8.17 Sawyers Creek – Yearly median turbidity (measured in NTU).

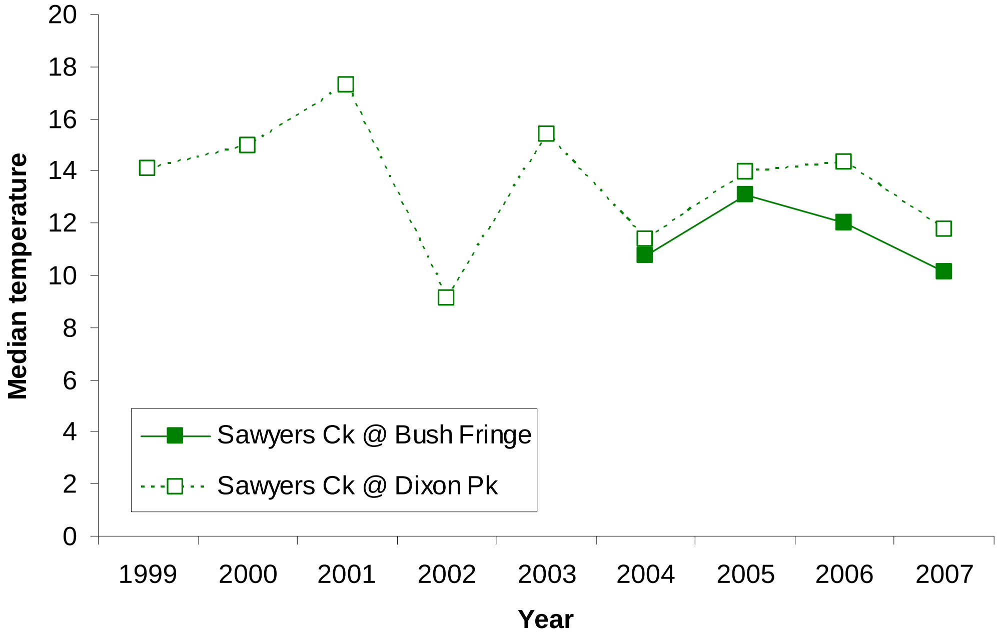


Figure 5.8.18 Sawyers Creek – Yearly median temperature.

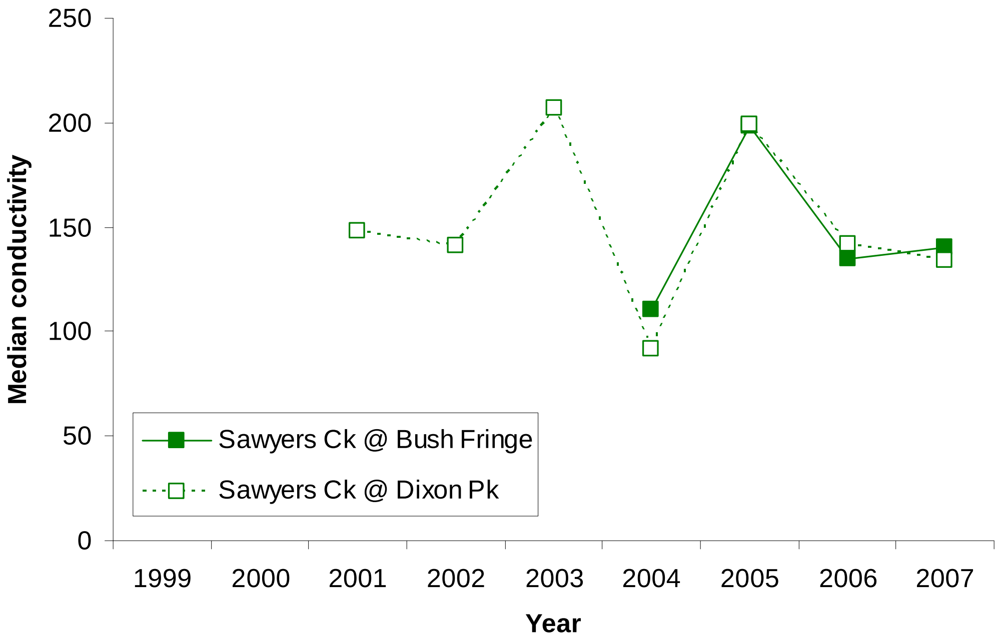


Figure 5.8.19 Sawyers Creek – Yearly median conductivity (measured in uS/cm).

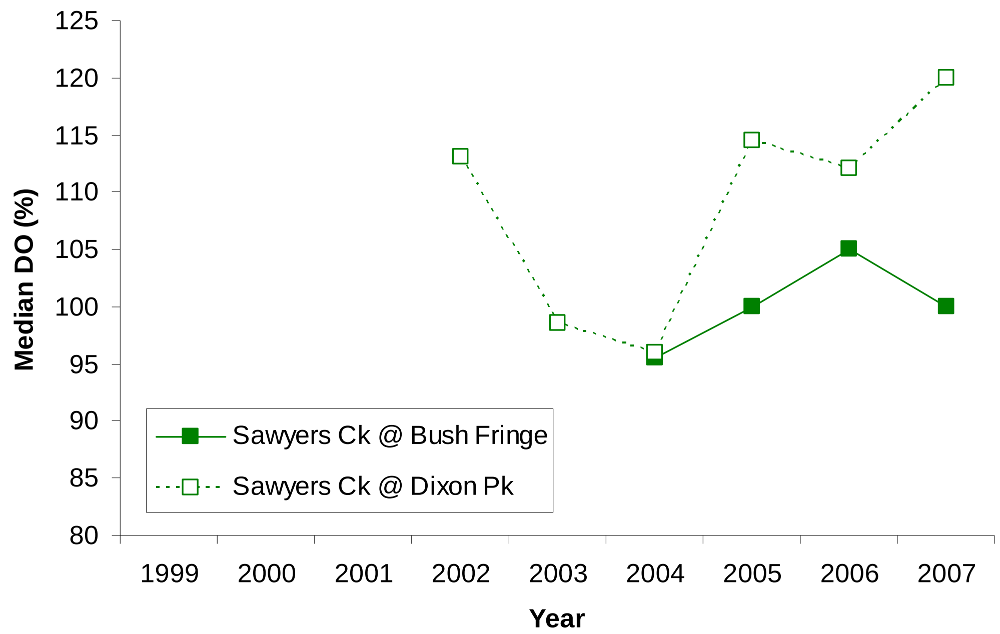


Figure 5.8.20 Sawyers Creek – Yearly median percentage dissolved oxygen saturation.

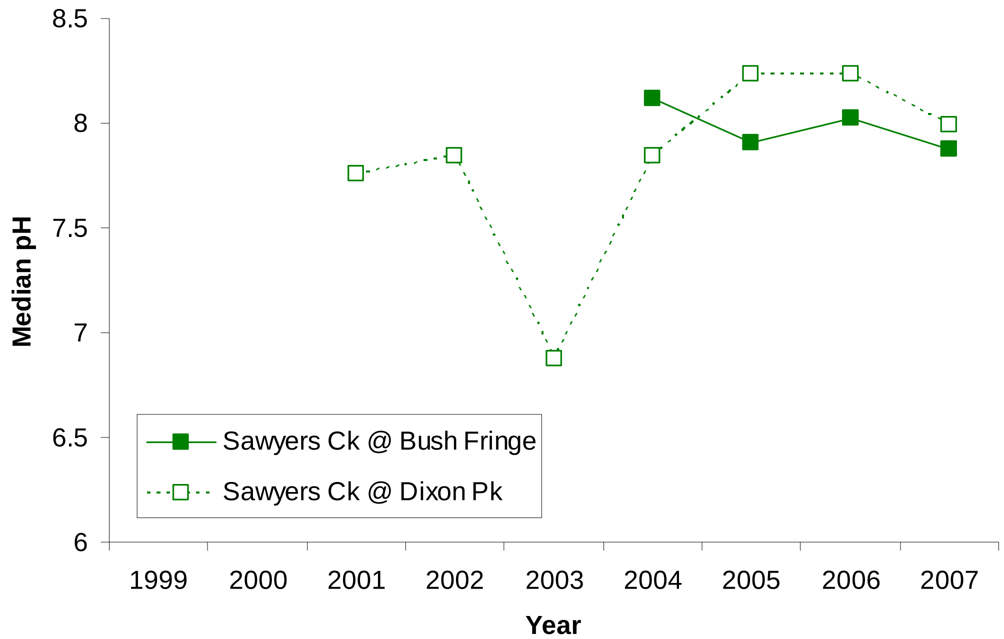


Figure 5.8.21 Sawyers Creek – Yearly median pH.

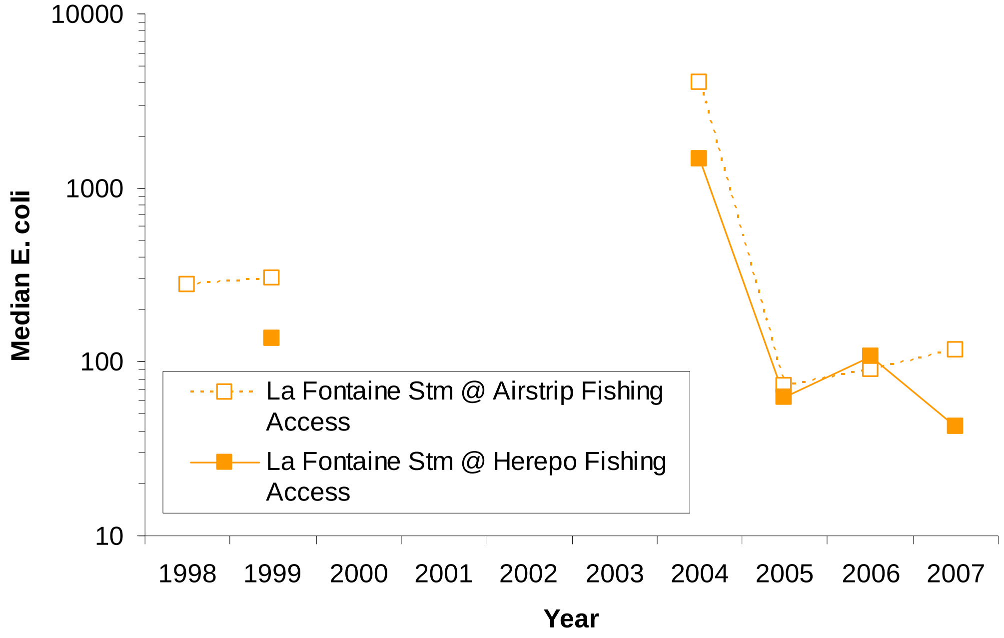


Figure 5.8.22 La Fontaine Stream – Yearly median E. coli/100 ml.

Note both sites are in pasture (P; orange), so the upstream site is shown in solid colour and the downstream site in dashed line and open box.

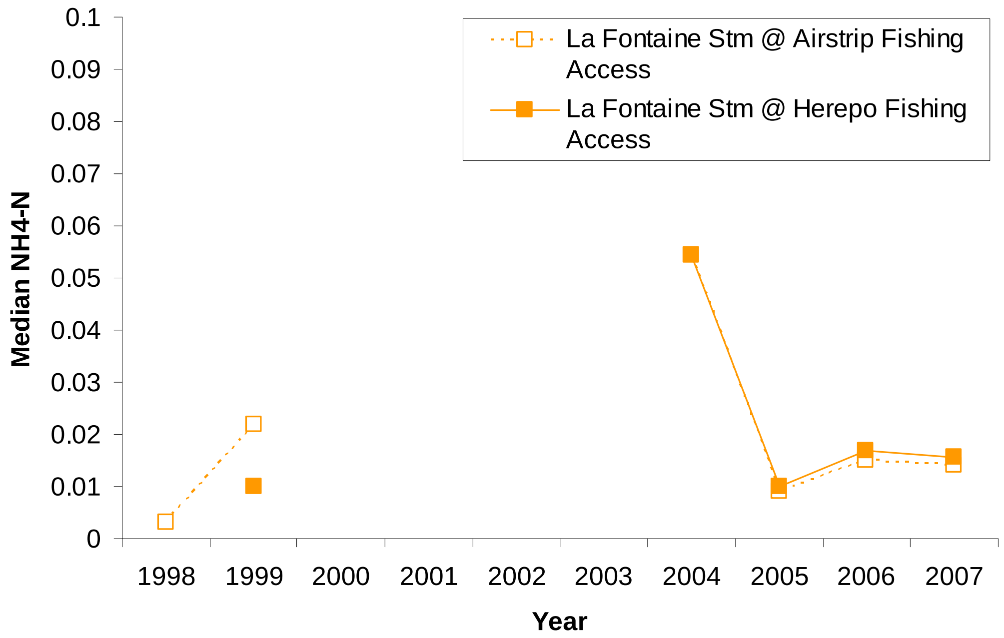


Figure 5.8.23 La Fontaine Stream – Yearly median ammoniacal nitrogen (NH_4-N) (measured in ppm).

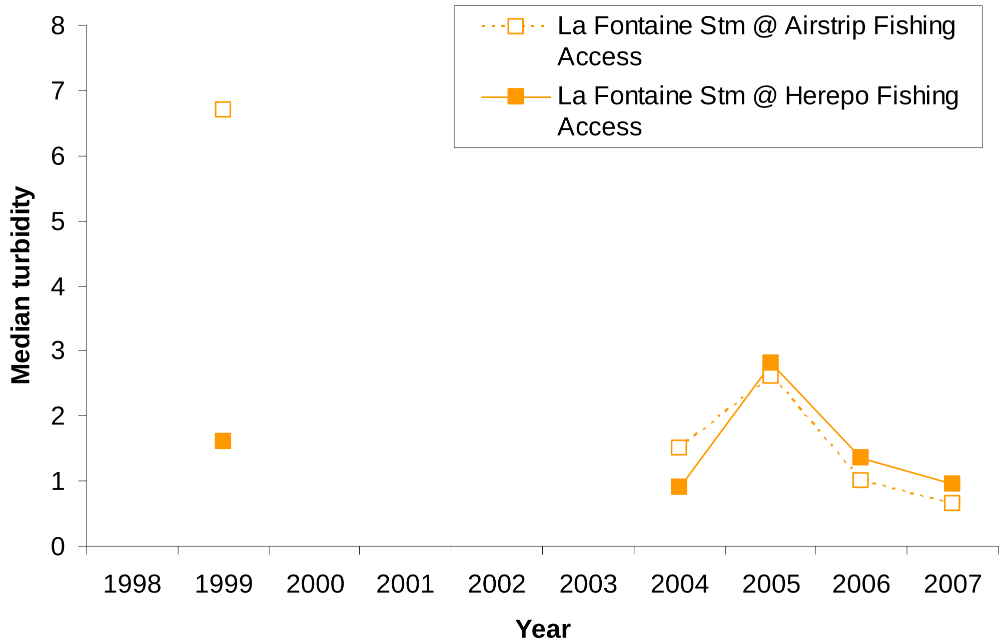


Figure 5.8.24 La Fontaine Stream – Yearly median turbidity (measured in NTU).

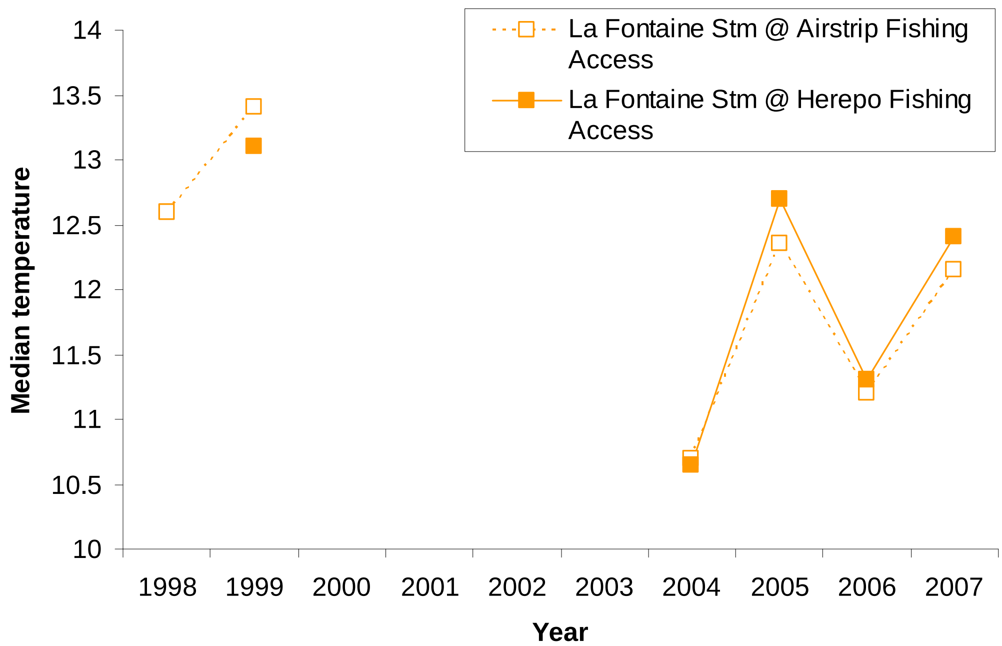


Figure 5.8.25 La Fontaine Stream – Yearly median temperature (^{o}C).

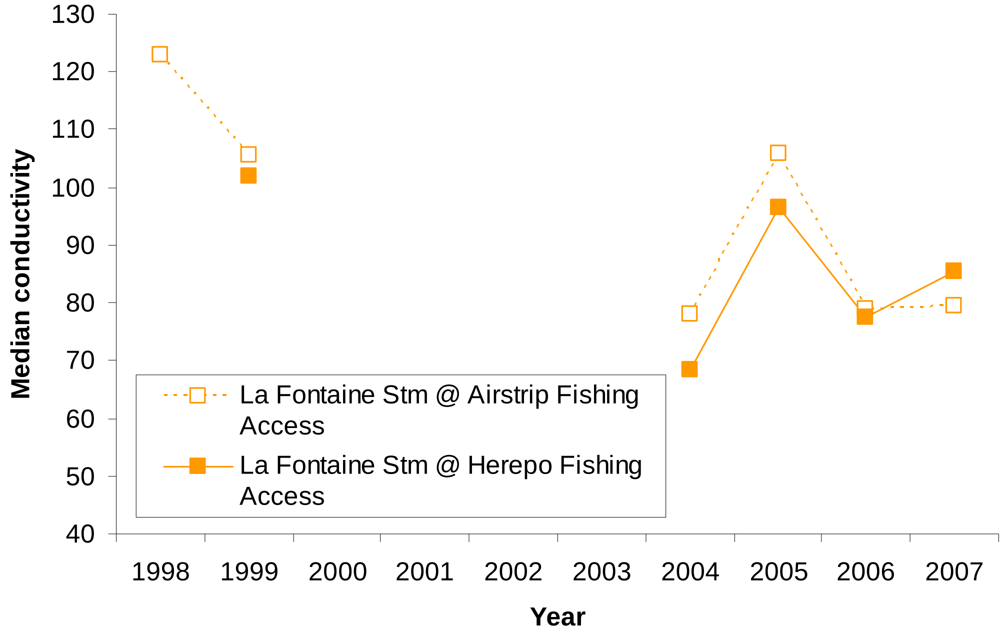


Figure 5.8.26 La Fontaine Stream – Yearly median conductivity (measured in uS/cm).

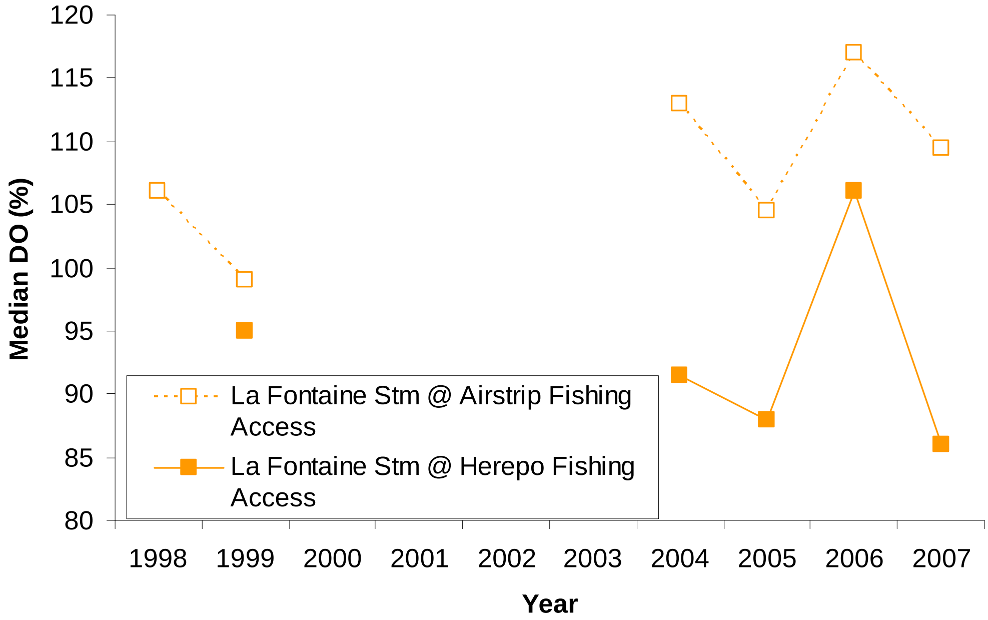


Figure 5.8.27 La Fontaine Stream – Yearly median percentage dissolved oxygen saturation.

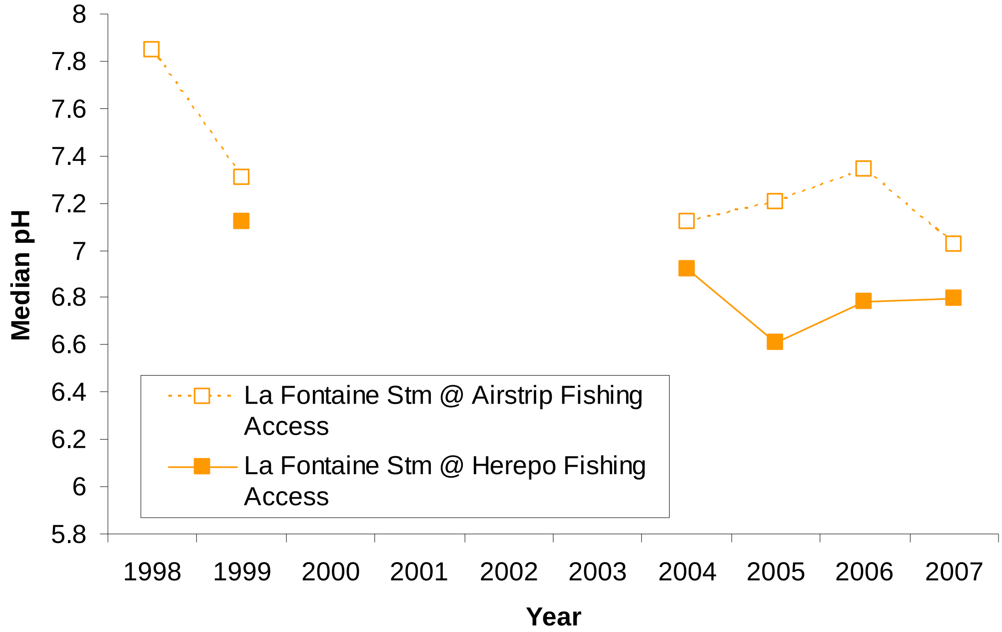


Figure 5.8.28 La Fontaine Stream – Yearly median pH.

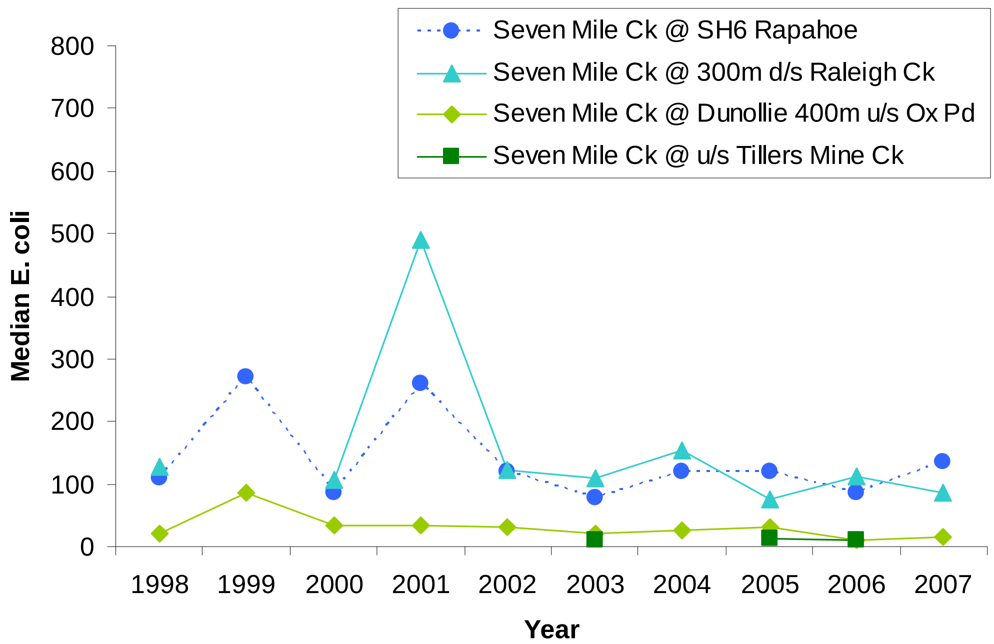


Figure 5.8.29 Seven Mile Creek – Yearly median E. coli/100 ml.

All Seven Mile Creek sites are in indigenous forest (IF). Sites are ordered from bottom (SH6 Rapahoe) to top (u/s Tillers Mine Ck).

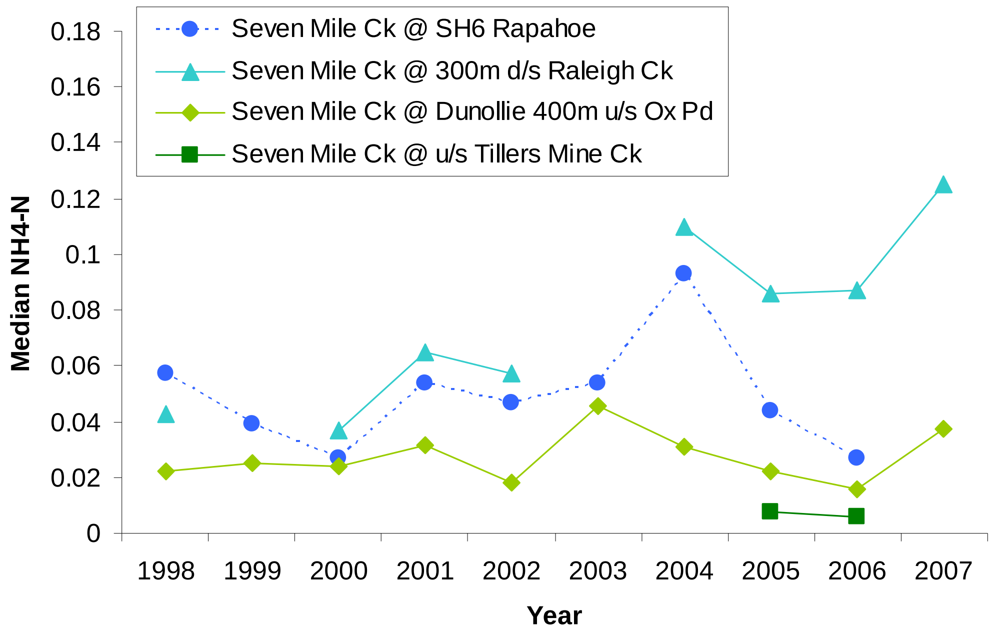


Figure 5.8.30 Seven Mile Creek – Yearly median ammoniacal nitrogen (NH_4-N)(measured in ppm).

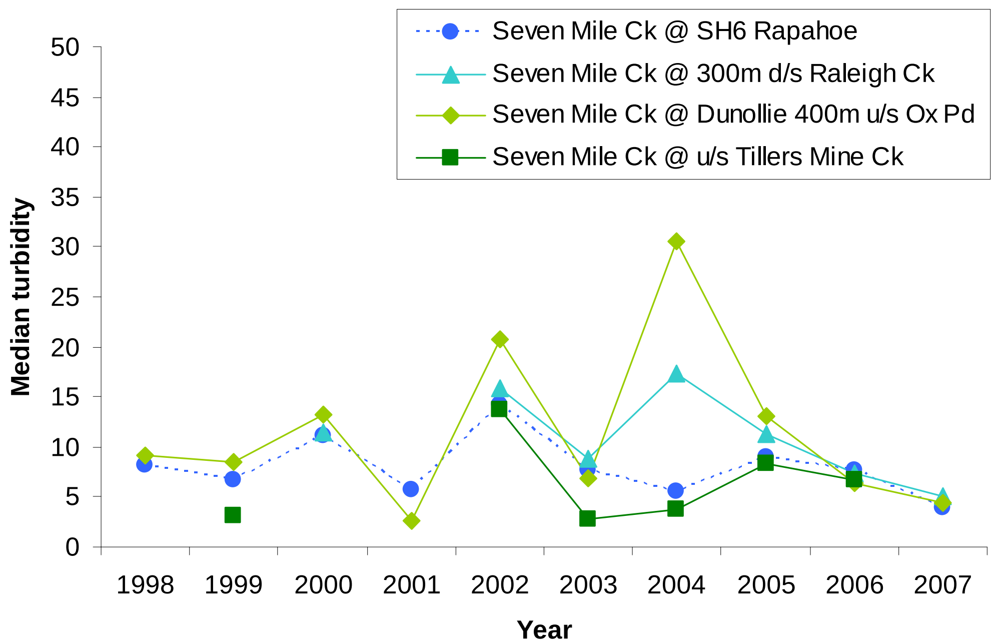


Figure 5.8.31 Seven Mile Creek – Yearly median turbidity (measured in NTU).

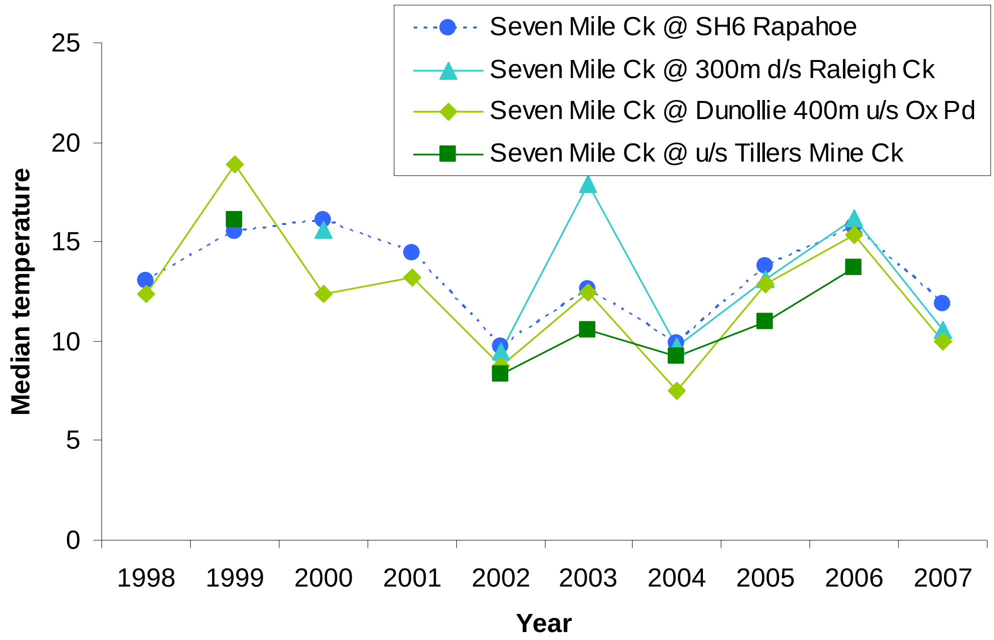


Figure 5.8.32 Seven Mile Creek – Yearly median temperature (^{o}C).

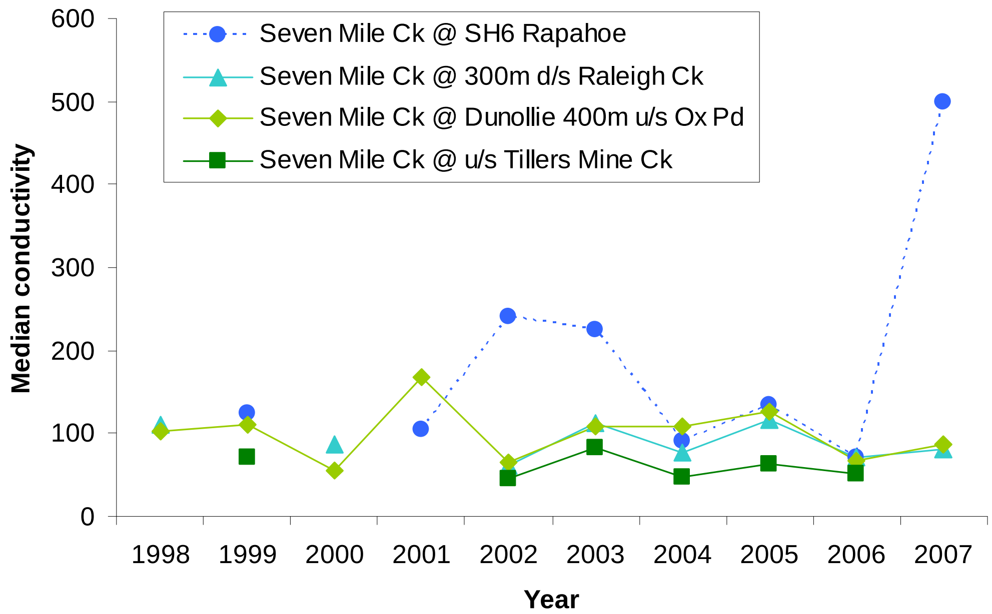


Figure 5.8.33 Seven Mile Creek – Yearly median conductivity (measured in uS/cm).

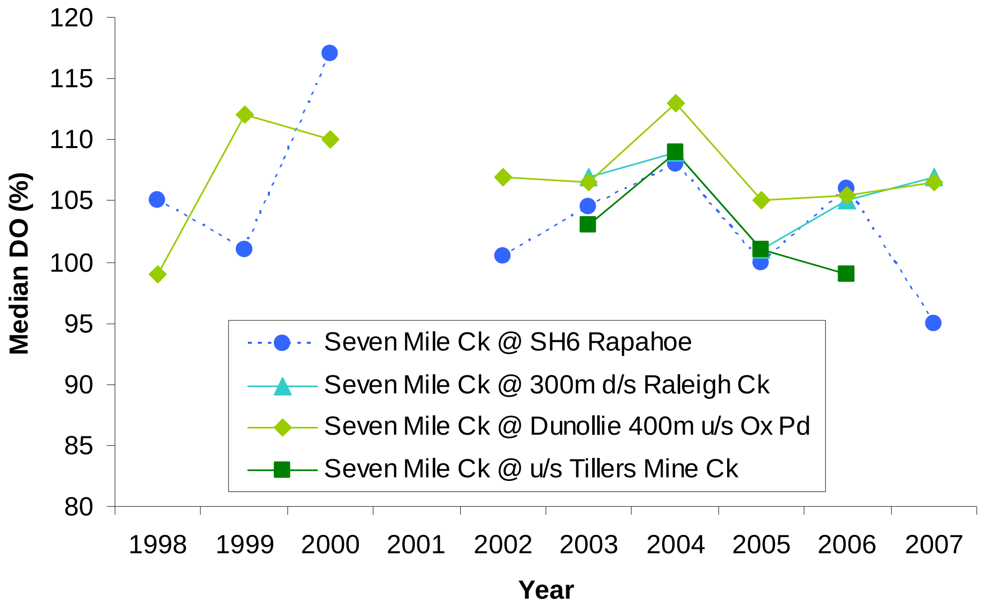


Figure 5.8.34 Seven Mile Creek – Yearly median percentage dissolved oxygen saturation.

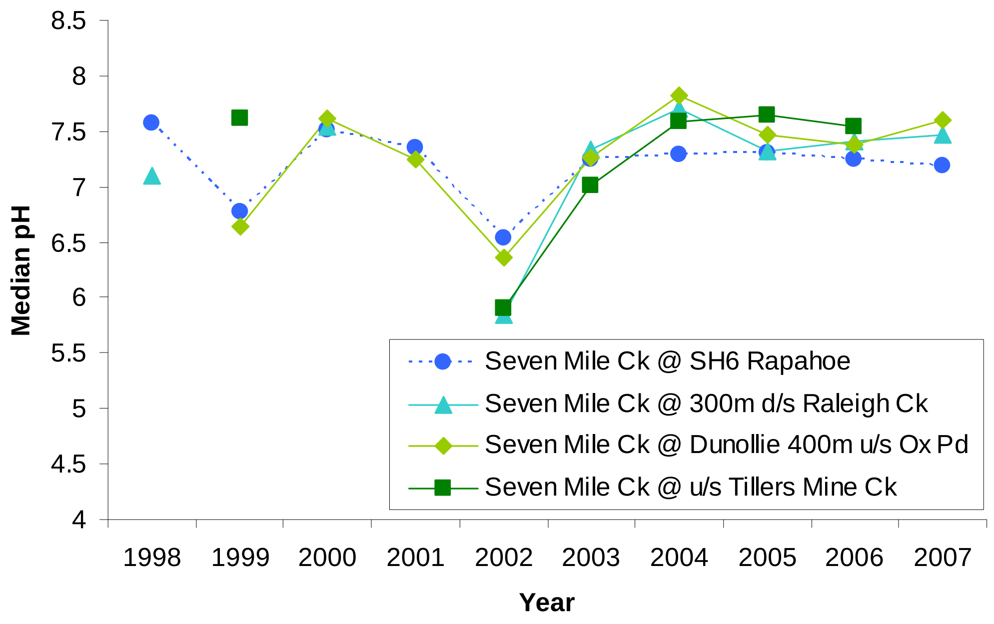


Figure 5.8.35 Seven Mile Creek – Yearly median pH.

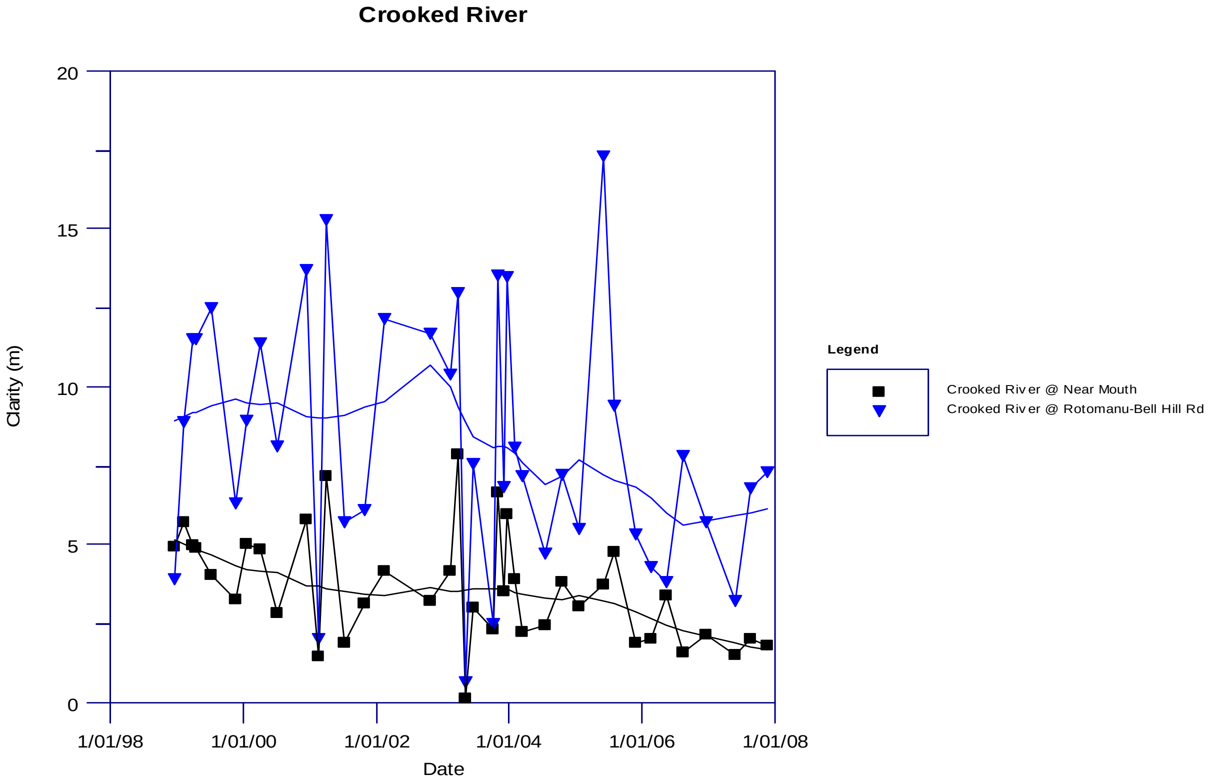


Figure 5.8.36 Crooked River – Visual clarity.

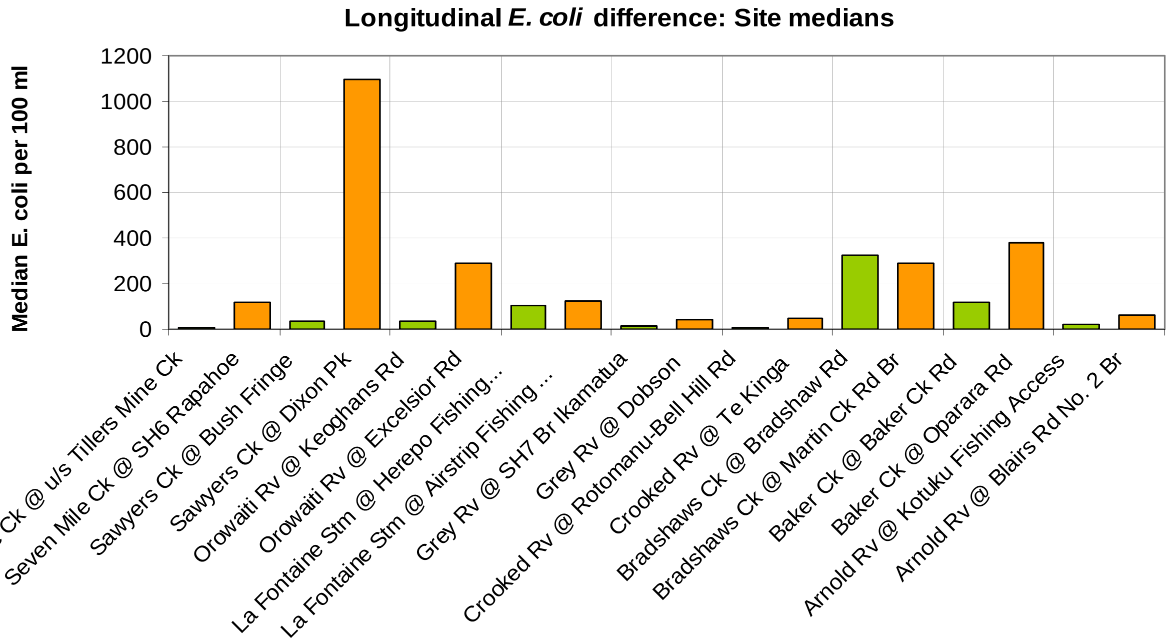


Figure 5.8.37 Longitudinal impact/reference differences: Site medians for E. coli.

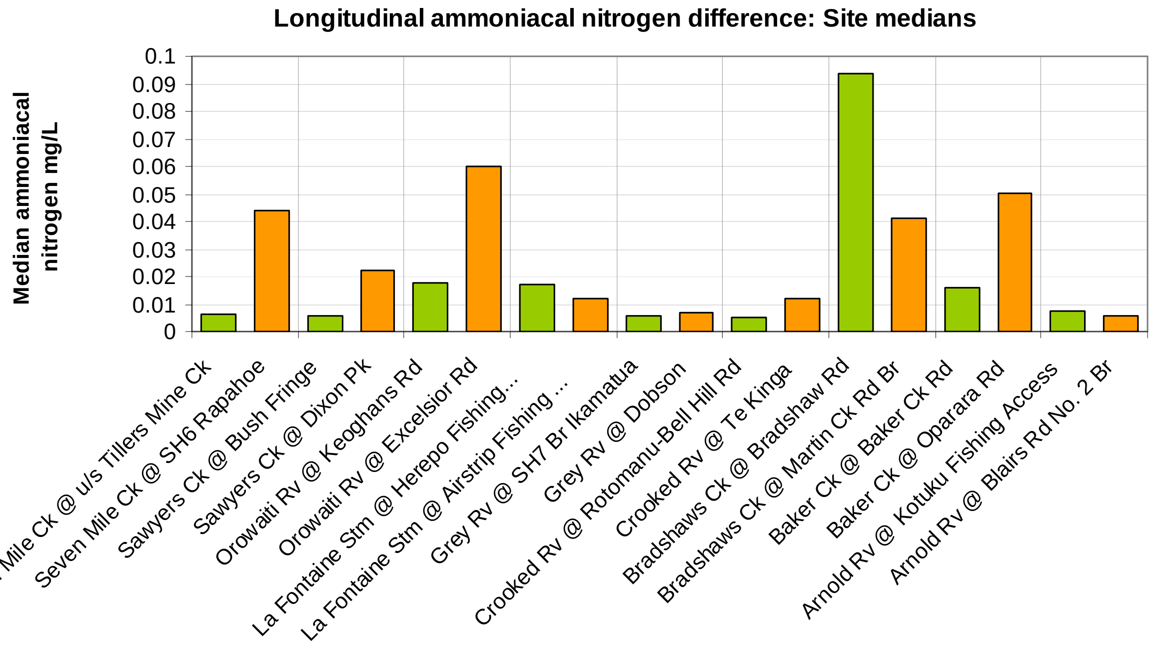


Figure 5.8.38 Longitudinal impact/reference differences: Site medians for ammoniacal nitrogen.

Note: Green bars indicate upstream reference site and orange bars indicate downstream impacted site.

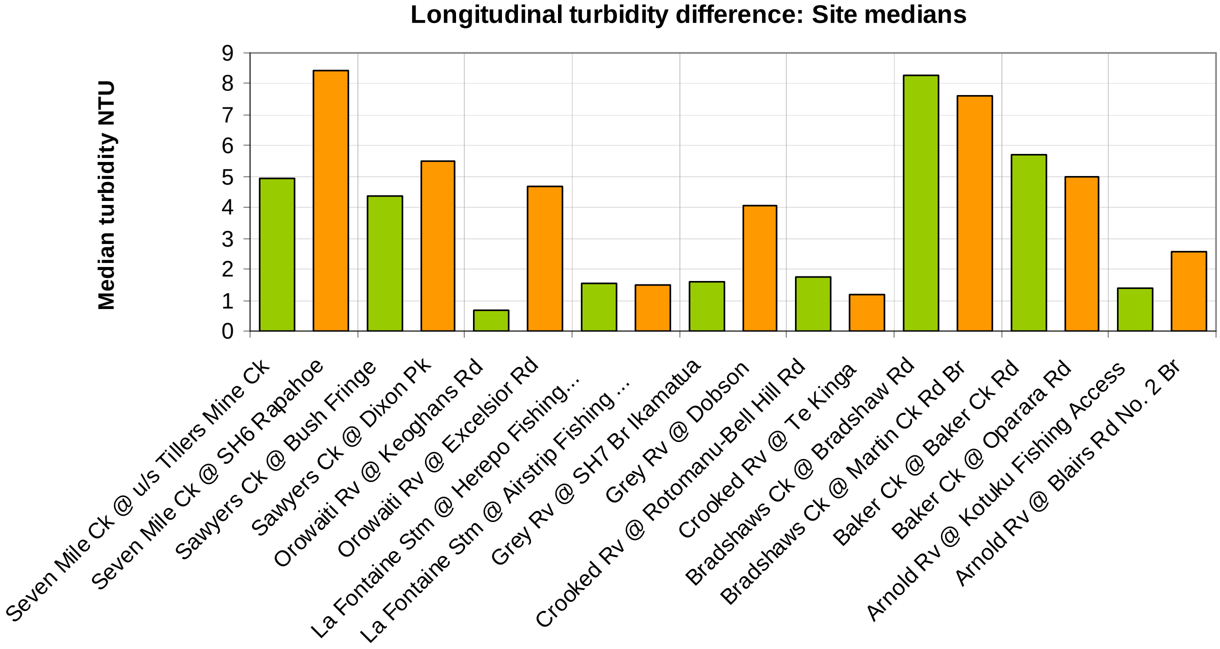


Figure 5.8.39 Longitudinal impact/reference differences: Site medians for turbidity.

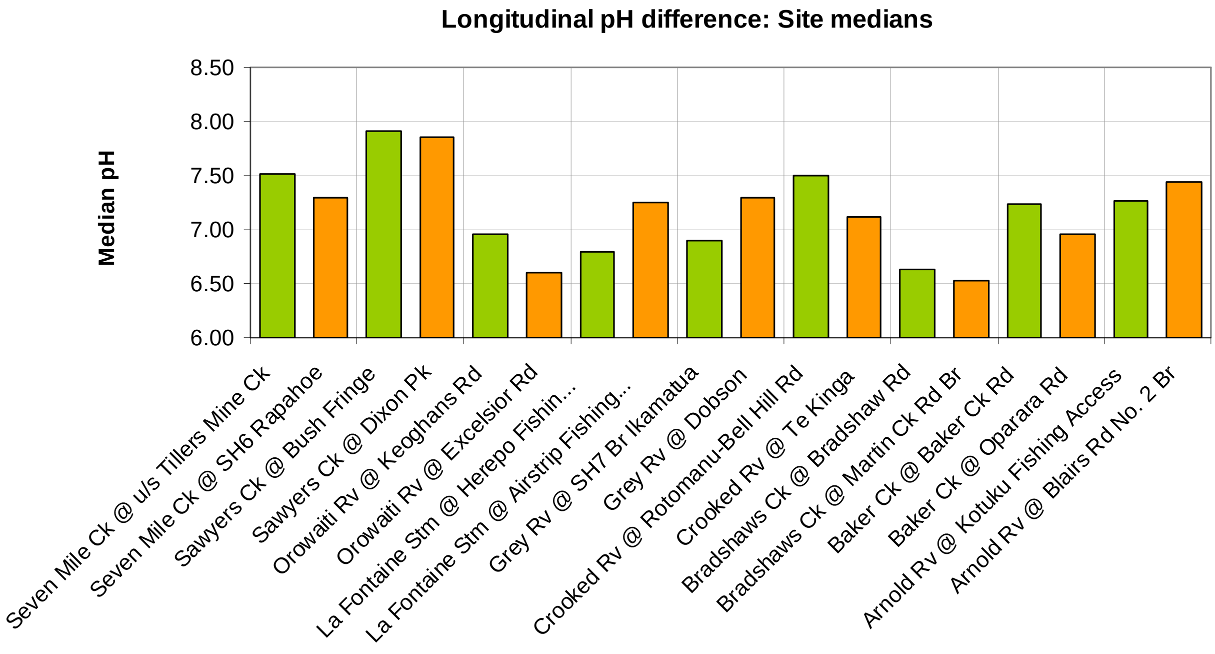


Figure 5.8.40 Longitudinal impact/reference differences: site medians for pH .

Note: Green bars indicate upstream reference site and orange bars indicate downstream impacted site.

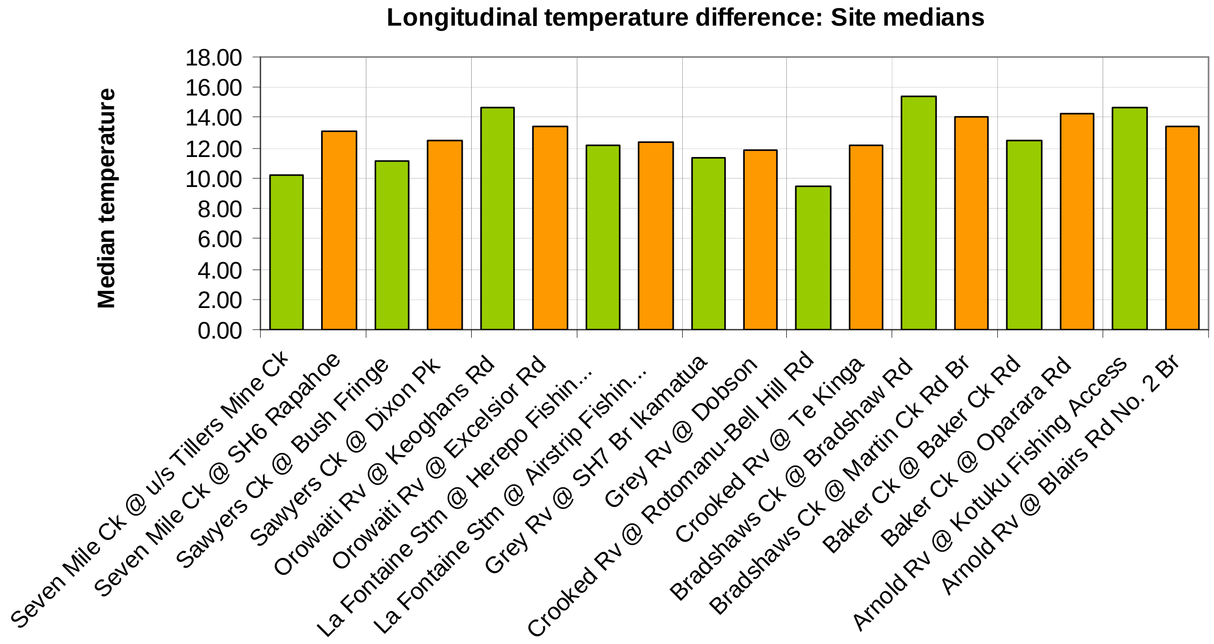


Figure 5.8.41 Longitudinal impact/reference differences: site medians for temperature.

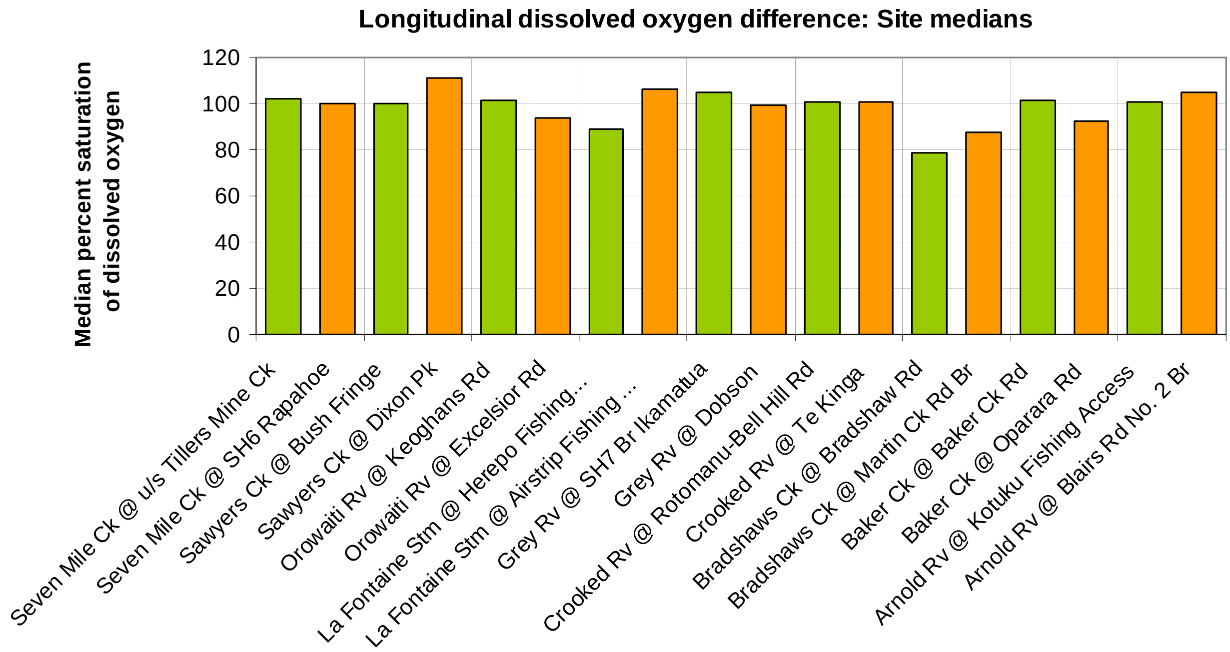


Figure 5.8.42 Longitudinal impact/reference differences: site medians for dissolved oxygen.

Note: Green bars indicate upstream reference site and orange bars indicate downstream impacted site.

5.9 Individual contact recreation sites

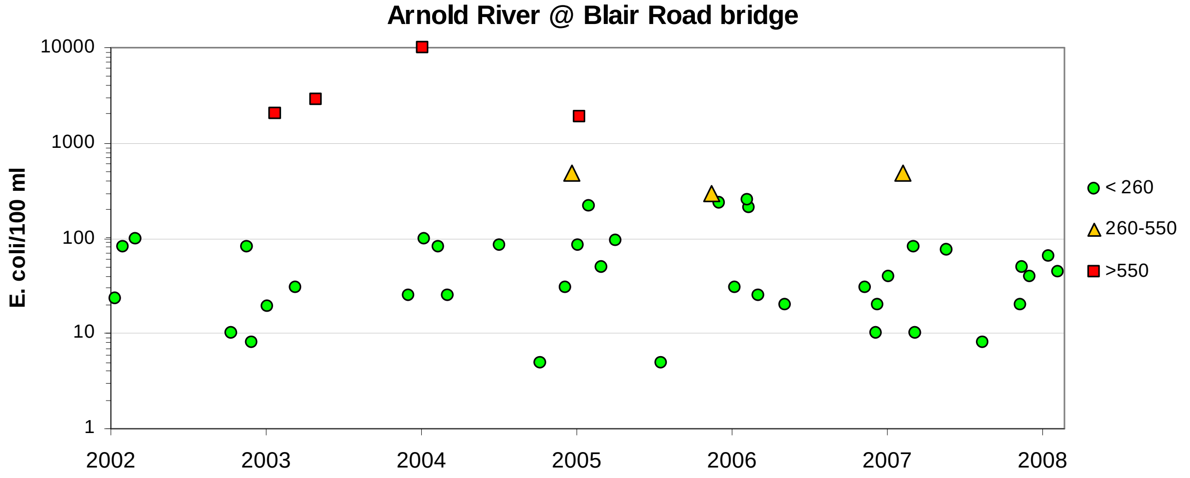


Figure 5.9.1 Single sample E. coli levels for Arnold River @ Blair Road bridge.

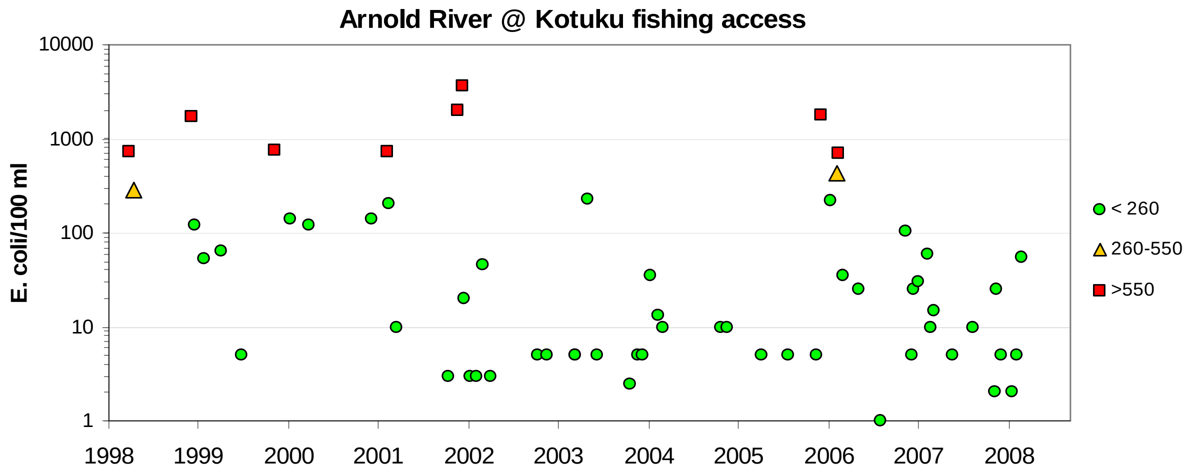


Figure 5.9.2 Single sample E. coli levels for Arnold River @ Kotuku fishing access.

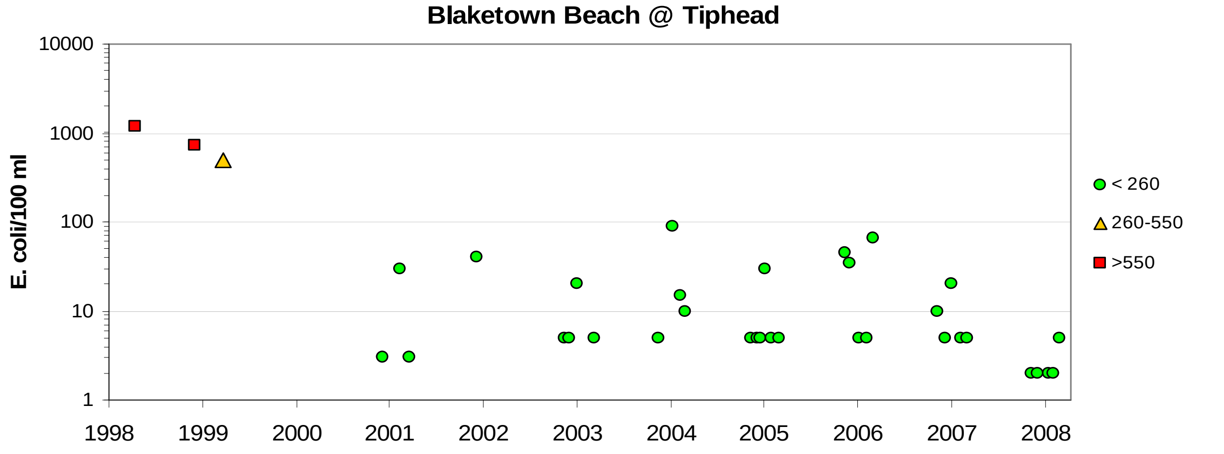


Figure 5.9.3 Single sample E. coli levels for Blaketown Beach @ Tiphead.

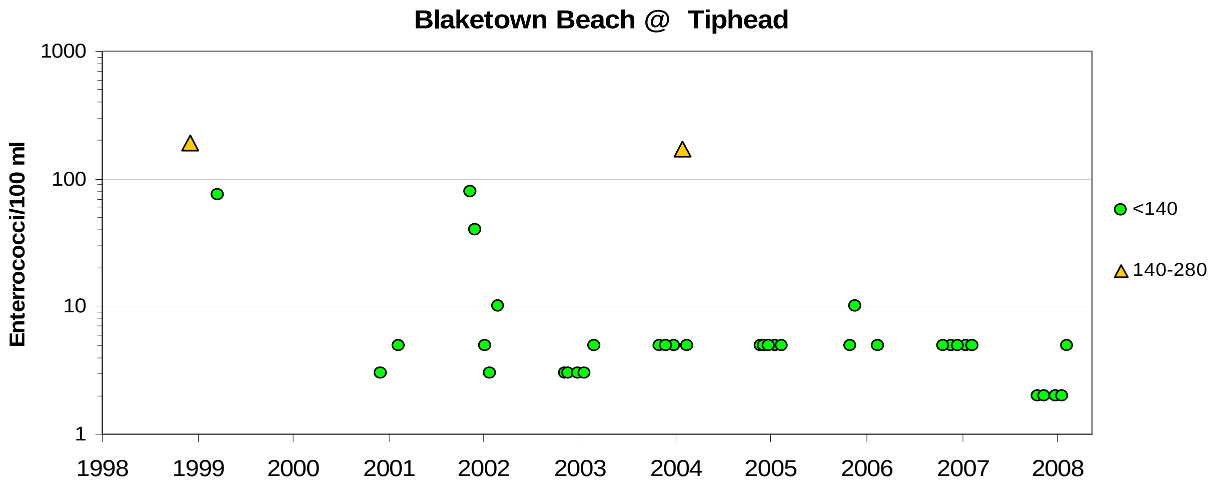


Figure 5.9.4 Single sample Enterrococci levels for Blaketown Beach @ Tiphead.

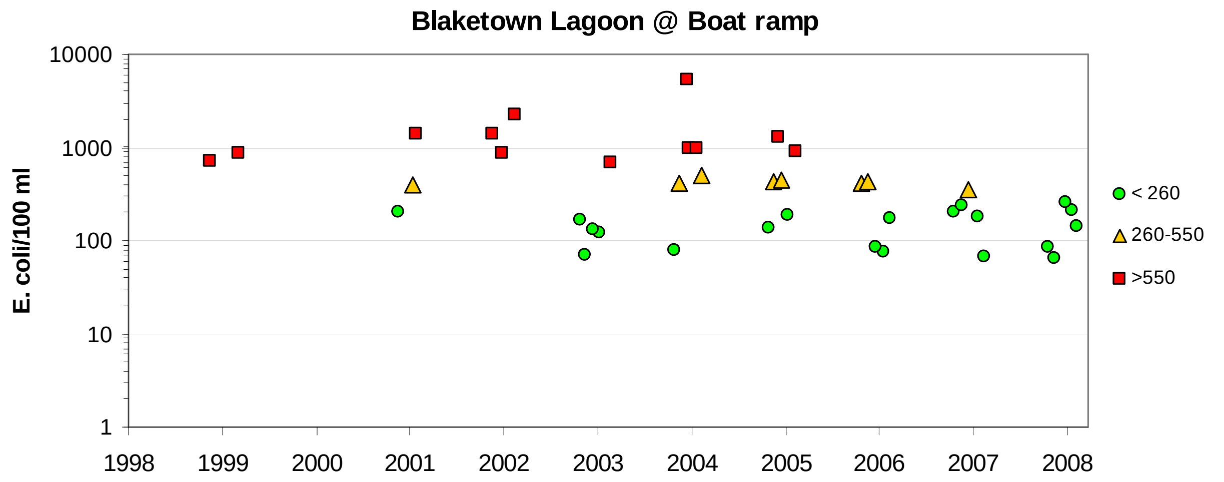


Figure 5.9.5 Single sample E. coli levels for Blaketown Lagoon @ Boat ramp.

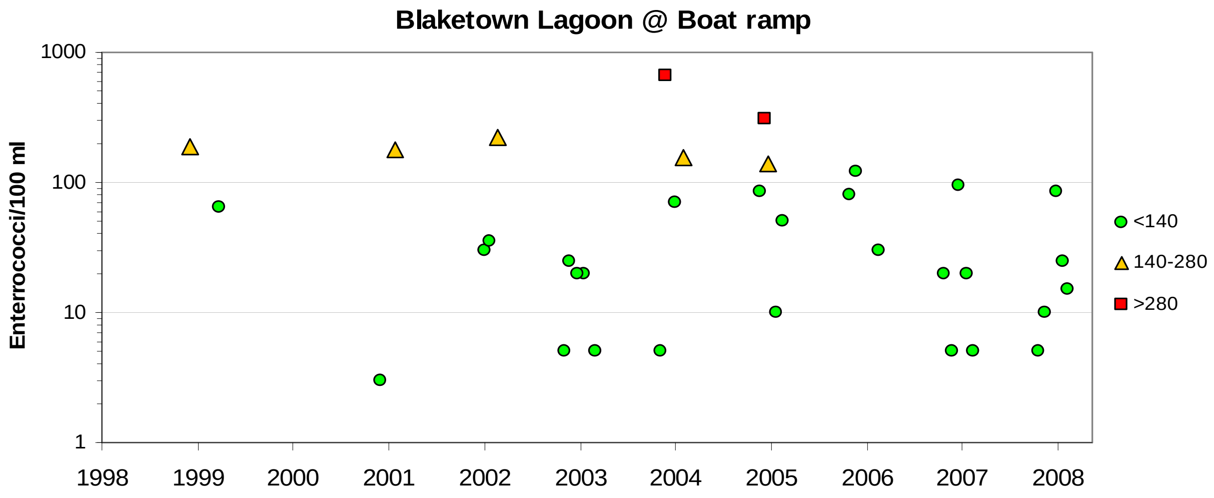


Figure 5.9.6 Single sample Enterrococci levels for Blaketown Lagoon @ Boat ramp.

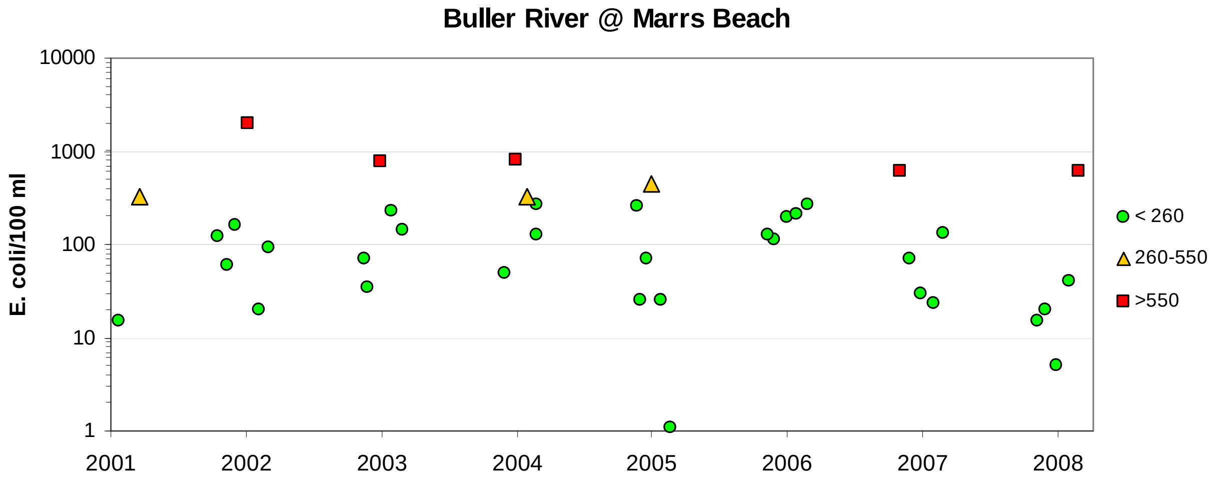


Figure 5.9.7 Single sample E. coli levels for Buller River @ Marrs Beach.

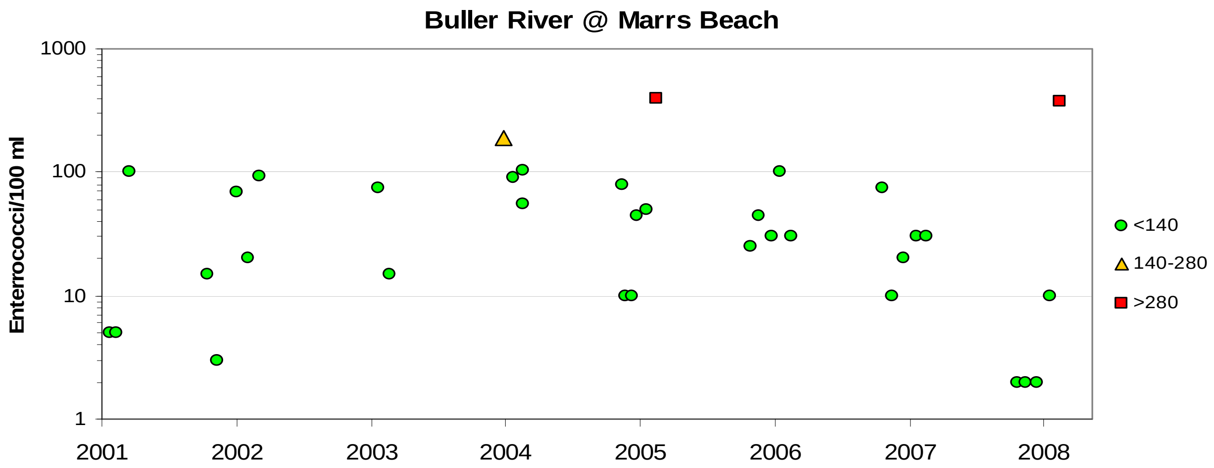


Figure 5.9.8 Single sample Enterrococci levels for Buller River @ Marrs Beach.

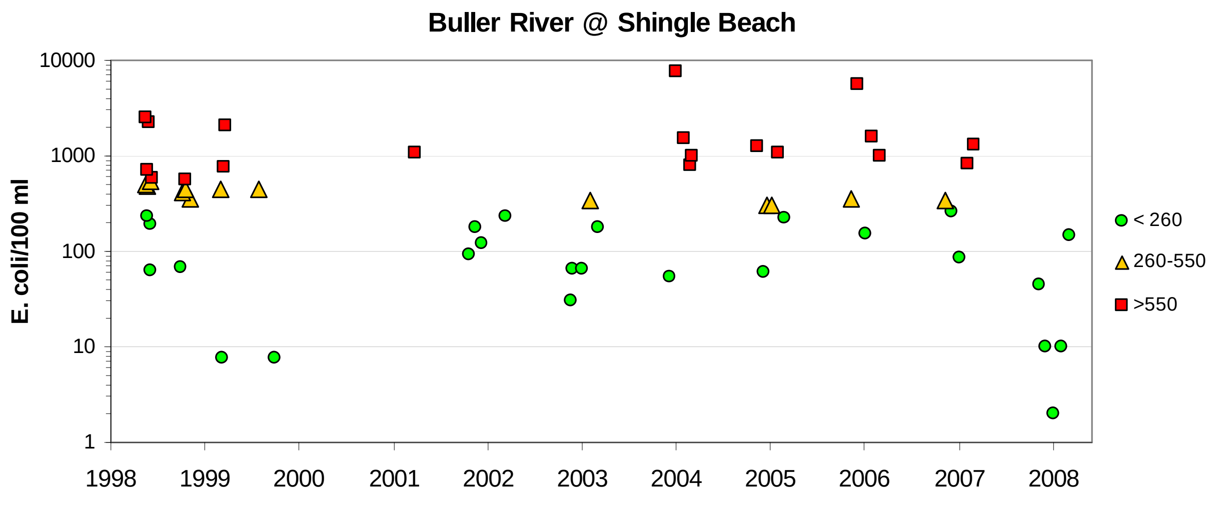


Figure 5.9.9 Single sample E. coli levels for Buller River @ Shingle Beach.

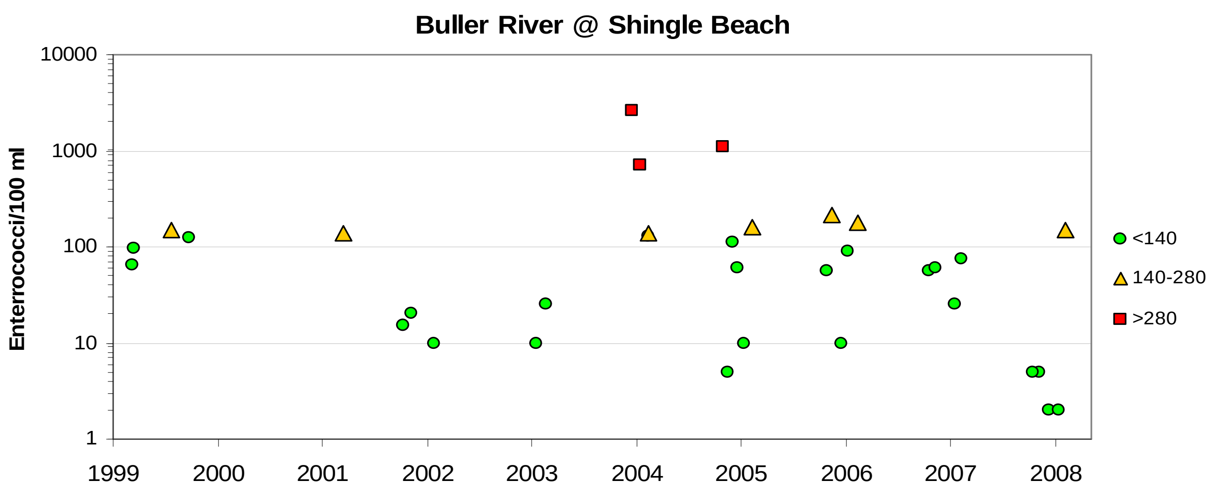


Figure 5.9.10 Single sample Enterrococci levels for Buller River @ Shingle Beach.

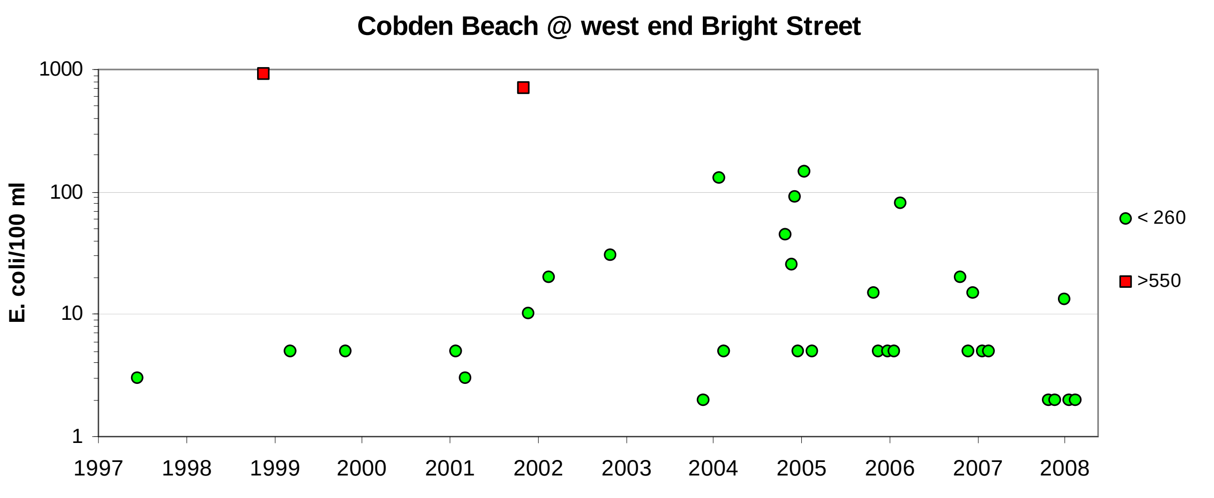


Figure 5.9.11 Single sample E. coli levels for Cobden Beach @ west end Bright Street.

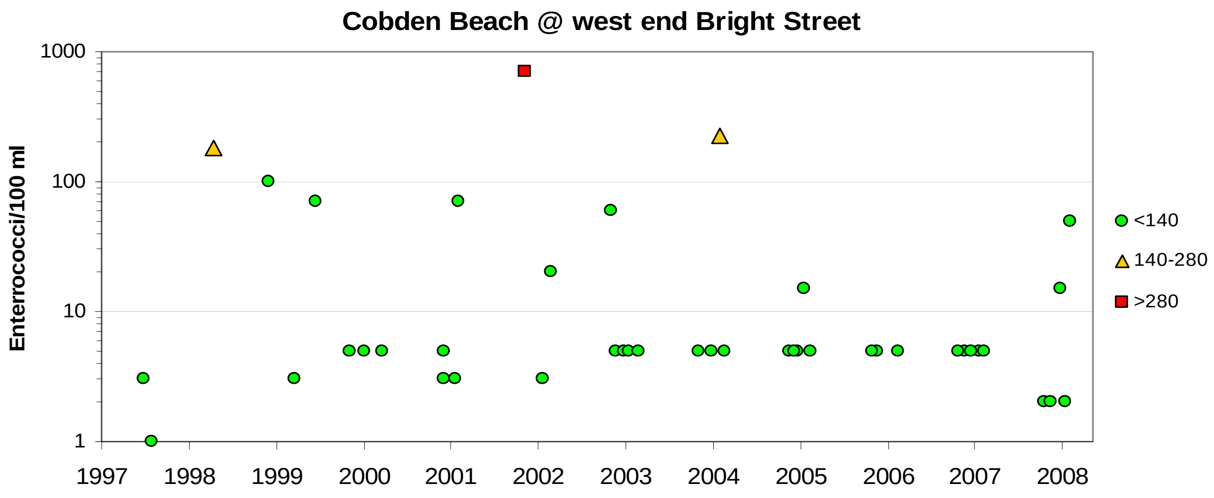


Figure 5.9.12 Single sample Enterrococci levels for Cobden Beach @ west end Bright Street.

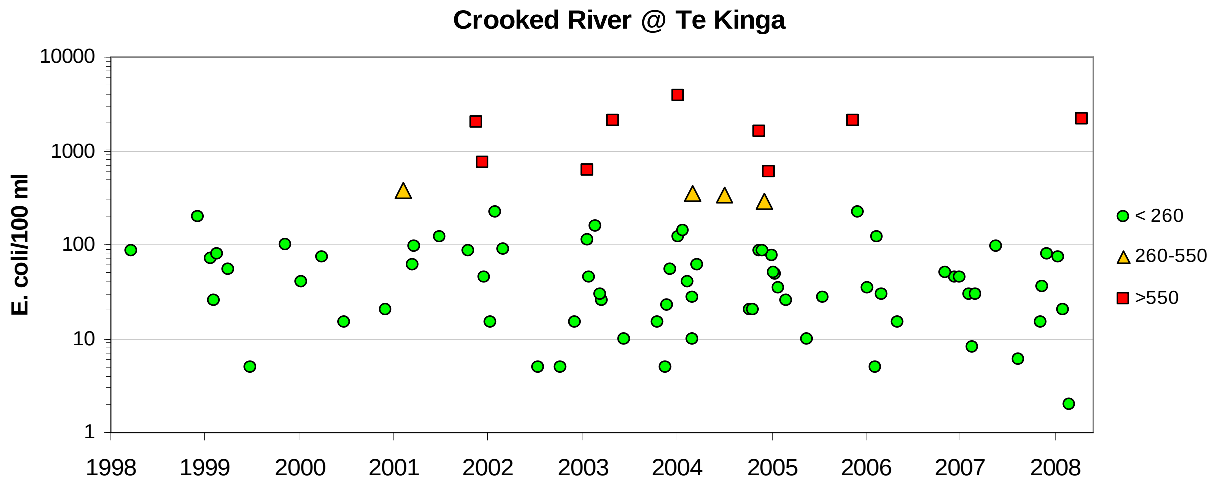


Figure 5.9.13 Single sample E. coli levels for Crooked River @ Te Kinga.

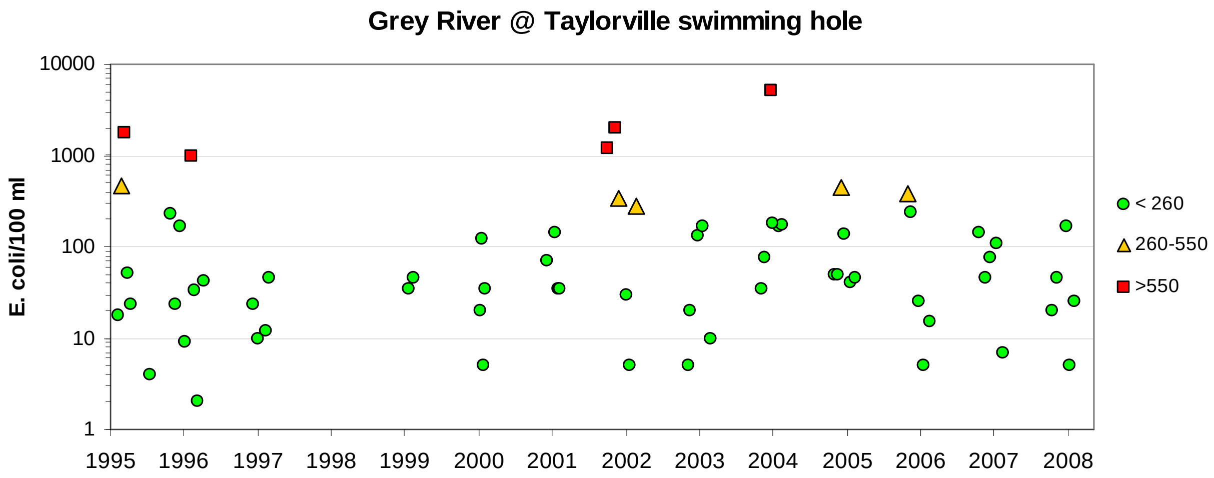


Figure 5.9.14 Single sample E. coli levels for Grey River @ Taylorville swimming hole.

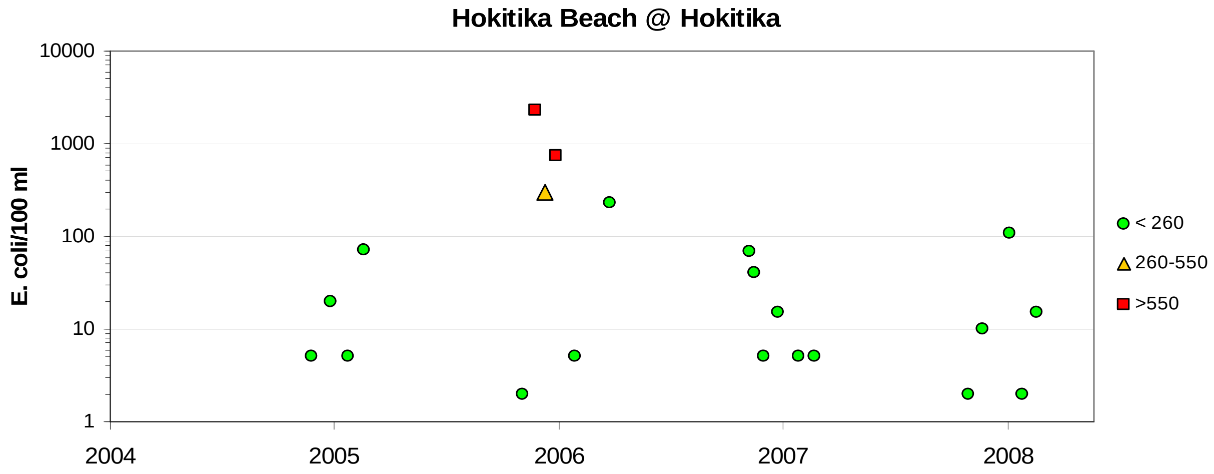


Figure 5.9.15 Single sample E. coli levels for Hokitika Beach @ Hokitika.

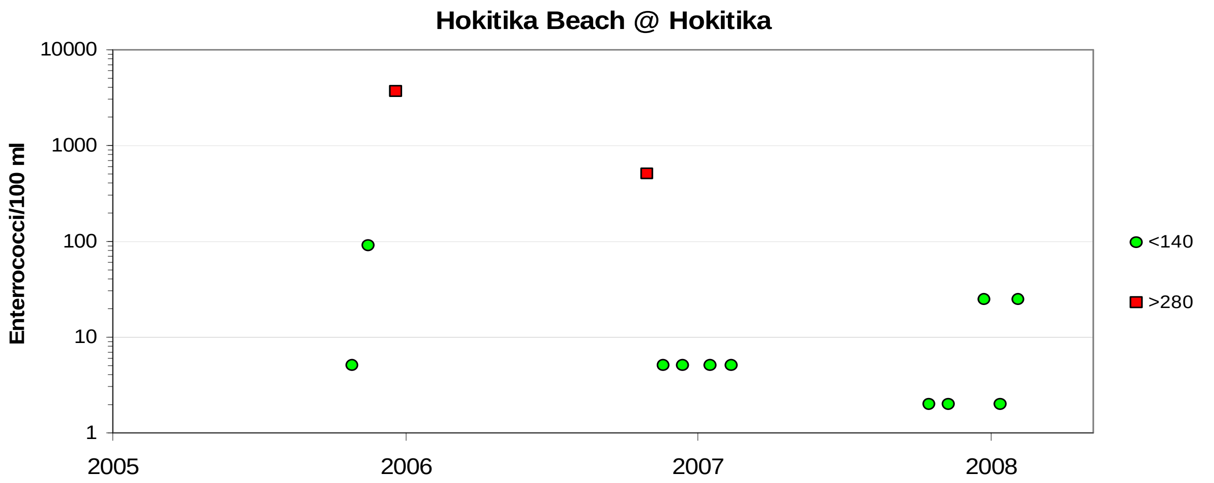


Figure 5.9.16 Single sample Enterrococci levels for Hokitika Beach @ Hokitika.

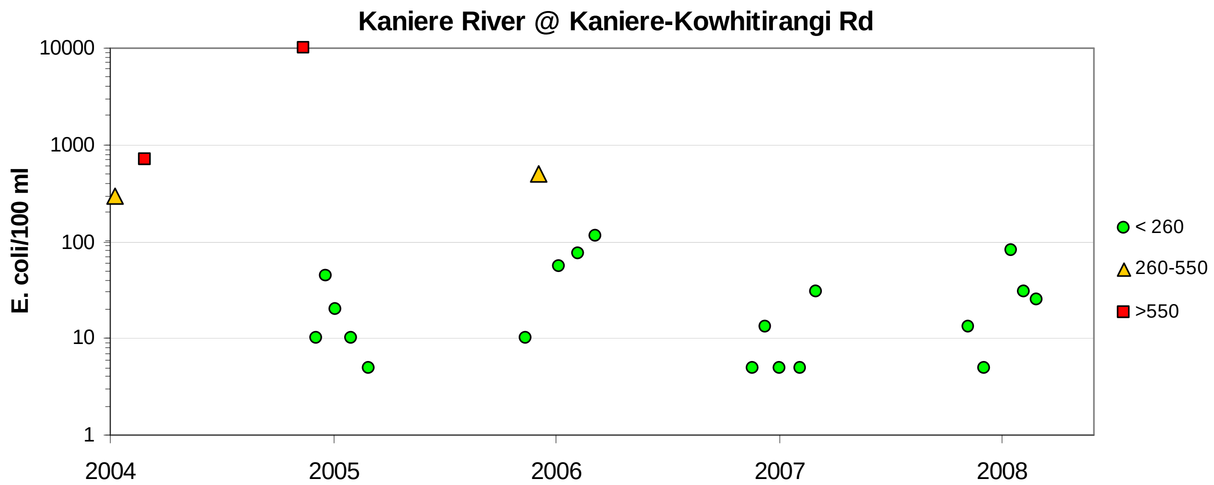


Figure 5.9.17 Single sample E. coli levels for Kaniere River @ Kaniere – Kowhitirangi Road.

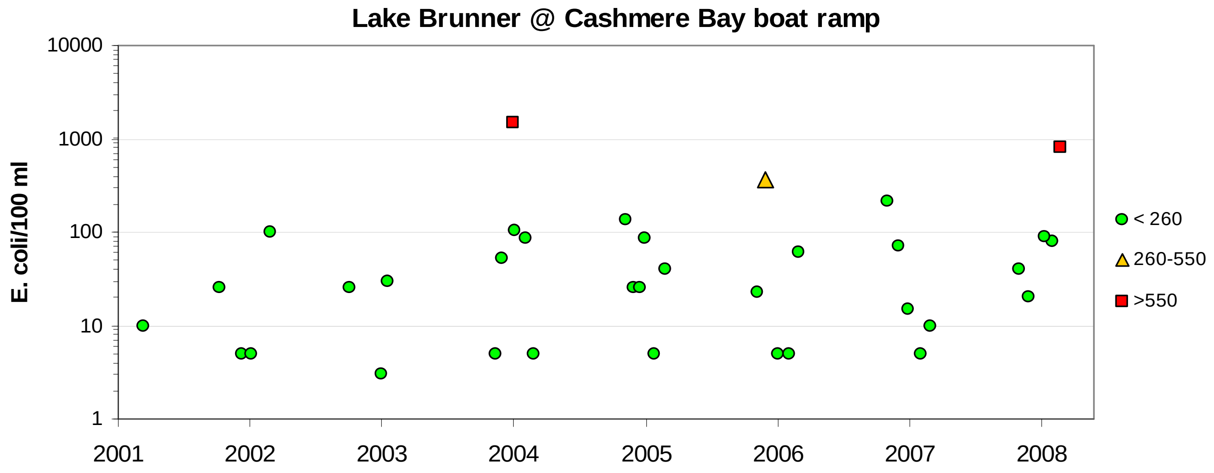


Figure 5.9.18 Single sample E. coli levels for Lake Brunner @ Cashmere Bay boat ramp.

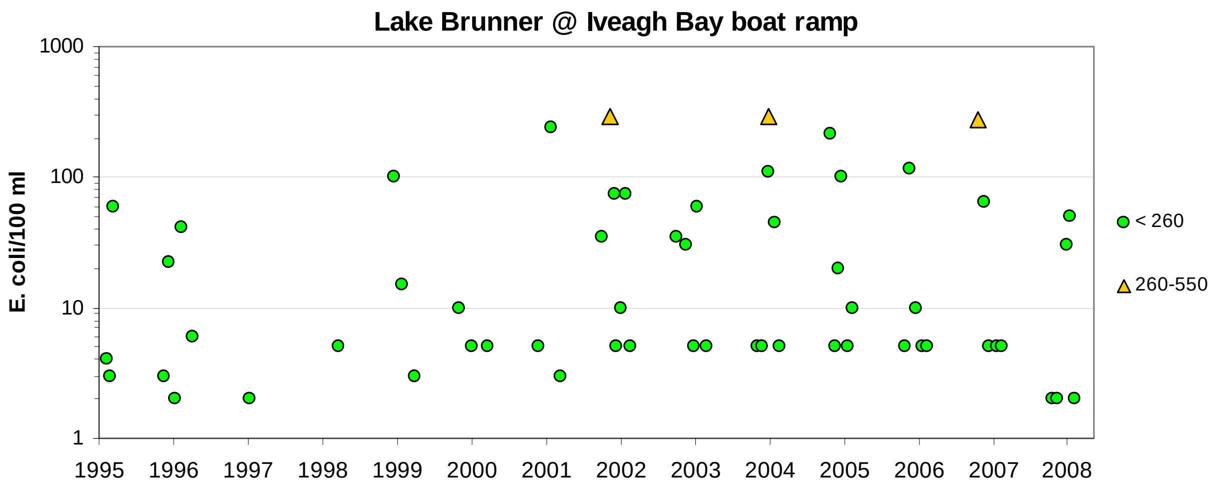


Figure 5.9.19 Single sample E. coli levels for Lake Brunner @ Iveagh Bay boat ramp.

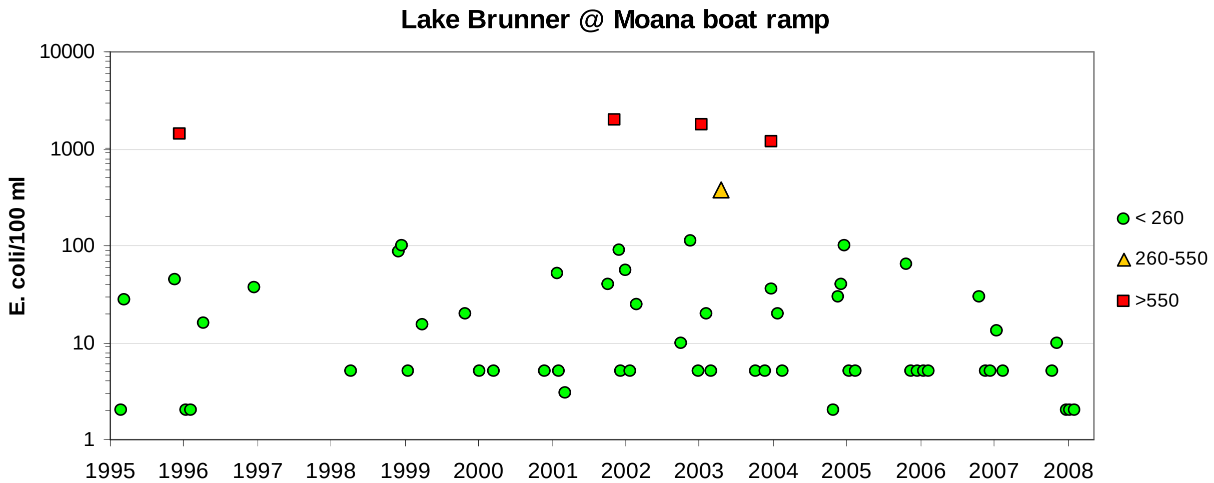


Figure 5.9.20 Single sample E. coli levels for Lake Brunner @ Moana boat ramp.

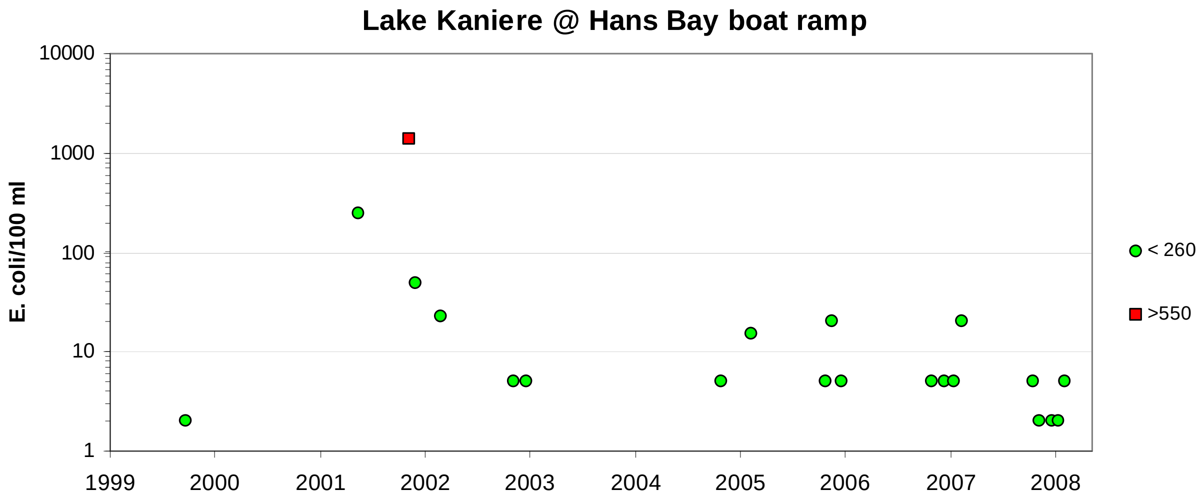


Figure 5.9.21 Single sample E. coli levels for Lake Kaniere @ Hans Bay boat ramp.

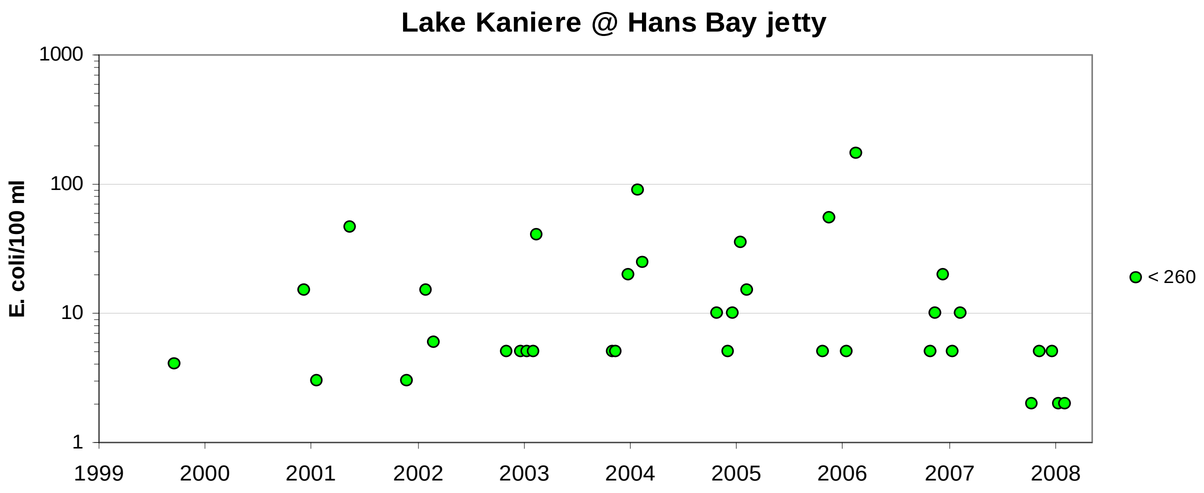


Figure 5.9.22 Single sample E. coli levels for Lake Kaniere @ Hans Bay jetty.

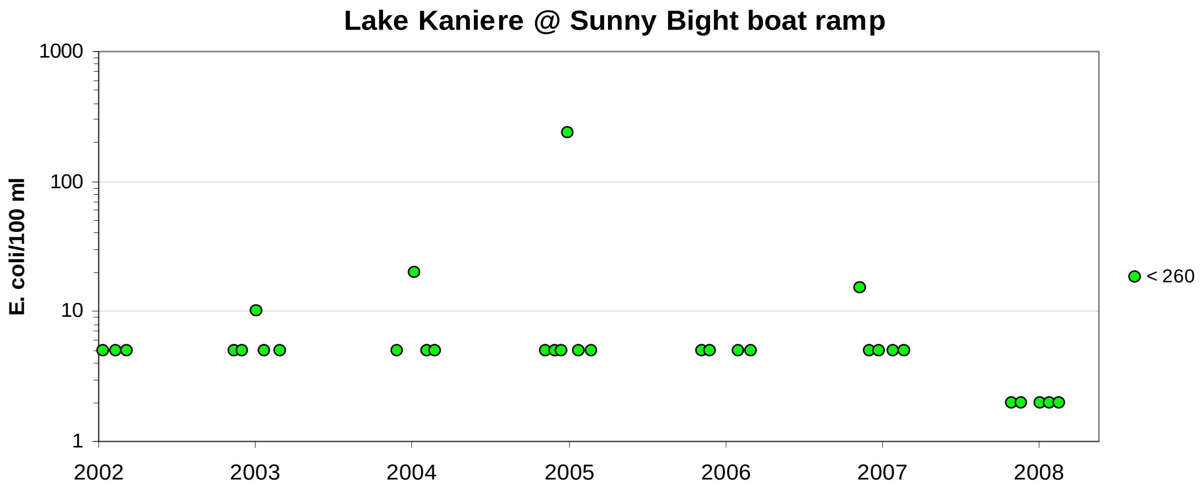


Figure 5.9.23 Single sample E. coli levels for Lake Kaniere @ Sunny Bight boat ramp.

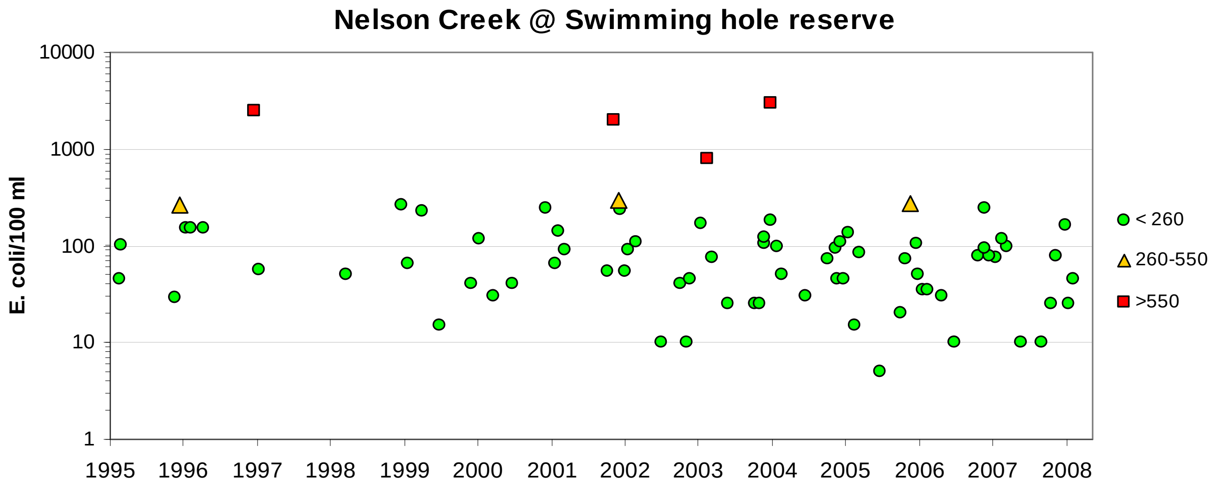


Figure 5.9.24 Single sample E. coli levels for Nelson Creek @ Swimming hole reserve.

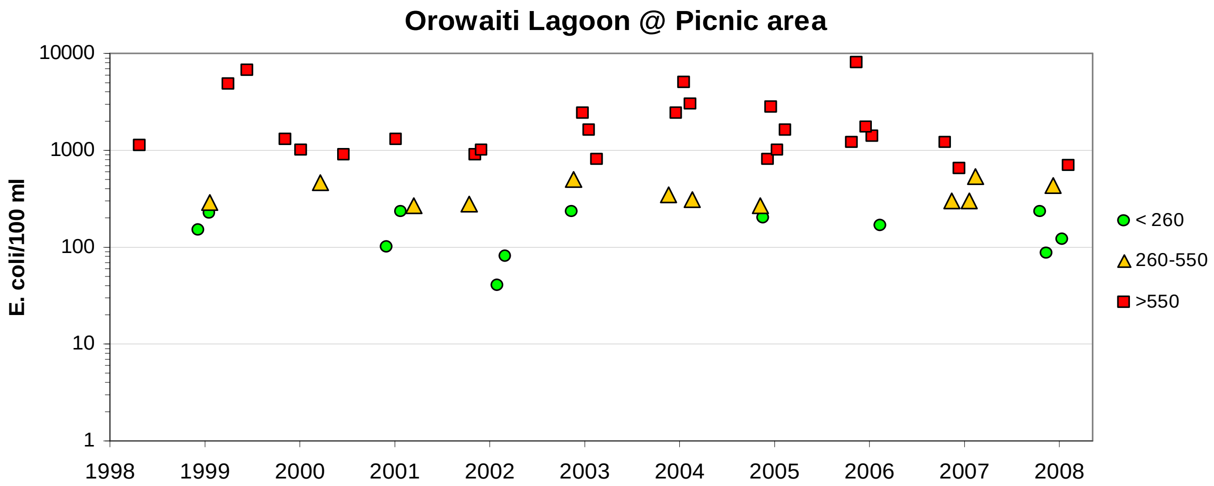


Figure 5.9.25 Single sample E. coli levels for Orowaiti Lagoon @ Picnic area.

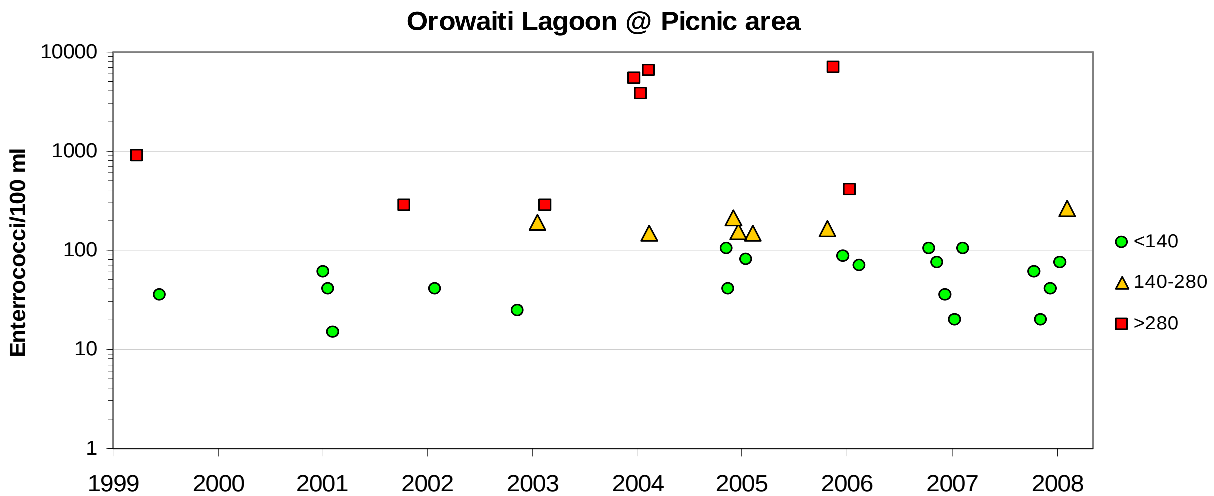


Figure 5.9.26 Single sample Enterrococci levels for Orowaiti Lagoon @ Picnic area.

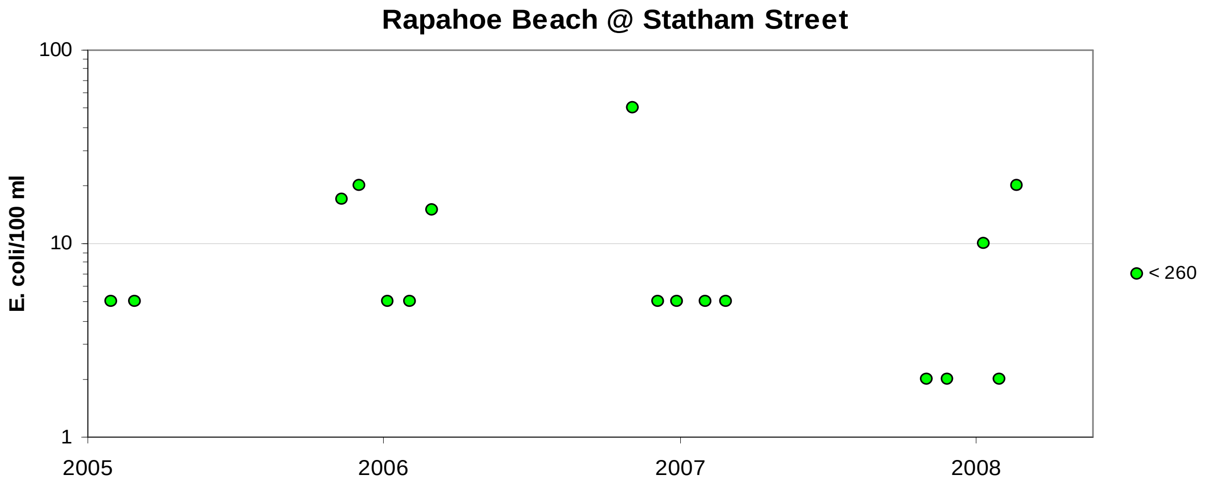


Figure 5.9.27 Single sample E. coli levels for Rapahoe Beach @ Statham Street.

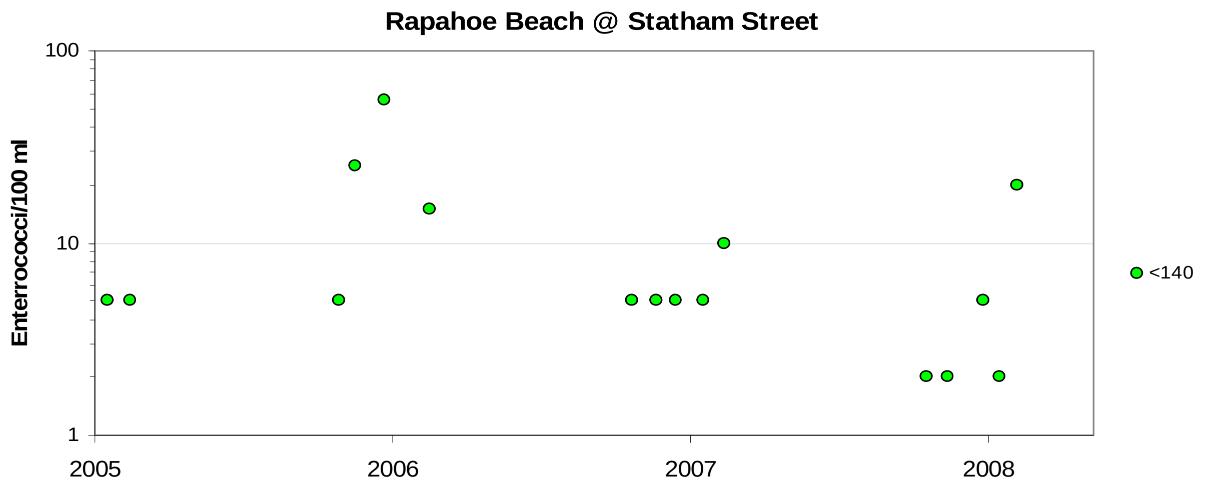


Figure 5.9.28 Single sample Enterrococci levels for Rapahoe Beach @ Statham Street.

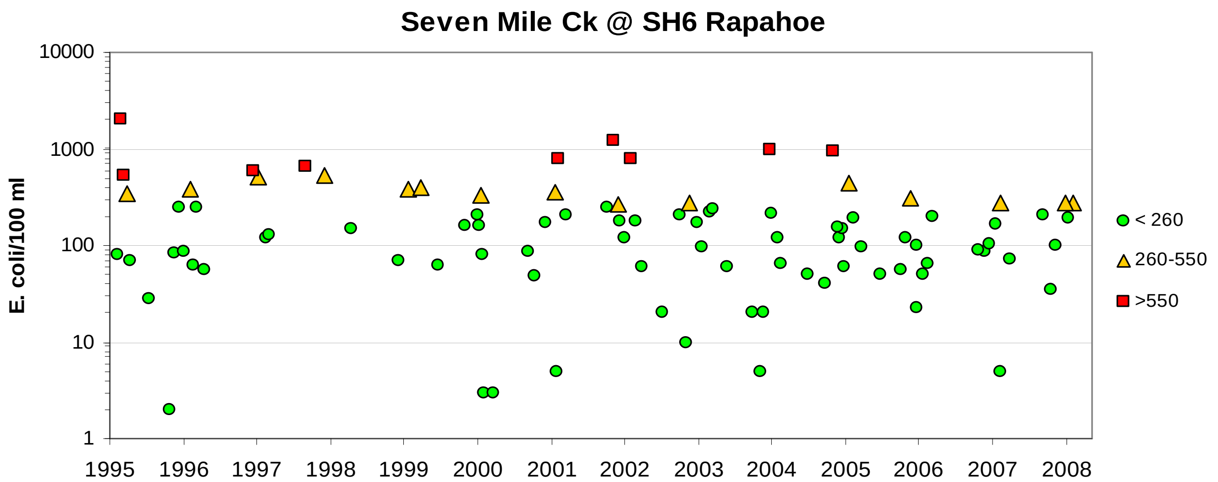


Figure 5.9.29 Single sample E. coli levels for Seven Mile Creek @ SH6 Rapahoe.

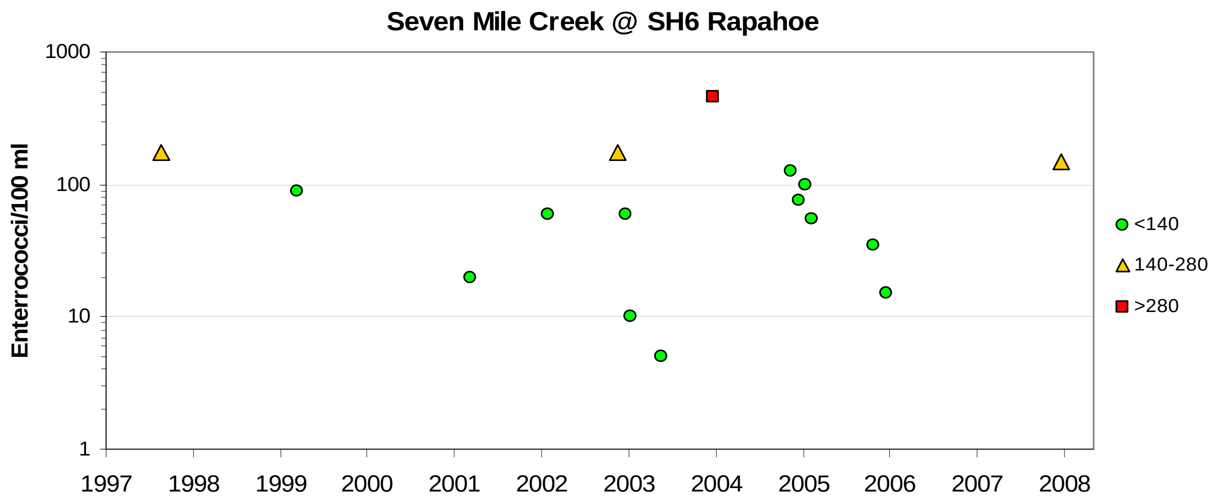


Figure 5.9.30 Single sample Enterrococci levels for Seven Mile Creek @ SH6 Rapahoe.

5.10 Regional-scale summary of water quality trends

The first step in producing summary figures was to compute annual median values at each site for all variables with sufficient length of record. Summary figures were then compiled with values from each site (i.e., annual median) used as the replicate data to calculate 25th, 50th (median) and 75th percentile values for the region in each year. This is similar to the approach taken by Scarsbrook (2006) in national SoE reporting.

Values of N for each year are given at the top of the graph.

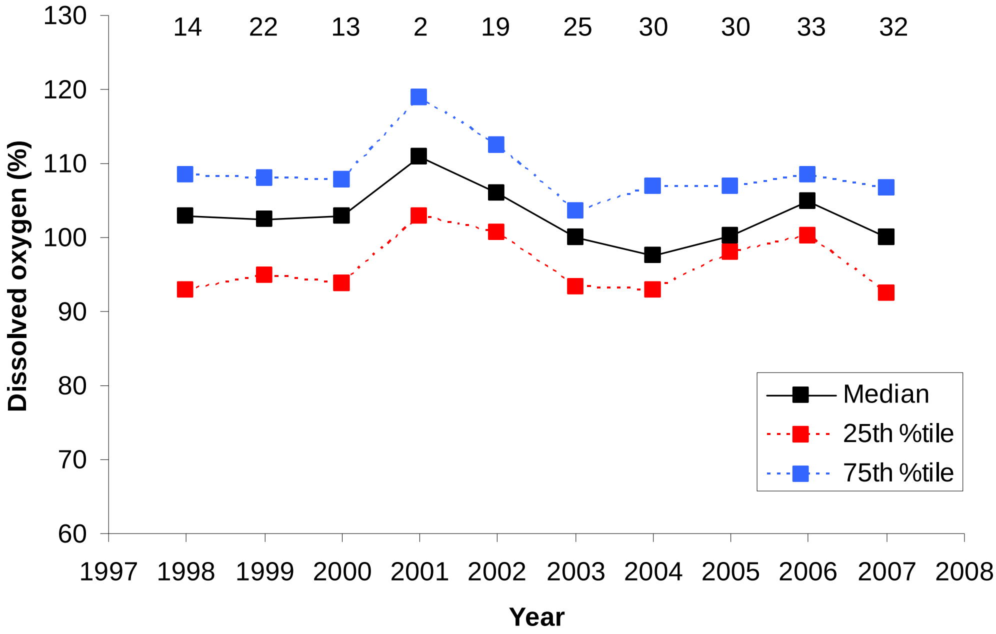


Figure 5.10.1 Seasonal annual median: Dissolved oxygen.

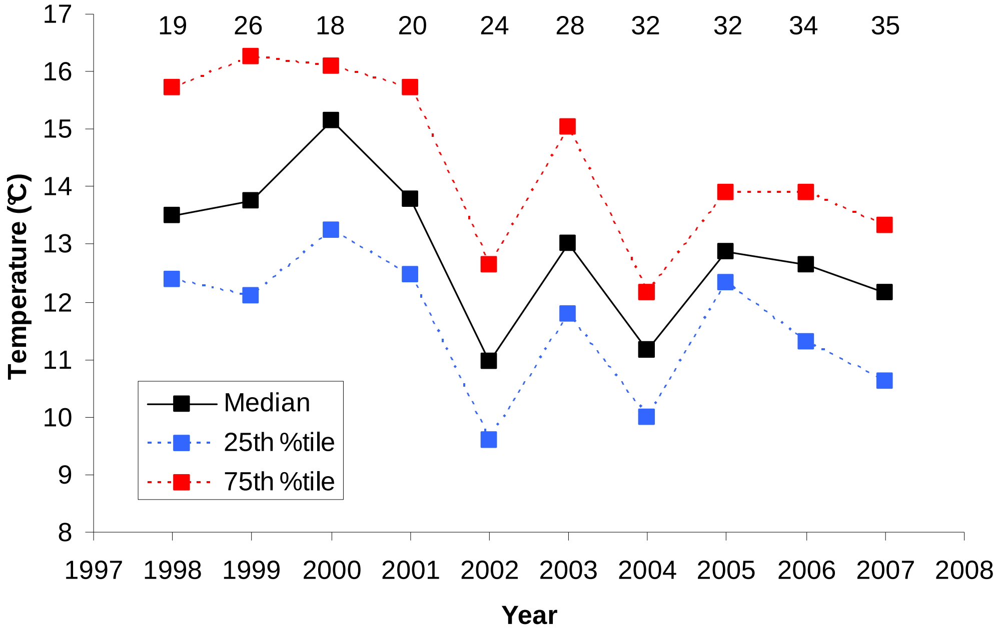


Figure 5.10.2 Seasonal annual median: Temperature.

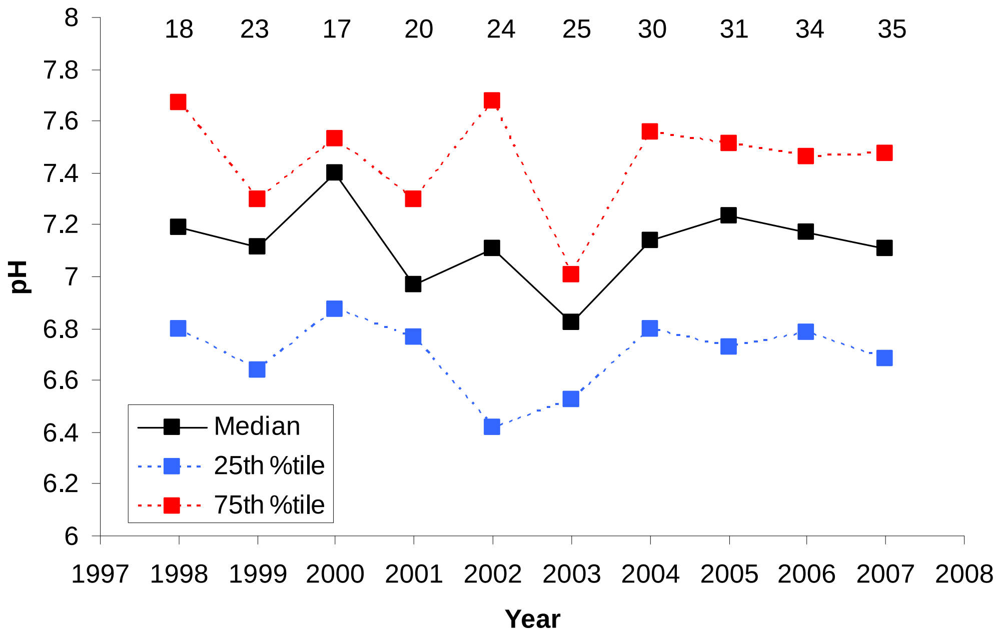


Figure 5.10.3 Seasonal annual median: pH.

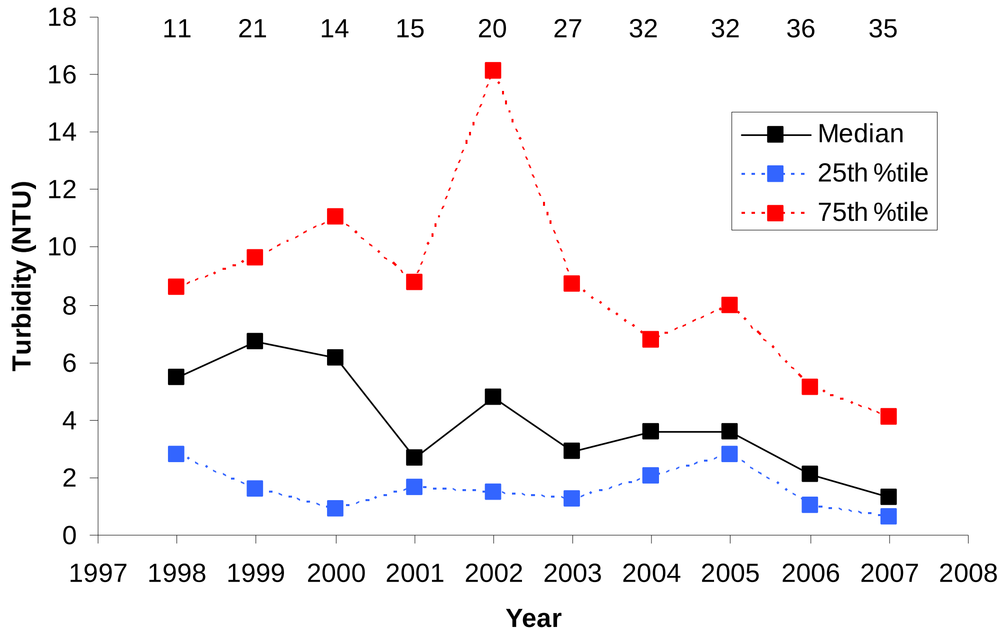


Figure 5.10.4 Seasonal annual median: Turbidity.

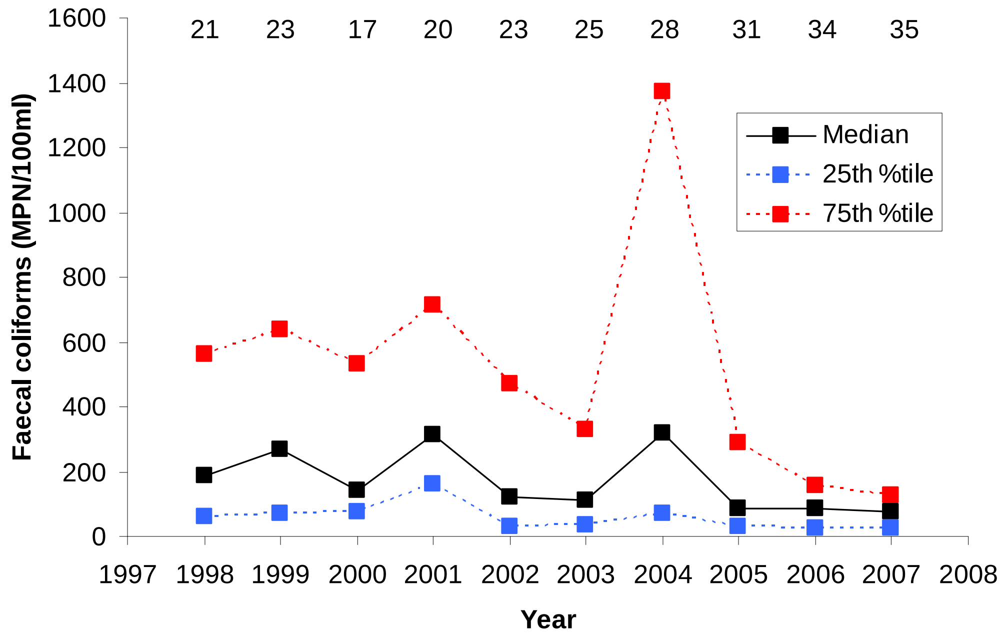


Figure 5.10.5 Seasonal annual median: Faecal coliforms.

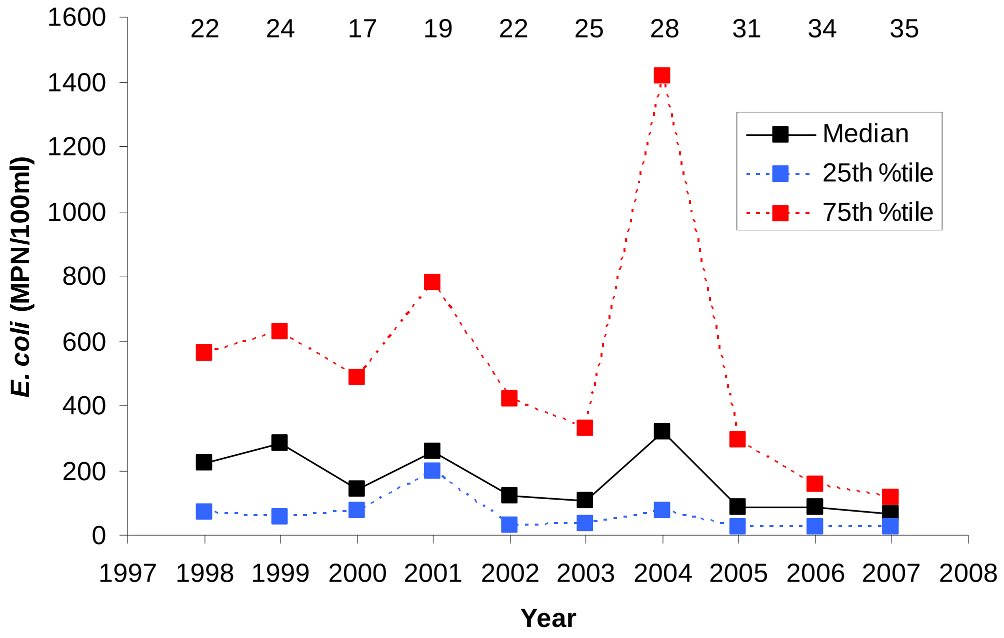


Figure 5.10.6 Seasonal annual median: E. coli.

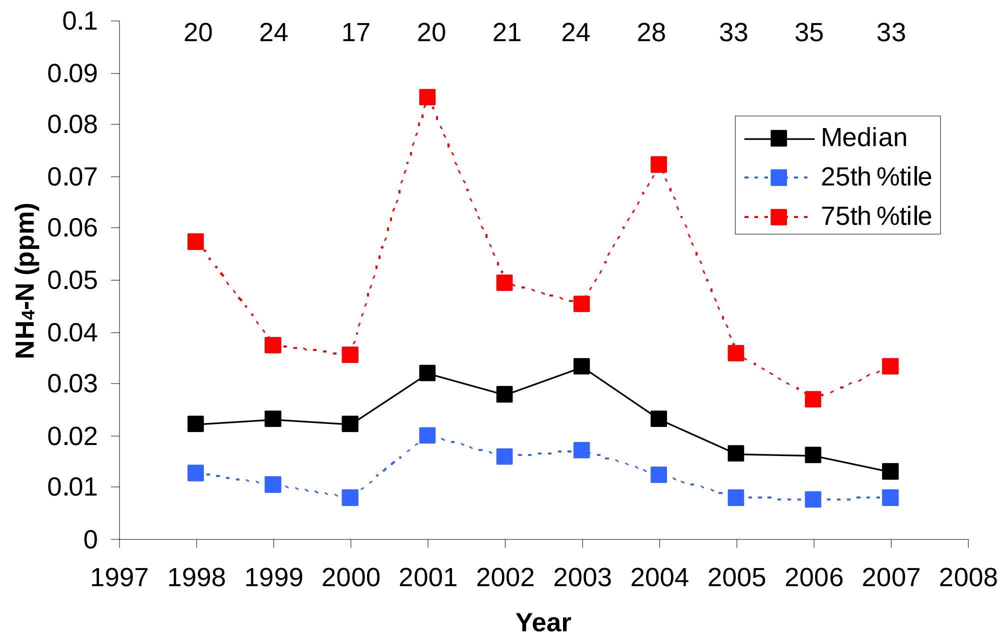


Figure 5.10.7 Seasonal annual median: Ammoniacal nitrogen.

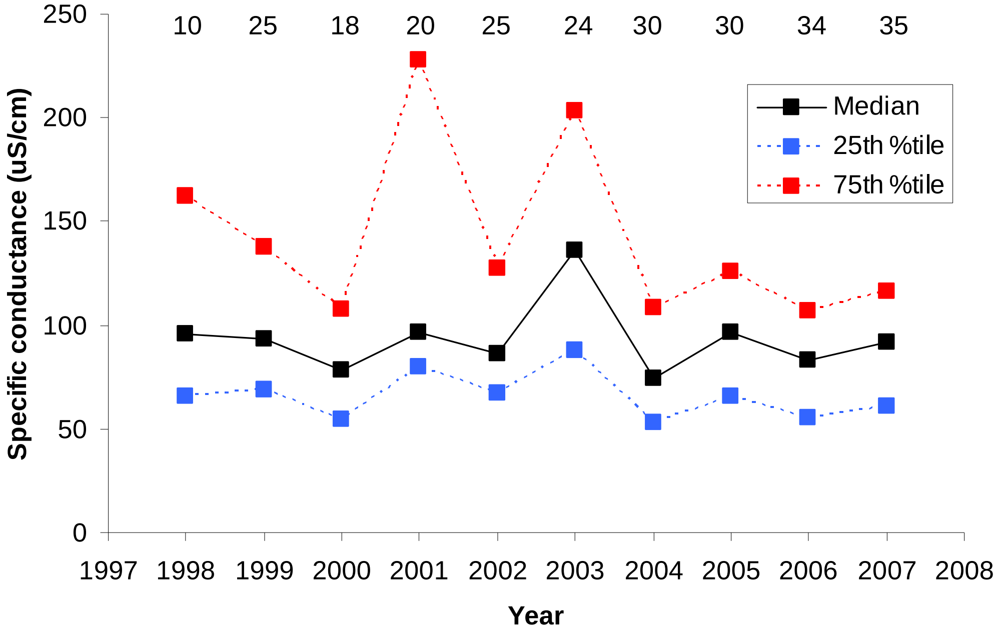


Figure 5.10.8 Seasonal annual median: Conductivity.

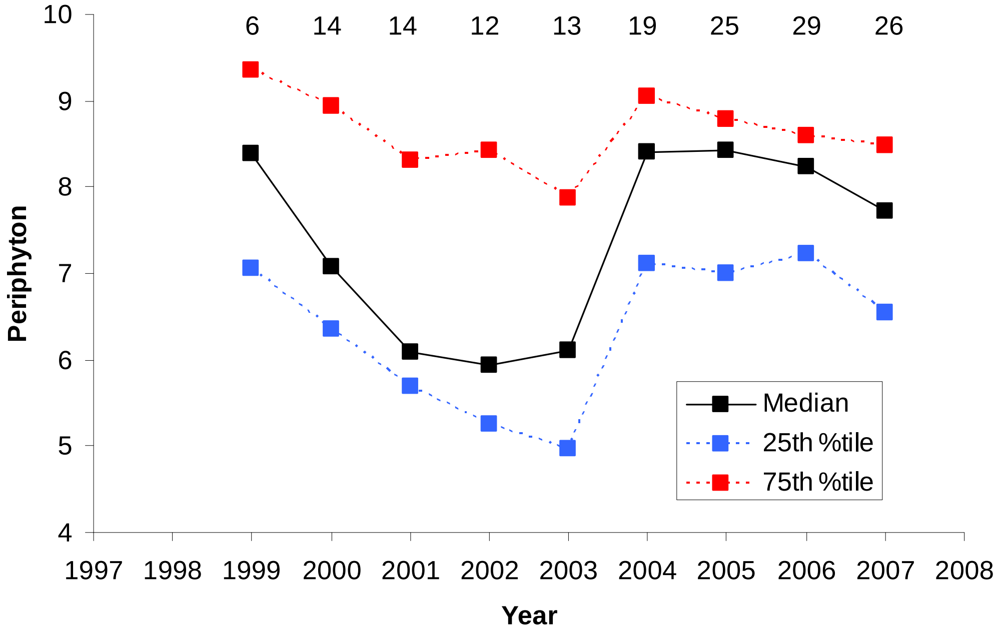


Figure 5.10.9 Seasonal annual median: Periphyton.

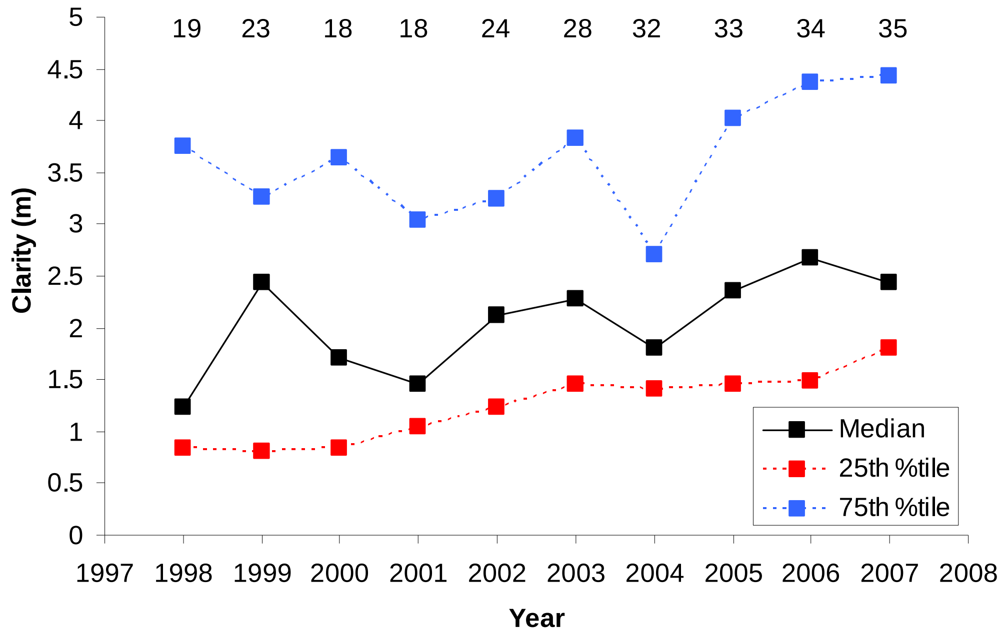


Figure 5.10.10 Seasonal annual median: Clarity.

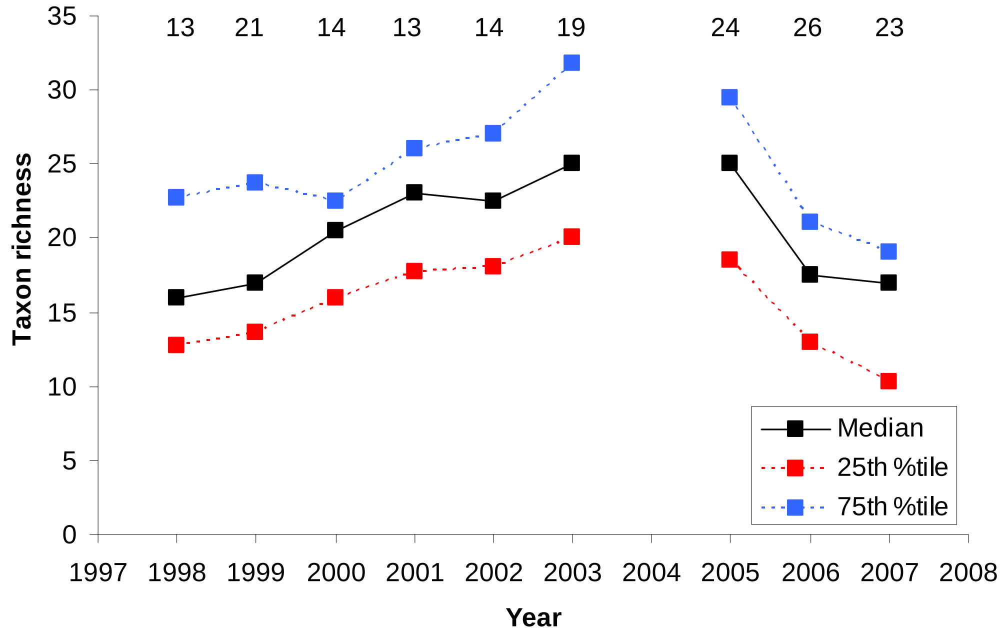


Figure 5.10.11 Seasonal annual median: Taxon richness.

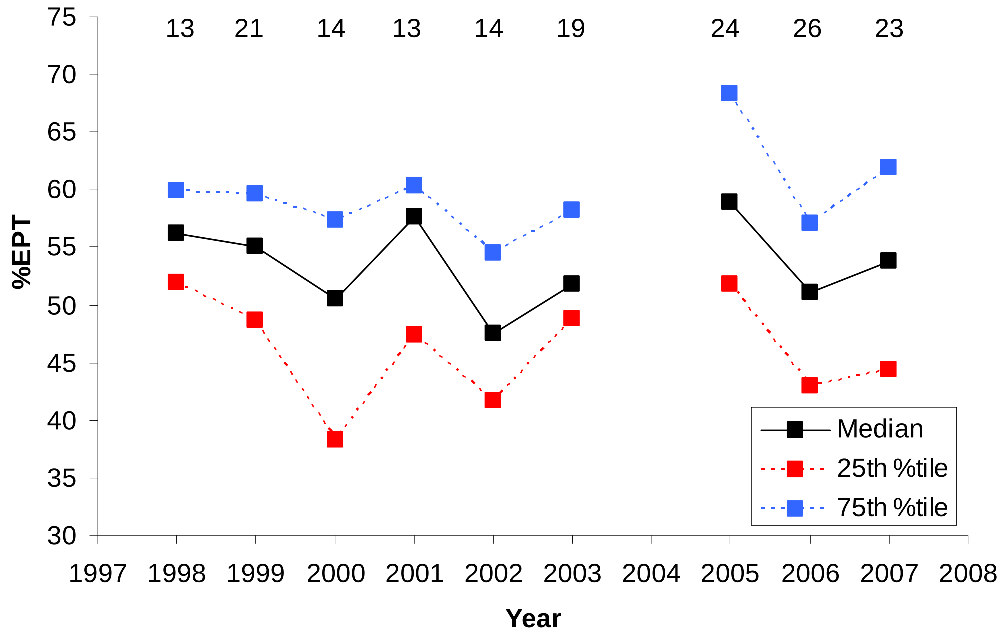


Figure 5.10.12 Seasonal annual median: Percentage EPT.

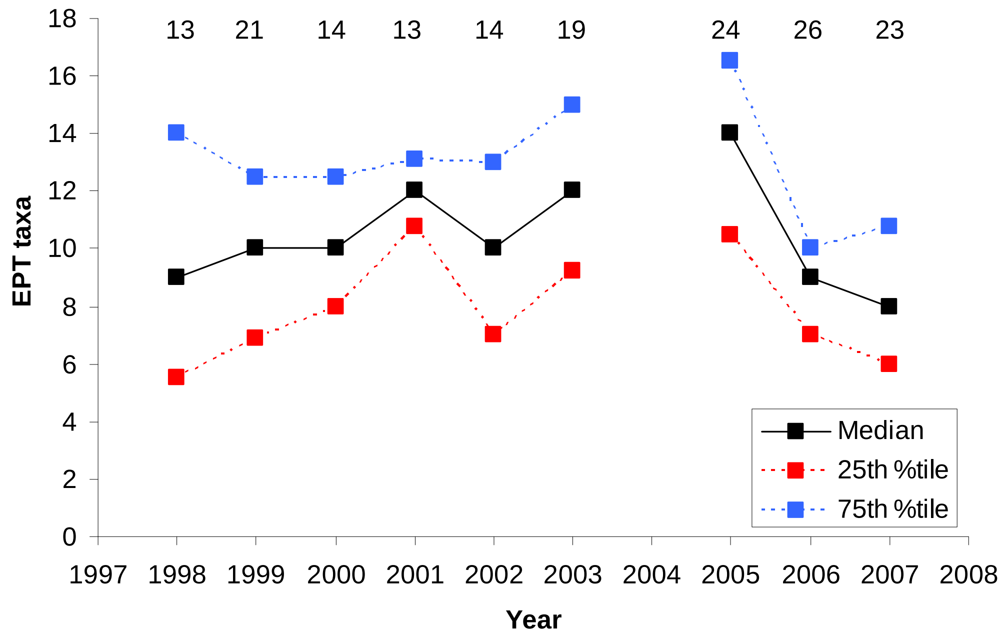


Figure 5.10.13 Seasonal annual median: EPT taxa.

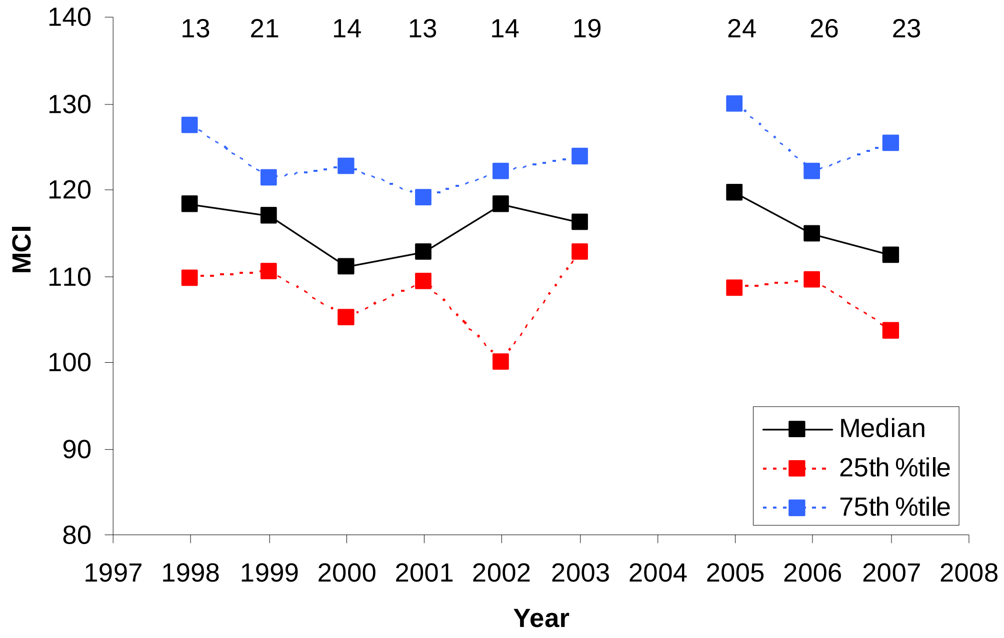


Figure 5.10.14 Seasonal annual median: Macroinvertebrate Community Index (MCI).

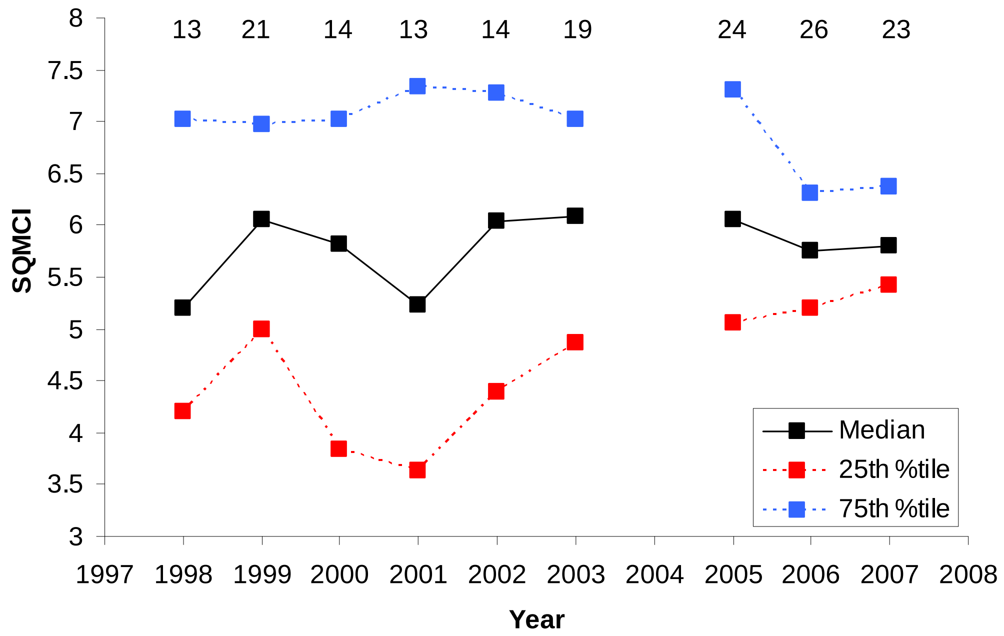


Figure 5.10.15 Seasonal annual median: Semi-Quantitive Macroinvertebrate Community Index (SQMCI).

5.11 Seasonal nutrient patterns at the central Lake Brunner water quality monitoring site

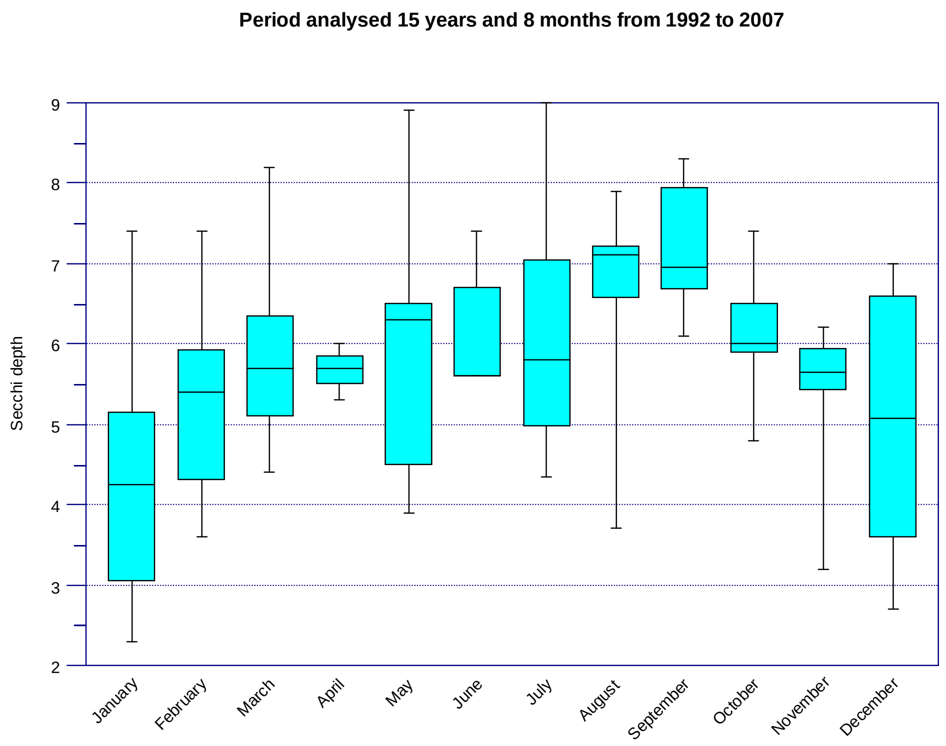


Figure 5.11.1 Seasonal variation in secchi depth as measured over 15 years at the central Lake Brunner sampling site.

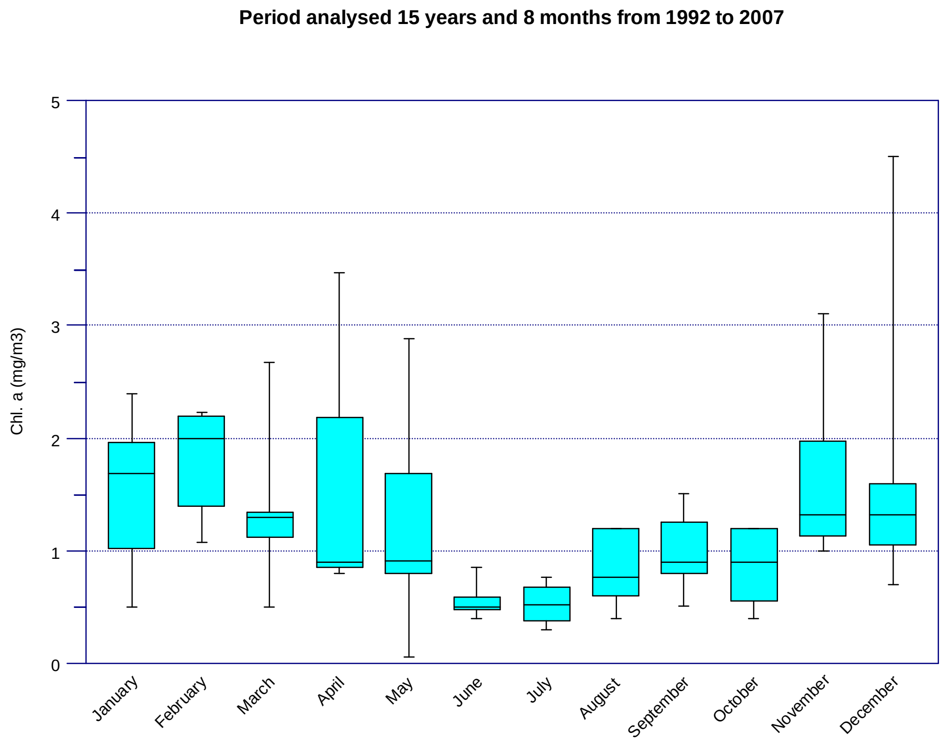


Figure 5.11.2 Seasonal variation in chlorophyll a as measured over 15 years at the central Lake Brunner sampling site.

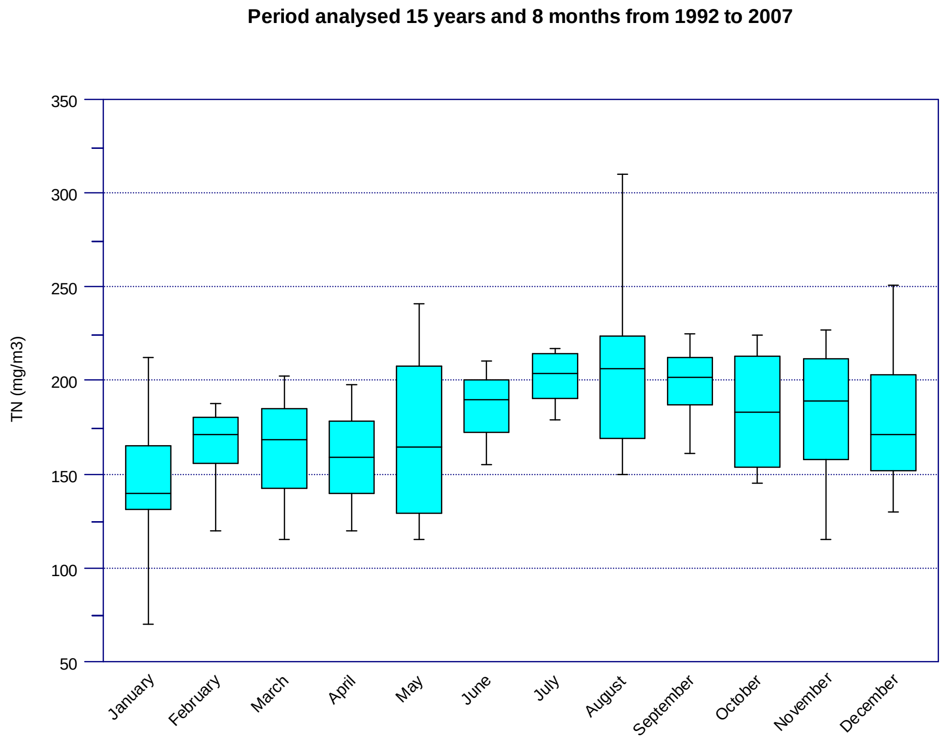


Figure 5.11.3 Seasonal variation in total nitrogen (TN) as measured over 15 years at the central Lake Brunner sampling site.

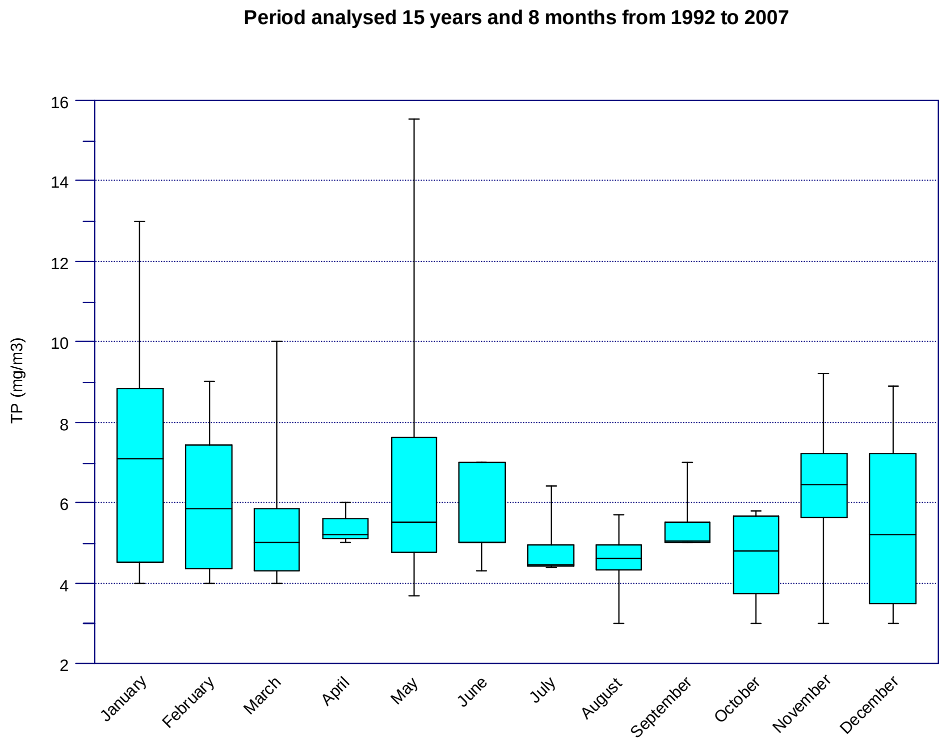


Figure 5.11.4 Seasonal variation in total phosphorus as measured over 15 years at the central Lake Brunner sampling site.

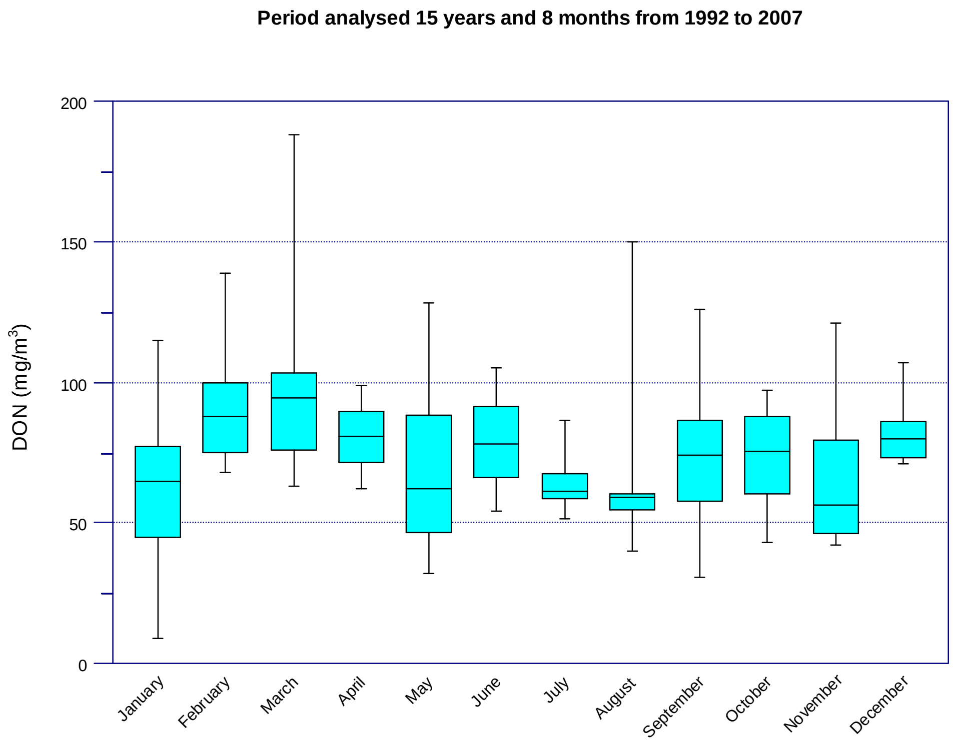


Figure 5.11.5 Seasonal variation in dissolved organic nitrogen as measured over 15 years at the central Lake Brunner sampling site.

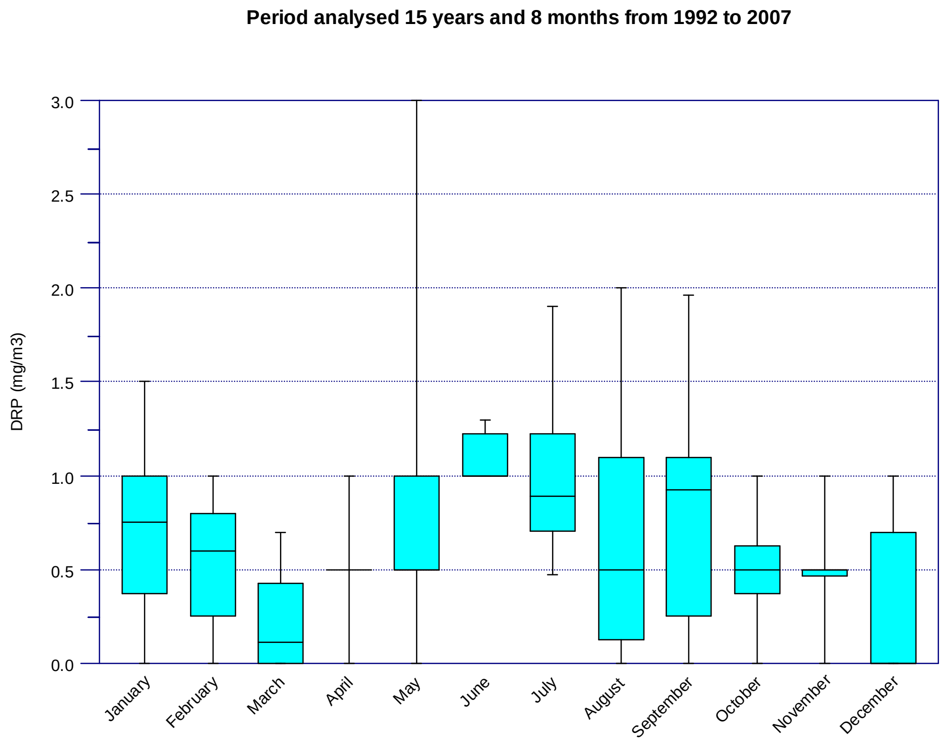


Figure 5.11.6 Seasonal variation in dissolved reactive phosphorus as measured over 15 years at the central Lake Brunner sampling site.

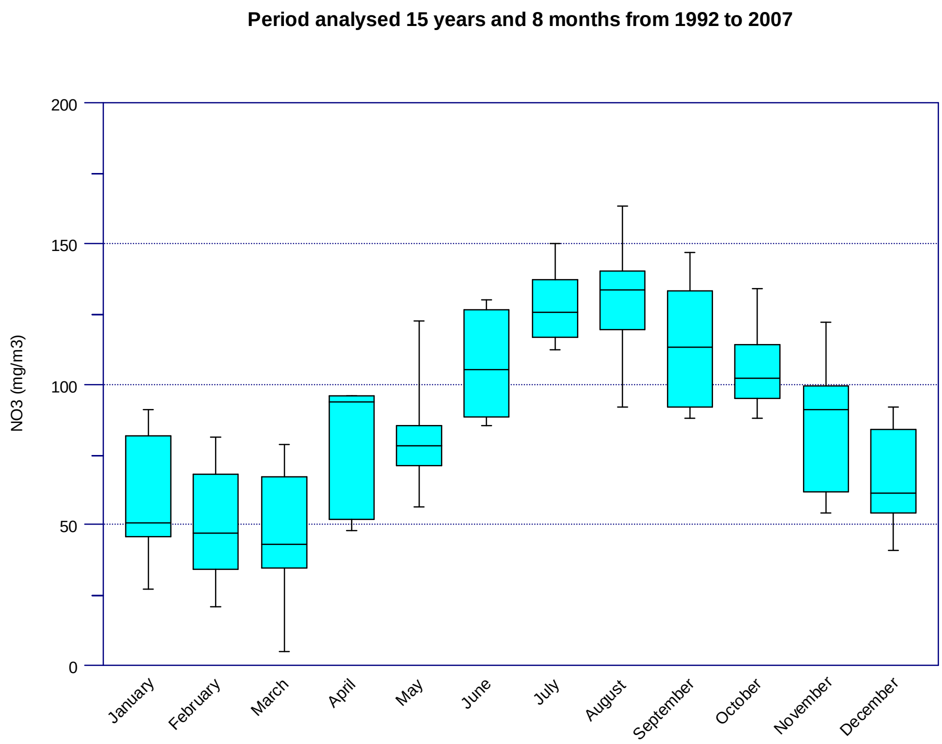


Figure 5.11.7 Seasonal variation in nitrate as measured over 15 years at the central Lake Brunner sampling site.

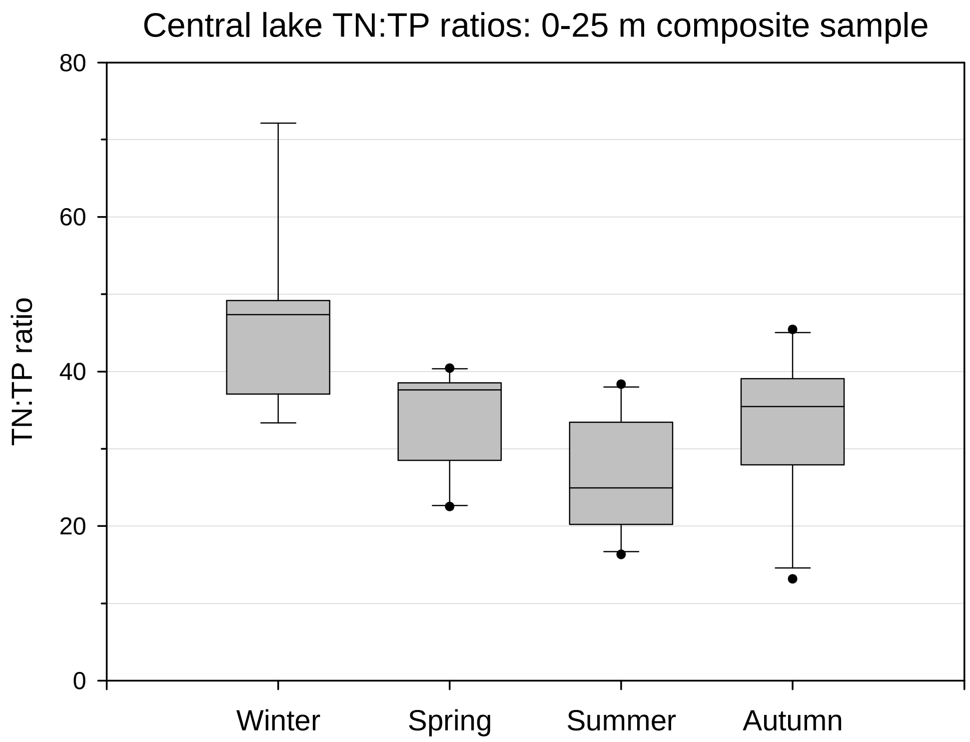


Figure 5.11.8 Seasonal TN:TP ratios measured over 15 years at the central Lake Brunner sampling site.

5.12 Lake Brunner catchment: water quality

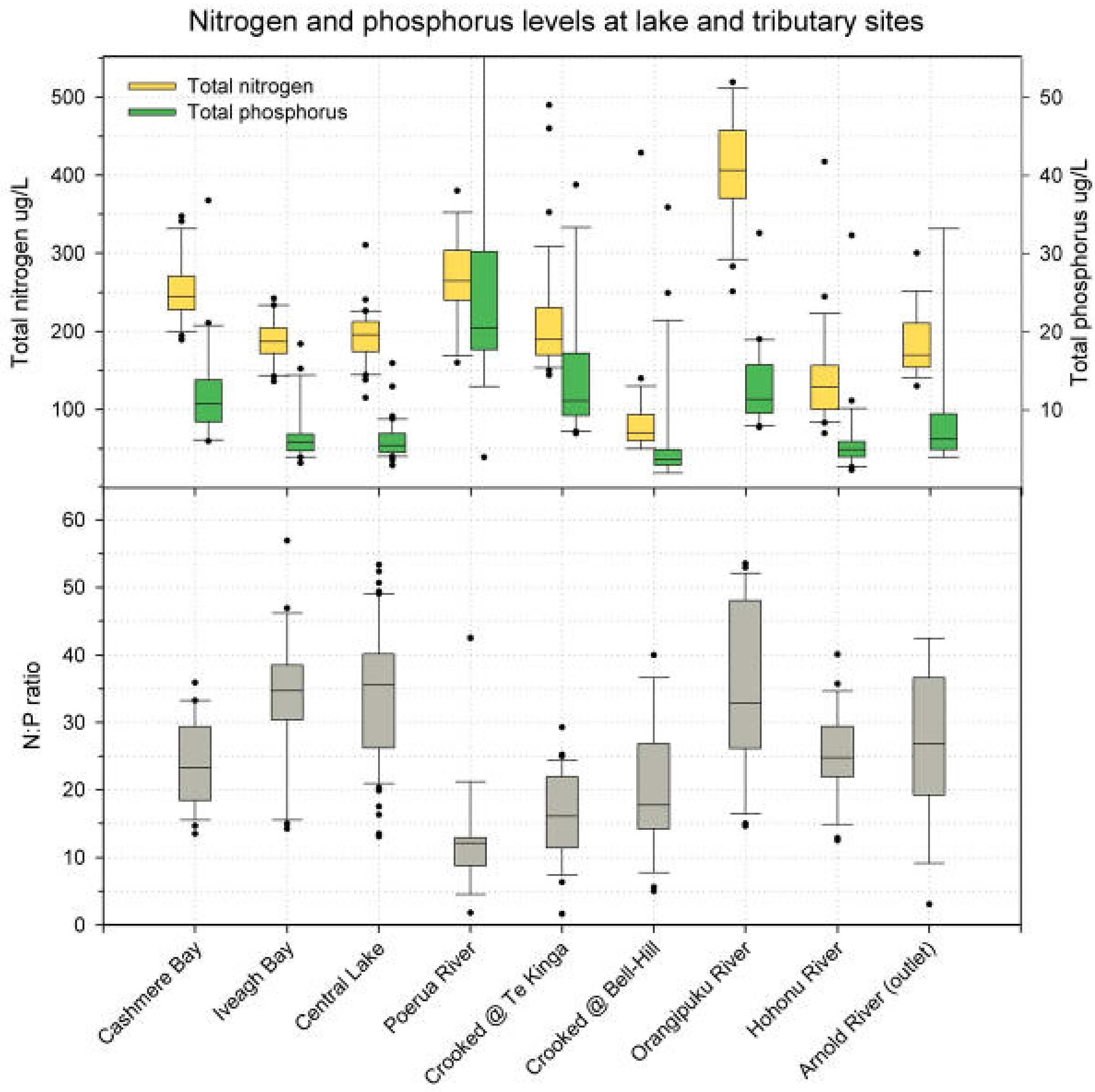


Figure 5.12.1 Ranges of total nitrogen and total phosphorus, and nitrogen:phosphorus ratios at lake and tributary sites, Lake Brunner.

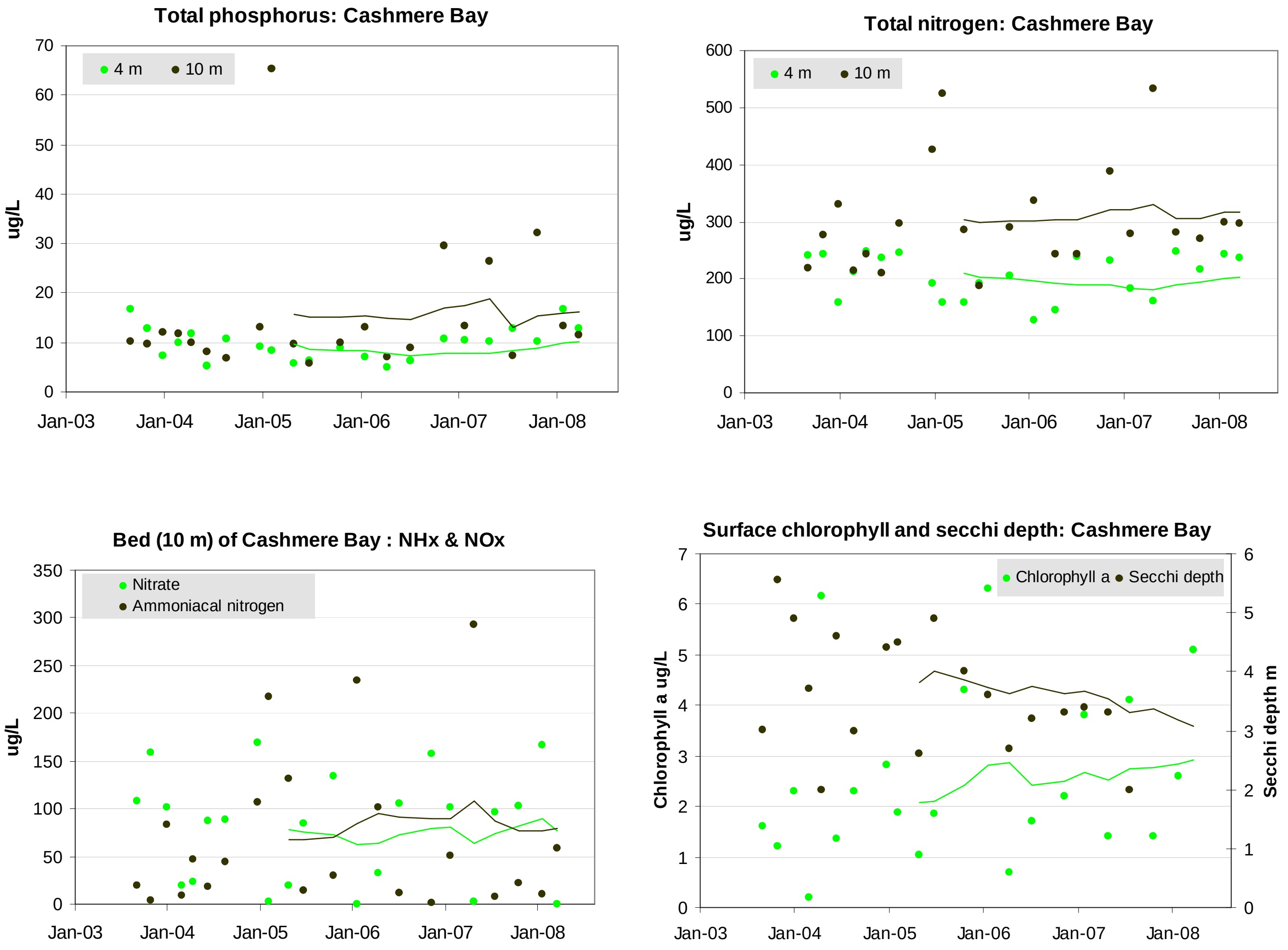


Figure 5.12.2 Total nitrogen, total phosphorus, nitrate, ammoniacal nitrogen, secchi depth and chlorophyll a, over time recorded at Iveagh Bay.

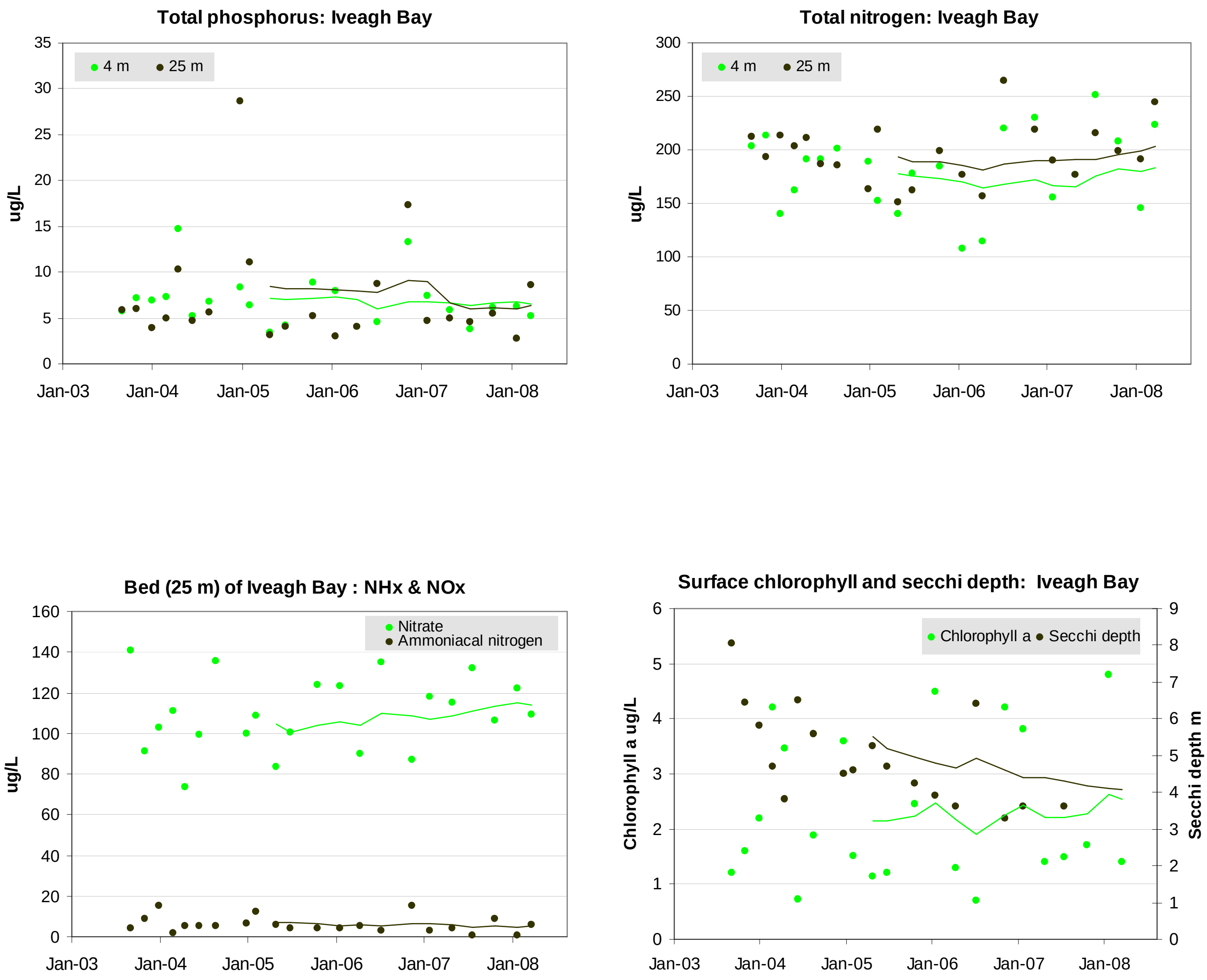
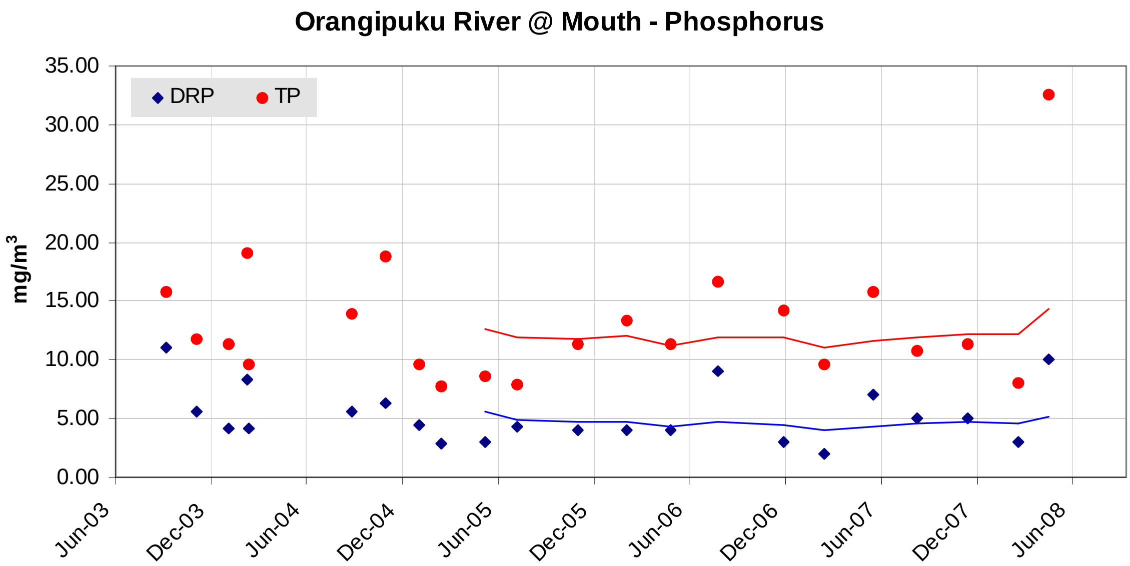


Figure 5.12.3 Total nitrogen, total phosphorus, nitrate, ammoniacal nitrogen, secchi depth and chlorophyll a, over time recorded at Cashmere Bay.



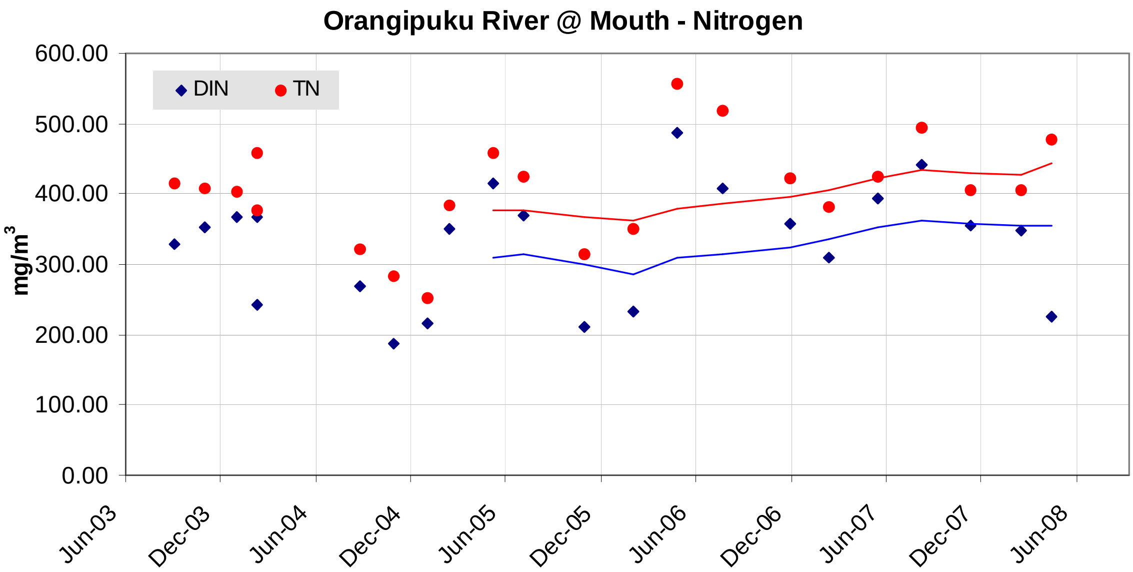
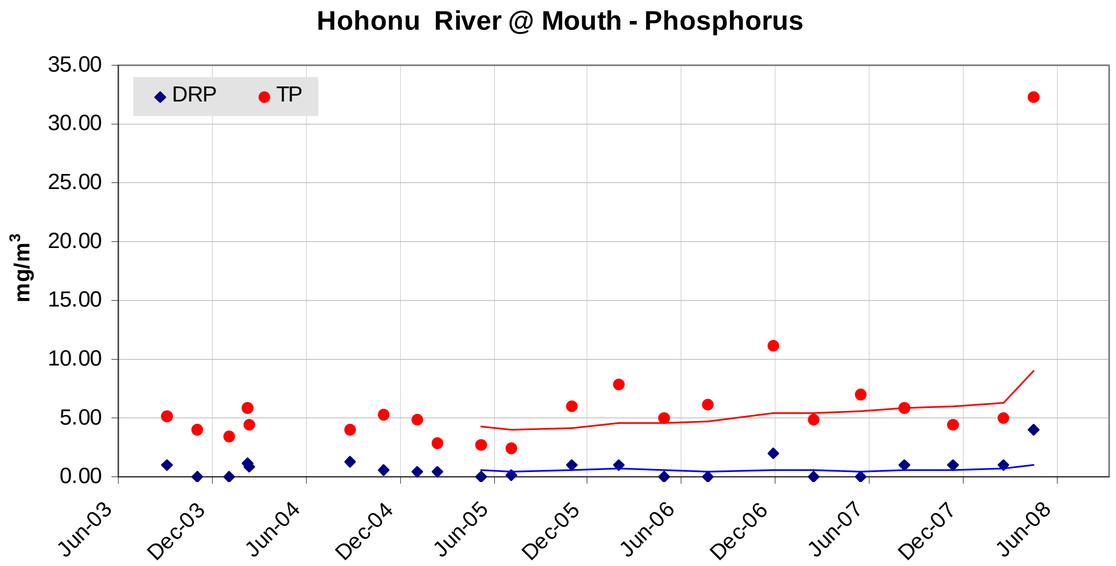


Figure 5.12.4 Phosphorus and nitrogen levels in the Orangipuku River measured near the river mouth, before it enters the lake.



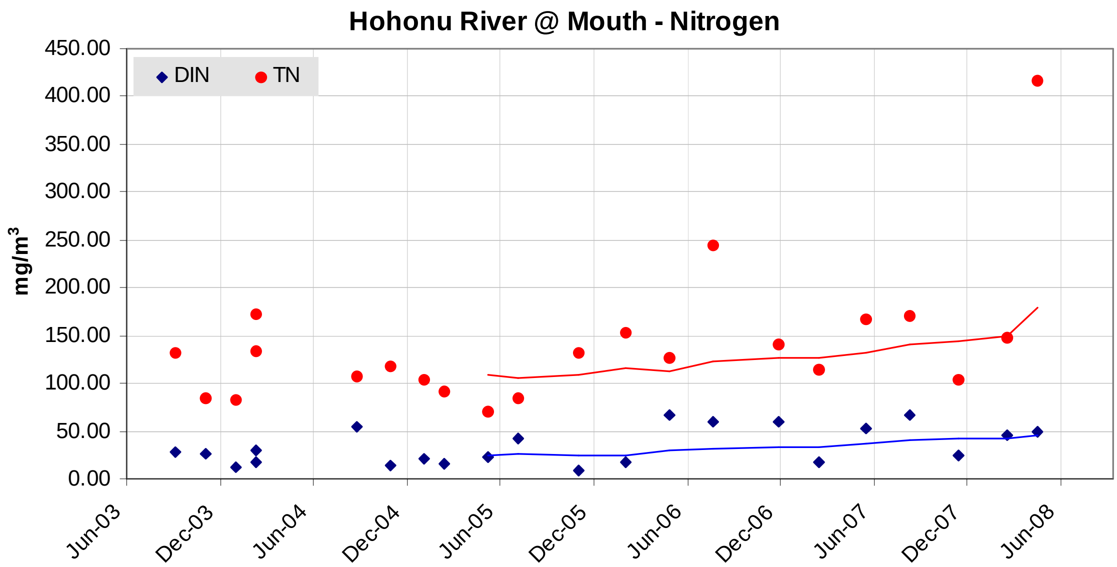
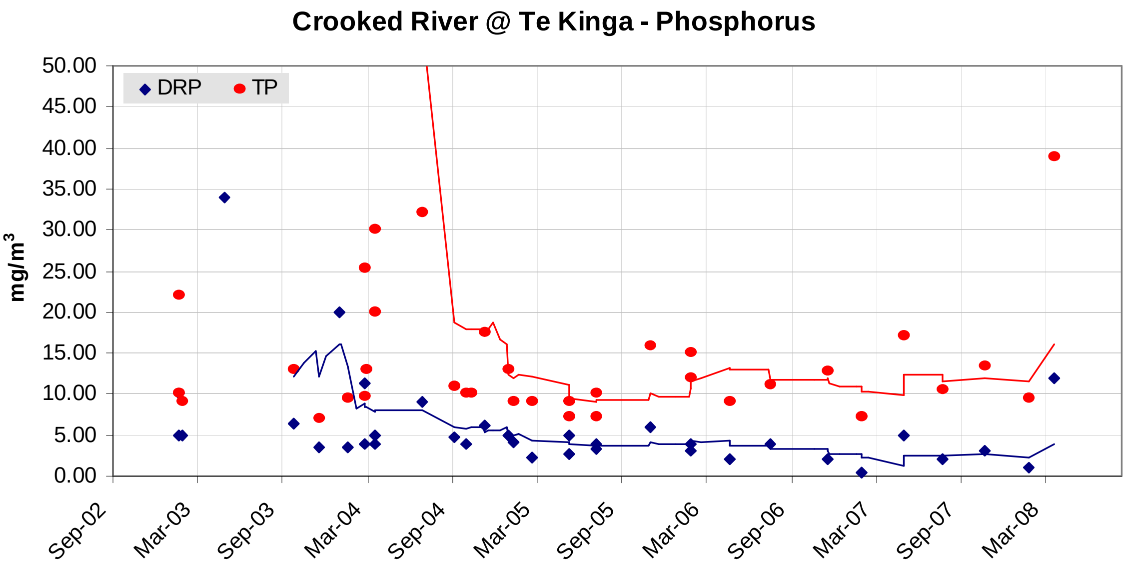


Figure 5.12.5 Phosphorus and nitrogen levels in the Hohonu River measured near the river mouth, before it enters the lake.



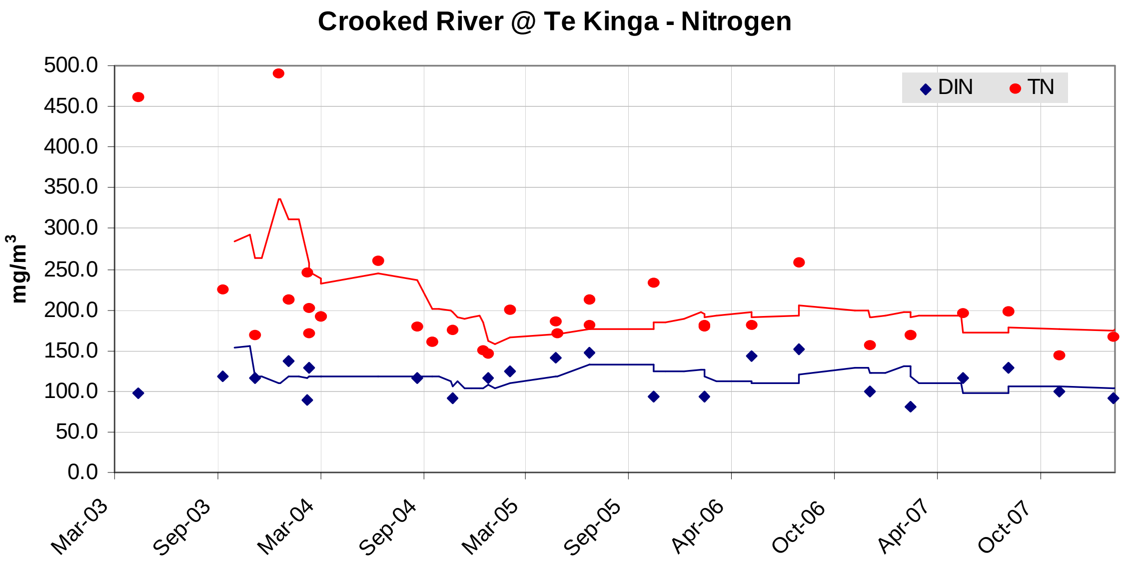


Figure 5.12.6 Phosphorus and nitrogen levels in the Crooked River measured at Te Kinga, near the river mouth, before it enters the lake. Two very high TP readings (280 mg/m^3 @ 2/5/03 and 300 mg/m^3 @ 9/1/04) have been omitted to ease the interpretation of remaining data.

6 References

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