State of the environment monitoring: water quality and ecosystem health of the lakes, streams and Te Whanga Chatham Island/Rehoku

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Executive Summary

Chatham Island has a wide variety of fresh water resources. More than 30 lakes and well over 80 small permanent streams occur on main Chatham Island. Te Whanga, an extensive shallow brackish lake/lagoon, is also a significant feature of the Island landscape; contributing close to 20% of the total Island area. These features are often very visible, easily accessible, and are highly valued, and so form a significant part of the appreciation of the natural Chatham Island environment. There has been little formal investigation or reporting of these freshwater resources. Most understanding is from casual observations during the descriptions of the natural history of the Islands. Some investigations have been associated with scoping the use of the natural geological resources of the Island (peat, rock, or mineral resources), or associated with studies of the natural plant and animal life.

The general understanding of the state of the water resources is described in the operative Chatham Islands Resource Management Document (CIRMD) (CIC 2001). The CIRMD provides descriptions or impressions of the high natural quality of water resources, and objectives are related to the "*maintenance and enhancement of the Islands water quality …, and Te Whanga …"* in particular. It also sets out a (largely advocacy driven) framework for the integrated management of the natural and physical resources of the island, and identifies issues, objectives, and directions to achieve the management.

The Chatham Islands Resource Management Document will require regular review, and requires monitoring to underpin and determine its effectiveness. One method of achieving this is adequate monitoring of the state and trends of the natural (fresh water) resources. Monitoring is necessary not only confirm the current understanding of the state of the freshwater resources, but also whether existing activities on the Island and methods of management are achieving the maintenance or enhancement of the Islands water quality.

A central government funded contract between Environment Canterbury and the Chatham Islands Council has allowed ECan staff to carry out an extensive preliminary survey, and then quarterly baseline water quality monitoring since April 2005. This report describes the results of the first years monitoring, the conclusions drawn from the results, and the monitoring activities proposed for the future.

The study has assessed water quality characteristics of a wide range of streams and lakes, and sites on the shoreline of Te Whanga. It has characterised the current natural state of the water quality and has assessed water quality in terms of national and international guidelines and current issues (or threats) to maintenance of good water quality. It has also assessed the similarity of natural water quality across the Island to determine whether common objectives are appropriate, or whether discrete groups or 'types' of lakes or streams exist. From these are some suggestions of issues that should be considered in managing the Chatham Island freshwater resources in the future.

LAKES: There are quite a number of small attractive shallow lakes around the island. They vary from deeply stained peat lakes, to clear dune lakes. Despite their natural appearance, the water quality indicates that they are all moderately to highly enriched with quantities of phosphorus and to a lesser extent nitrogen (nutrients). In contrast to most other lakes in New Zealand, they are all naturally phosphorus rich, but environmental problems are reduced by the limited concentrations of available nitrogen. Only lakes Rangitai and Huro show notable environmental problems of consistently poor water quality, with frequent algal blooms. The extent of the algal blooms in those lakes appear limited only by available nitrogen. All of the lakes therefore appear to be particularly sensitive to any increased sources of nitrogen contamination.

STREAMS: There are a surprising large number of permanently flowing streams on the Island. They are short but often with impressive shutes or waterfalls, and are mostly highly stained by peat soil components. They show quite variable water quality, and are generally alkaline and well oxygenated. This is surprising as most mainland peat streams are acidic and often oxygen depleted. They are all variably phosphorus rich, low in nitrogen concentrations, and show considerable variation in other chemistry. Like the lakes, they remain sensitive to any increase in nitrogen sources. The water quality is distinctive in different parts of the Island, and can be largely explained by the varying basement geology. The communities of stream insect

life are very simple, and made up of common and water quality tolerant groups often associated with the abundant bryophyte (moss) growths. The insect communities are not considered particularly useful for monitoring stream health due to their simple structure and predominance of water quality tolerant generalist taxa. However, these features also make them vulnerable invasion by more competitive exotic species. Our observations of the fish life, are consistent with earlier descriptions of generally abundant native galaxiid species and eels, and absence of exotic species.

TE WHANGA: Te Whanga is an impressive large brackish lake/lagoon. In this first year of sampling it remained consistently closed to the sea. Under settled weather conditions it was clear and appeared in a good state, but in contrast, under windy conditions it became turbid and rafts of aquatic plants could be washed ashore. It has quite uniform salinity (40-60% seawater), and had moderately high nutrient concentrations, which were considered high relative to other coastal lagoons in New Zealand and Australia. Te Whanga is moderately phosphorus rich, and the northern and central basins are usually more nitrogen poor than the southern basin. However, the southern basin is more nitrogen enriched and potentially more prone to unregulated growth of algae and aquatic plants. The variable observations of the state of Te Whanga suggests it is already nutrient enriched. It is important to limit further inputs of nitrogen as much as possible to maintain existing values and to prevent deterioration in visible expressions of nutrient enrichment. Maintaining more tidal flushing, through more frequent open connection to the sea, may also be beneficial in limiting and removing nutrient accumulation from land sources.

Overall, the freshwater resources of Chatham Island are distinctive and reflect the variable geology of the Island. Waters are all phosphorus rich to various degrees, which is unusual for most New Zealand freshwater resources. Luckily, they are generally correspondingly low in nitrogen concentrations, which may be limiting the current extent of nutrient enrichment problems. However, most human and agricultural development involves production of nitrogen wastes or contamination. A major challenge will therefore be to limit nitrogen production or losses to the streams, lakes and Te Whanga, if their current state and current values are to be maintained.

Major primary sources of nitrogen contamination are discharges from solid waste rubbish dumps (landfills), industrial waste (i.e. fish factory waste), domestic effluent (i.e. septic tank waste), and concentrations of livestock waste (cattle yards, piggeries etc.). Concentrations of these activities should ideally be sited away from the catchments of the lakes and Te Whanga, and away from streams that flow into them. They are best sited along the coastal fringes. Secondary sources of nitrogen can include livestock grazing stream, lake and Te Whanga margins, high wildfowl densities, intentional and/or unintentional disposal of carcases in or adjacent to waterways (casualty livestock and wildfowl culls), and increased growth of nitrogen-fixing plants in catchments (whether cultivated (legumes such as Lucerne, peas or clover) or pests (such as gorse)). These activities or sources should be sited, where possible, away from the interior of the Island, and in catchments ultimately draining to the coast. The coast generally provides greater dilution and dissipation of such contaminants.

The other challenge is to prevent the introduction of invasive exotic water plants and animals which would easily disrupt the current ‘simple’ but productive ecology of the freshwater lakes, streams, and Te Whanga.

The current extent of monitoring is considered a minimum to identify the degree of water quality variation over time and across the Island. It also allows changes over time to be identified although quarterly monitoring will generally require in excess of 10 years data to determine statistically significant trends.

Other issues worthy of scrutiny are the suitability of water quality for drinking water supplies, more ecological investigations of critical water quality, flow and level requirements, and surveillance for aquatic invasive, exotic, or pest species.

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1 Introduction

Chatham Island has a diverse and dynamic landscape, as a result of its complex recent geological history. Prevailing north easterly and southerly winds blow across the ocean to bring regular and often abundant precipitation to the Island. This temperate, cool, moist climate, set predominantly in gentle low relief, has contributed to forming an array of freshwater resources (streams, lakes and wetlands).

Like elsewhere in New Zealand, the streams and lakes of Chatham Island have been subject to varying degrees of human modification. For instance, most streams bisect land that has been cleared for agricultural production, but was once a mosaic of forest types, scrublands, peat basins and rush wetlands. These have been variously affected by changing drainage patterns, burning, vegetation clearance, introduction of exotic vegetation, tracking, and livestock grazing. Central and northern Chatham Island have experienced the greatest level of modification whilst the southern tablelands are least modified with many areas still largely ‘wilderness areas’.

In 2004 Environment Canterbury (ECan) entered a contractual agreement (central government funded) with the Chatham Islands Council (CIC) to supply a range of regional council services to the Chatham Islands. One component of this was to establish baseline and trend monitoring of the water resources on main Chatham Island (RMA S35 functions: a duty to monitor), so as to identify any current or potential water quality resource management issues, and to support the current planning of water resource management as set out in the Chatham Islands Resource Management Document (CIRMD (CIC 2001)). This programme incorporating routine freshwater and saline (Te Whanga) water quality monitoring started in April 2005 and is ongoing.

Programme aims and objectives
The aims of the surface water quality monitoring programme are to:

- Characterise the range of stream[1], river and lake types on Chatham Island
- Characterise the chemical and physical water quality variables in lakes, streams and Te Whanga
- Assess the habitat and macroinvertebrate communities in Chatham Island streams as indicators of the health and biodiversity of water bodies
- Establish a long-term monitoring programme to allow identification of trends in the water quality of freshwater resources on Chatham Island

These will provide information that will be useful for:

- Assessing the effects of current activities on water bodies
- Predicting the effects of any future changes in land use or management
- Assisting with CIRMD water management planning to maintain or improve the state, uses or values of water resources

1.1 Background

Chatham Island freshwater resources are indicative of a very distinctive set of ecosystems that evolved under conditions of geographic isolation, convergence, variable climate, and geology. Established scientific information dates the Chatham Islands at 70 to 80 million old, but new evidence (GNS, 2004) suggests the islands may have most recently emerged from the sea as little as 4 million years ago during the Pliocene Period. If the Island terrestrial and freshwater ecology are only 4 million years old, then this may be reflected in limited biodiversity, and less scope for unique or diverse assemblages of endemic flora and fauna.

Basement catchment geology of Chatham Island consists of a mixture of unconsolidated sand, volcanic basalt, limestone, and schist, overlain with peat, sand, mudstone and silt. Considerable areas

[1] The term ‘streams’ is used to cover creeks, streams and rivers in the remainder of the report

of limestone outcrop deposits are also present, particularly along the western margins of Te Whanga. Therefore, there could be a range of geochemical and landscape variations expected, as a result of both the varying basement and overlying geology.

More than 30 lakes and well over 80 small permanent streams occur on main Chatham Island. Te Whanga, an extensive shallow lake/lagoon, is also a significant feature of the Island landscape; contributing close to 20% of the total Island area. Drainage from peat basins, and direct rainfall runoff are the predominant source of recharge to streams and lakes on the Island. Whilst there is limited information available on the Island's (non-peat) groundwater resource, springs are known to occur in the southern volcanic tablelands, and in areas to the north and north west of the Island, and these have in places been developed as small private domestic or stock water supplies. In contrast, groundwater seepage from peat basins are a key source of recharge for most streams, occurring from extensive basins of deep peat soils with high or fluctuating water tables. These peat drainage waters are often highly coloured with suites of dissolved organic carbon compounds (tannins and lignins) and are generally unsuitable for consumptive uses without treatment.

For the most part, streams have low gradients and flow relatively gently through undulating landscapes. At the coast they can exhibit impressive chutes and waterfalls where they intercept basement rock and descend abruptly to the coast or beach. Streams that enter Te Whanga or lakes often continue a more gentle flow through to their destination, often without intercepting basement rock. Te Awainanga River is the largest river on the Island and the most significant freshwater source feeding into Te Whanga (entering at the southern basin).

There has been little formal investigation or reporting of the freshwater resources of Chatham Island. Most understanding is from casual observations, during the descriptions of the geology or natural history of the Islands (i.e. in Campbell *et al*. 1993). Some investigations have been associated with scoping the use of the natural resources of the Island (peat, rock, or mineral resources), but most recently, investigations have been as a result of natural biodiversity and resource management focus.

Chatham Island streams have not been a common focus of study. This is because they are relatively small, and their water quality is generally unsuitable for most consumptive uses. Te Awainanga River has been the focus of attention in recent years, as a possible hydro-electric power station site. Other streams are generally too small or remote to be suitable for use other than as localized hydro-power sources. As terrestrial biodiversity on Chatham Island has been increasingly studied, the streams have begun to come under scrutiny for their corresponding natural values. They have long been known to support a number of native and endemic fish species (Phillips 1960; Rutledge 1989), most of which are diadromous (that is, including a seaward migration and marine larval stage). Eels have at times been commercially harvested on the Island, and a range of other common native fish (bullies, smelt, inanga, and koaro) occur. Notable species identified include the threatened giant kokopu, the banded kokopu, and a newly found endemic mudfish species (in lakes on the southern table lands; Mitchell, 1995). These ecosystems and their fish communities are not well known, but were thought to exhibit significant levels of endemism and natural biodiversity. The lack of any introduced freshwater fish species may also contribute to the perceived abundance of indigenous fish, often in habitats which are much less adversely affected than those in mainland New Zealand (DOC, 1999).

The lakes of Chatham Island have been recently investigated in association with a survey to identify any exotic or introduced aquatic plants (Champion and Clayton 2004). They are currently free of introduced plants that dominate most mainland New Zealand lakes, particularly of the exotic Eurasian and North American submerged oxygen weeds and emergent macrophytes. The lakes are also notable in their range of perceived water quality, particularly clarity and colour. Some are, or have been, used as potable water supplies and so the maintenance of their existing water quality is an issue.

Te Whanga is generally considered to be one of the least modified of the Island's water resources. A recent study has been conducted of the physical functioning of Te Whanga (Goring 2004), although there remains little study or understanding of its nutrient status and ecology. How unmodified (or pristine) Te Whanga really is, or how its ecology is influenced by the opening and closing of the mouth is also largely unknown. Te Whanga has long been a centre of human activity, and today it remains strongly treasured by the community for its unique cultural, historic and ecological value. It is rich in wildlife habitat and diversity, and consists of a mix of freshwater and marine aquatic communities. The Island's whitebait fishery (smelt-based) is largely based upon the fishery, and several other fish species are recreationally or culturally harvested. Te Whanga is currently free of commercial harvest activity by local agreement.

The water resources on Chatham Island have been variously subjected to vegetation removal, channelisation, grazing and trampling of riparian vegetation and other impacts from livestock. Peat soils are particularly susceptible to trampling, pugging, and associated erosion. They can also entrap livestock leading to casualty stock issues (decaying carcasses) in stream-beds, lake margins and riparian areas.

The effects of land use activities on Chatham Island stream and lake water quality is reflected in the quantities of nutrients and sediment that can enter the water through diffuse sources (e.g. runoff from agriculture and groundwater inputs). Such inputs alter the instream habitat value, water quality and affect the natural diversity of plants and animals. Interactions in the flow of nutrients and other contaminants between the Island's freshwater resources, Te Whanga and the adjacent coastal environment require some further investigation. Te Whanga may be is particularly susceptible to changes in the water quality from inflowing streams and land use activities on the Island.

Specific discharges of (point source) contaminants on the Island are rare, due in the most part to the low population density, and coastal patterns of habitation and development. Currently solid waste disposal (land fills, rubbish dumps), land disposal of wastewater (fish processing wastes), and sewage effluent occur largely on the coastal fringes, and discharge directly or indirectly (diffusely) to the coastline. This leaves most freshwater bodies free of the direct effects of point source discharges, often the focus of major scrutiny elsewhere in New Zealand or internationally.

In 2005 ECan began baseline and trend monitoring of the freshwater resources of main Chatham Island. This report is a synopsis of the water quality, nutrient status and macroinvertebrate community composition of samples taken from April 2005 and June 2006.

2 Methods

2.1 Site selection

An initial survey carried out in April 2005 identified 24 easily accessible streams, 5 lakes and 4 Te Whanga sites as representative and suitable for water quality and/or ecological sampling. The majority of stream sites were at road crossing culverts and bridges, and lake/Te Whanga sites were chosen at accessible road access points and/or, adjacent to stream mouths. No attempt was made to sample the water resources of the remote (and largely inaccessible) southern part of the Island.

Between September 2005 and June 2006 a further 7 lake, 1 stream and 1 Te Whanga site were added to the programme. With the exception of Lake Huro, all lake sites were located in the northern half of the Island. Six of the streams flow directly to Te Whanga, the remainder flow directly to the sea. Te Whanga sites were chosen to represent sites within the major identifiable basins (Figure 2.1, Appendix 1).

Monitoring sites were chosen to be representative of the range of identifiable conditions on the Island and represented or integrated the likely influences of specific land uses on water quality. This was achieved by generally including:

- the most accessible lake, stream and Te Whanga sites
- ensuring broad geographical coverage (including streams from the southern, middle and north to northwest parts of the Island),
- representing the range of identifiable landscape and topography, as well as covering the range of visible and known geology (e.g. schist, basalt, and limestone basements, and peat and sand land cover),
- Catchments with differing types and intensities of land use (i.e. productive grazing, semi drained pakahi swampland, secondary scrub, relatively undeveloped swamp and shrub land)
- representative stream and lake types (for example dune and peat lakes, streams overlying volcanic and limestone geology)
- Te Whanga sites representative of the different compartments (northern, central, southern basin(s) and mouth).

Photographs illustrating the lake, stream, and Te Whanga sites selected are presented in Appendix 2.

2.2 Sample collection

Water quality monitoring was conducted at three monthly intervals (i.e. quarterly) at each site from April 2005 to June 2006. Quarterly sampling is considered the minimum effective interval for categorising the likely variability and any seasonal differences in water quality.

Samples were collected at the epilimnetic (surface) zone in lakes, at knee depth in Te Whanga after wading from the shoreline, and from the centre of stream channels - away from the bank. The samples were collected in a standardised manner according to the ECan Field and Office Procedures Manual for Water Quality Sampling (ECan 1999).

At each site, field observations and measurements (using field meters) were recorded for physico-chemical determinands. Water samples were collected in laboratory prepared bottles for a range of nutrient and chemical analyses, (Appendix 3.). A separate sample for chlorophyll-*a* analysis was collected at lake and Te Whanga sites. The full range of physical and chemical determinands tested is listed in Appendix 3.

At the end of each collection day the water samples were frozen unless they were to be returned to New Zealand on the flight the next day whereby they were chilled to 4°C and stored in the dark.

Chlorophyll-*a* samples were all stored chilled at 4°C. All chilled and frozen samples were transported directly to the ECan laboratory at the end of each field trip.

Biological sampling was conducted at 19 stream sites in April 2005. At each site a 500 um mesh triangular mouth sweep net was used to sample transects across representative habitats (runs, riffles, pools, and margins). These often included sampling areas of either bedrock with or without attached bryophytes (mosses), and/or soft peaty and sandy bed sediments. Sample contents often contained large quantities of material, and were condensed for storage and transport by the washing and removal of large quantities of plant, wood, gravel, silt and sand material. The composite sample generated from each site was preserved with 90% ethanol, such that the final sample concentration exceeded 70% ethanol. If significant numbers of fish or other macrofauna (shrimps etc.) were collected, these were often stored separately in 70% ethanol.

A description of the catchment land use, catchment condition, and instream habitat was also recorded to aid interpretation of the water quality and biological data.

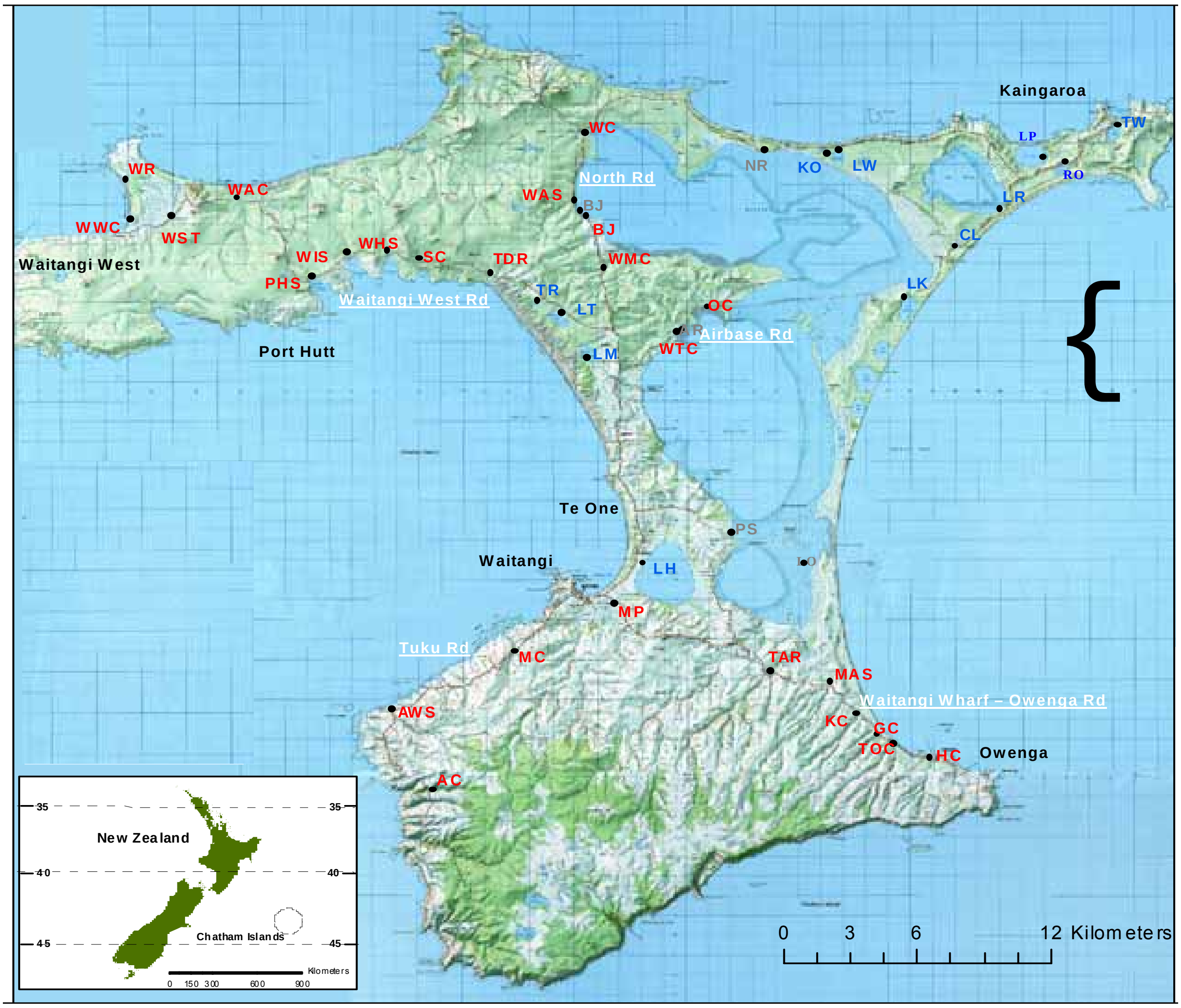


Figure 2.1 Water quality monitoring sites on Chatham Island / Rehoku 2005 – 2006 (refer to Appendix 1 for site names)

2.3 Sample analyses

Environment Canterbury's water quality laboratory performed analysis of the water quality samples. The details of the determinands analysed, laboratory analytical methods and respective detection limits is given in Appendix 3.

Preserved biological samples were subsampled using a barrel sample splitter, to reduce the sample to a manageable size and faunal density. Stream invertebrates were counted and identified using a Bogorov tray and the "100 fixed count + scan for rare taxa" method (Winterbourn and Gregson, 1989; Stark *et al*., 2001, Meredith *et al*., 2003).

2.4 Data Analysis

Data were analysed using Microsoft Excel 2000, Statistica (V7) and Primer (V6). Microsoft Excel 2000 was used for the calculation of summary statistics and charts. Statistica (V7) was used for preparation of box plots. Primer (V6) was used for multivariate analyses.

Where determinand concentrations were below the analytical limits of detection, the laboratory reported the results as `less than' the detection limit'. These non-detect data were converted to a value equal to 'half the detection limit' for the purposes of further data analyses. Data reported as `greater than the detection limit were converted to a value equal to the upper detection limit.

Lake water quality data from the epilimnetic (surface zone) used a core set of determinands (chlorophyll-*a*, TN and TP) to calculate a trophic level index (TLI) for each lake following the New Zealand national methodology set out in Burns *et al*., (2000). However, as sampling was not conducted by boat and as lakes were generally very shallow, secchi disk clarity was not measured and so the overall TLI index was calculated from the average of 3 rather than 4 indices.

Multivariate analyses were used to delineate groupings of lakes and streams on the basis of their water quality attributes. Cluster diagrams and Multi Dimensional Scaling (MDS) ordination were used to depict the relative similarity between:

- lakes based on the water quality parameters of DO, pH, HCO3, conductivity, clarity, DOC, Chlorophyll-*a* TN, DIN, DRP, TP and SO4.
- Streams based on the water quality parameters of DO, pH, HCO3, conductivity, clarity, DOC, NH3N, NNN, TN, DIN, DRP and TP

For the lake sites the DO, DOC, TN, DIN, DRP, TP, SO4 data were log transformed, no transformation was applied to the pH, HCO3, conductivity, clarity and Chlorophyll-*a* data. All data were normalized and the Euclidean distance measure applied to produce a similarity matrix. From this similarity matrix a cluster diagram and a 2-dimensional non-metric MDS ordination of sites was generated.

For each stream site an average value was calculated for each determinand. The NH3N, NNN, TN, DIN, DRP and TP data were log transformed, no transformation was applied to the DO, pH, HCO3, conductivity, clarity and DOC data. All data were normalized and the Euclidean distance measure applied to produce a similarity matrix. From this similarity matrix a cluster diagram and a 2-dimensional non-metric MDS ordination of sites was generated.

Interpretation of the MDS ordination is based on the closeness of samples/sites on the plot. The closer the samples/sites are, the more similar they are with respect to the determinands used to generate the plot. For each plot a stress value is given. Stress (goodness-of-fit) is a measure of the accuracy of the 2-dimensional ordination of points on the MDS plot in representing the actual values in the similarity matrix (Clarke and Warwick, 2001). Stress values of <0.2 indicate good ordination with no indication that the plot is a misleading interpretation of the data.

3 Results

The physical and chemical results for all water quality samples tested between April 2005 and June 2006 are summarized in Appendix 4.

3.1 Climate patterns

Monthly rainfall climate records were obtained from National Institute of Weather and Atmospheric research (NIWA) for station K98615 located at Waitangi (Figure 3.1). These allowed water quality results to be interpreted in the context of the generally prevailing climate (rainfall) patterns.

The Island received significantly less than average rainfall in January, February, August and November 2005, and with less than average rainfall occurring over the 5 consecutive months between July and November 2005. This should therefore be considered a dry or drought period or months, with corresponding lower stream flows and/or lake levels.

Conversely, greater than average rainfall occurred over the period March – June 2005, and in December 2005, but with significant falls in April and December. Total annual rainfall for 2005 was 884 mm. This is close to the annual average of 889 mm, but less than in 2004 (1073 mm). The 2006 rainfall records (February to July) indicate slightly higher than average rainfall over the late summer/autumn period, with greater than average rainfall in March 2006. This would indicate that the Island exhibited increasing rainfall over the 12 month sampling period, varying from a very dry start to the sampling, to a wetter than average final sampling period.

The rainfall data are supported by field observations that the 2005 winter/spring sampling period was generally warmer and dryer than normal. Relatively low stream flows, stable streambeds, and higher algal biomass (especially on bryophyte mats) at some streams, were obvious over this time. The December 2005 rainfall appeared to be insufficient to significantly sustain increases in flow, so that by March 2006 there was a further noticeable drop in stream flows and lake levels. In the northern half of the Island, lower lake levels were particularly observable at Lake Te Roto, the Causeway Lakes, Lake Huro (Figure 3.2), Te Whanga and Lake Wharemanu. The increase in rainfall from February through to June 2006 caused an observable rise in stream flows (Figure 3.3) and lake levels across the Island. The response to increased rainfall was particularly noticeable in the middle part of the Island along Tuku Road and Waitangi Wharf - Owenga Road in June 2006.

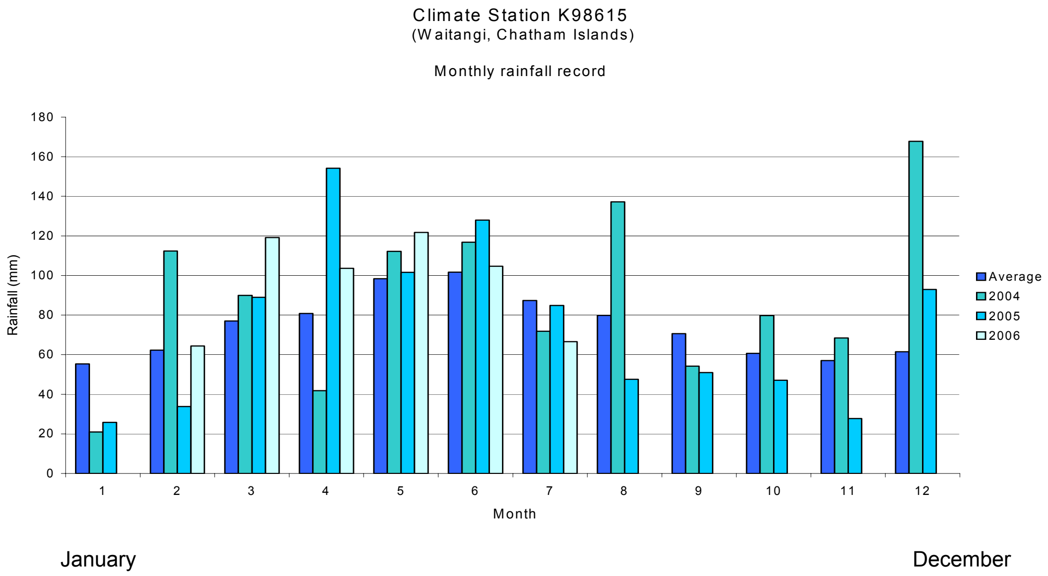


Figure 3.1 Monthly rainfall data (2004 – 2006) against average summary rainfall record (1957 – 2006)

Figure 3.2 **Lake levels at Lake Huro December 2005 and March 2006 (from left to right, facing NE), Chatham Island.**

Figure 3.3 **Stream flow at Stony Creek, March and June 2006 (from left to right, facing upstream), Chatham Island.**

3.2 Lake Results

A total of 12 lakes were sampled between April 2005 to June 2006 (Figure 2.1, Appendix 1). Of these, 9 were monitored on a quarterly basis, with the remaining 3 lakes (Pateriki, Rotorua and Marakapia) sampled on only one or two occasions (as time permitted). Lake physical characteristics and general field observations are summarised in Table 3.1. Summary water quality statistics are listed in Appendix 4. Trophic level index analysis (TLI) results are listed in Appendix 6.

3.2.1 General lake water quality

The 9 lakes sampled quarterly, varied greatly in their water quality (Figure 3.4, Figure 3.5). Median conductivity varied from 50 to 93 mS/m, indicating they are all essentially freshwater lakes (were neither brackish nor saline), but contained variable concentrations of dissolved salts. Two lakes (Te Wapu and Pateriki) located on sand dunes along the north coast near Kaiangaroa, had significant saline influence as a result of intermittent connection to the sea. At Te Wapu the median conductivity was 530 mS/m (~10% seawater: seawater is equal to about 5150 mS/m), while Pateriki was approximately 50% seawater (cited by Champion and Clayton 2004).

All except three lakes were alkaline (median pH range 8.1 - 8.6). Lake Wharemanu was strongly acidic (median pH of 4.4), and lakes Koomutu and Rotorua were slightly acidic (median pH of 6.1 and 6.7 respectively). The Chatham lakes therefore have a tendency to be alkaline unless strongly influenced by raw peat waters.

The highest clarity waters were Lakes Rangitai and Tennants, which had SHMAK clarity readings greater than 1 m on most sample occasions. Neither exhibited any periods of inorganic (sediment) turbidity or high algal biomass. However, lakes Kaingarahu and Huro both had distinctive green algal blooms with poor clarity (9 and 11 cm respectively) and high median chlorophyll-*a* concentrations (110 and 34 ug/L respectively) that remained high throughout the entire monitoring period. Of the remaining 8 lakes, 2 were peat bottomed (Wharemanu and Koomutu) with low light penetration and very low clarity readings. The intense peat-staining, and high concentrations of dissolved and suspended peat material means these lakes are considered dystrophic (dark ’red brown’ coloured water rich in humic substances).

Tennants Lake and Lake Marakapia were the only lakes that were deeper than 2 m (Table 3.1). Nine of the lakes were dune lakes, of which, 3 displayed signs of peat staining during the wetter winter 2006 period, and 1 lake exhibited peat staining year round.

The water levels in all lakes, except lakes Koomutu and Tennants, fluctuated with the rainfall patterns that occurred over the sampling period, particularly over the winter/spring of 2005. Spring and summer water levels at Causeway, Wharemanu, Te Roto and Huro were lower than in April and September 2005, with a noticeable decrease over the 2005/06 summer period.

Table 3.1 Physical characteristics and general field observations of twelve Chatham Island lakes monitored from April 2005 – June 2006

Ref ID	Waterbody	Max depth* (m)	Area (ha)*	Sediment Type	Water colour	Surrounding Land use	Comments
TR	Lake Te Roto	1.5	6	Sand	Brown/yellow	pastoral farming	One outflow stream, stock access.
LT	Tennants Lake	4	50	Sand	Clear/yellow	pastoral farming	Two outflow streams, stock access.
LM	Lake Marakapia	2.5	36	Sand, organic mud margin	Green	pastoral farming	Turbid. Two outflow streams, stock access.
LW	Lake Wharemanu	-	31	Peat	Peat stained	native forest / scrub	
KO	Lake Koomutu	-	3	Peat	Peat stained	native forest / scrub	
LR	Lake Rangitai	1.3	867	Sand, peat margin	Clear/yellow	pastoral farming	Provides water supply to Kaingaroa community. Stock access.
CL	Causeway Lakes	-		Sand	Brown/yellow	pastoral farming	Significant water fowl population. Stock access.
LK	Lake Kaingarahu	-	75	Sand	Green	native forest / scrub	Algae bloom and turbid.
RO	Lake Rotorua	1.2	25	Mud	Brown/yellow	native forest / scrub,	
TW	Lake Te Wapu	0.5	34	Sand	Peat stained	Rubbish dump, native forest / scrub , pastoral farming	One inflow stream, stock access.
LP	Lake Pateriki	1.4	129	Sand	Brown/yellow		Intermittent outlet to sea. 3 inflow streams.
LH	Lake Huro	0.3	598	Sand, peat margin	Green, some peat staining	pastoral farming	Algae bloom and turbid. Significant water fowl population. Stock access and 1 outflow stream.

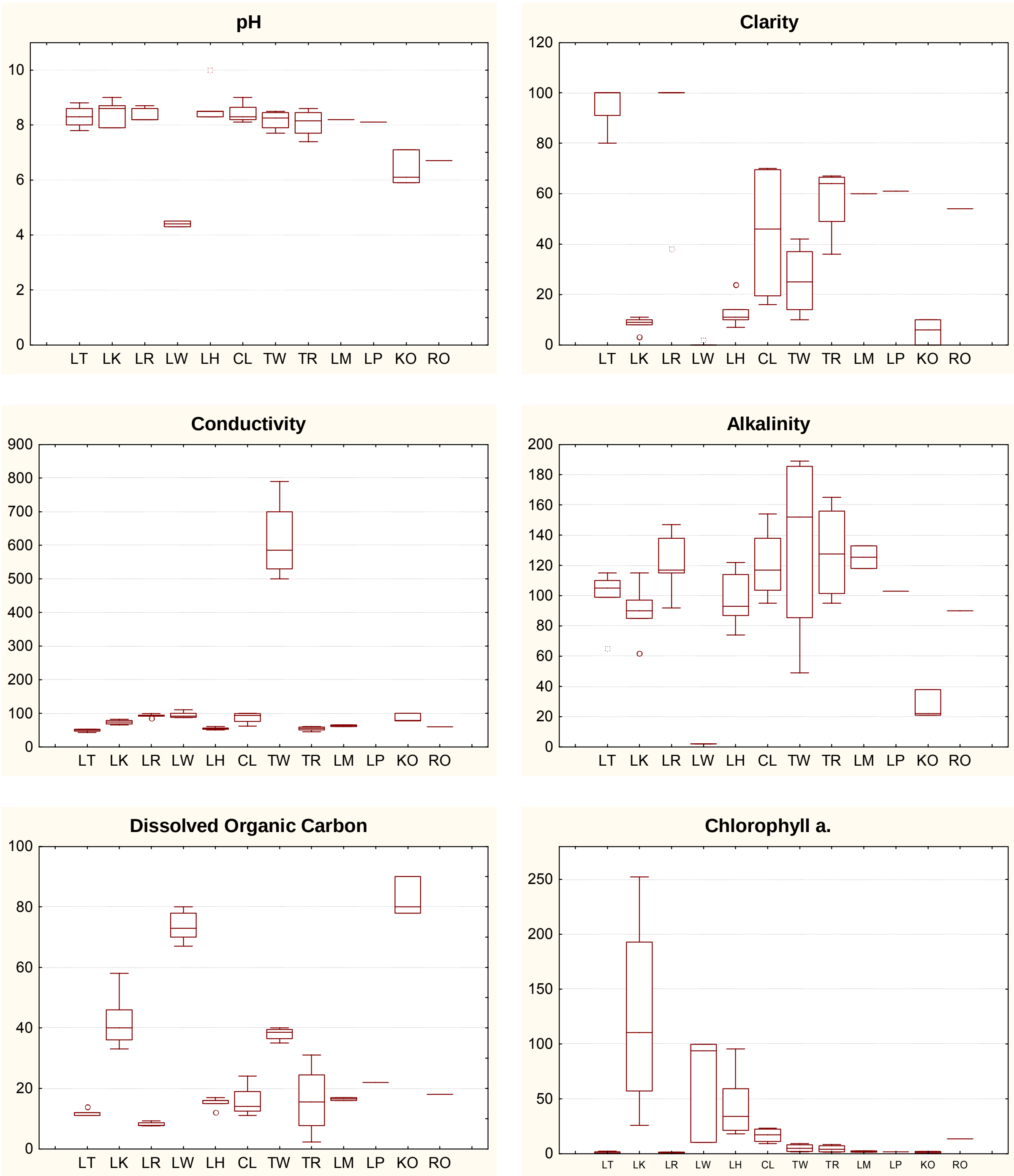


Figure 3.4 Physical and chemical results for pH, clarity, conductivity, alkalinity, dissolved organic carbon and chlorophyll-*a* of twelve lakes on Chatham Island

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95% iles
Refer to Appendix 1 for site name list

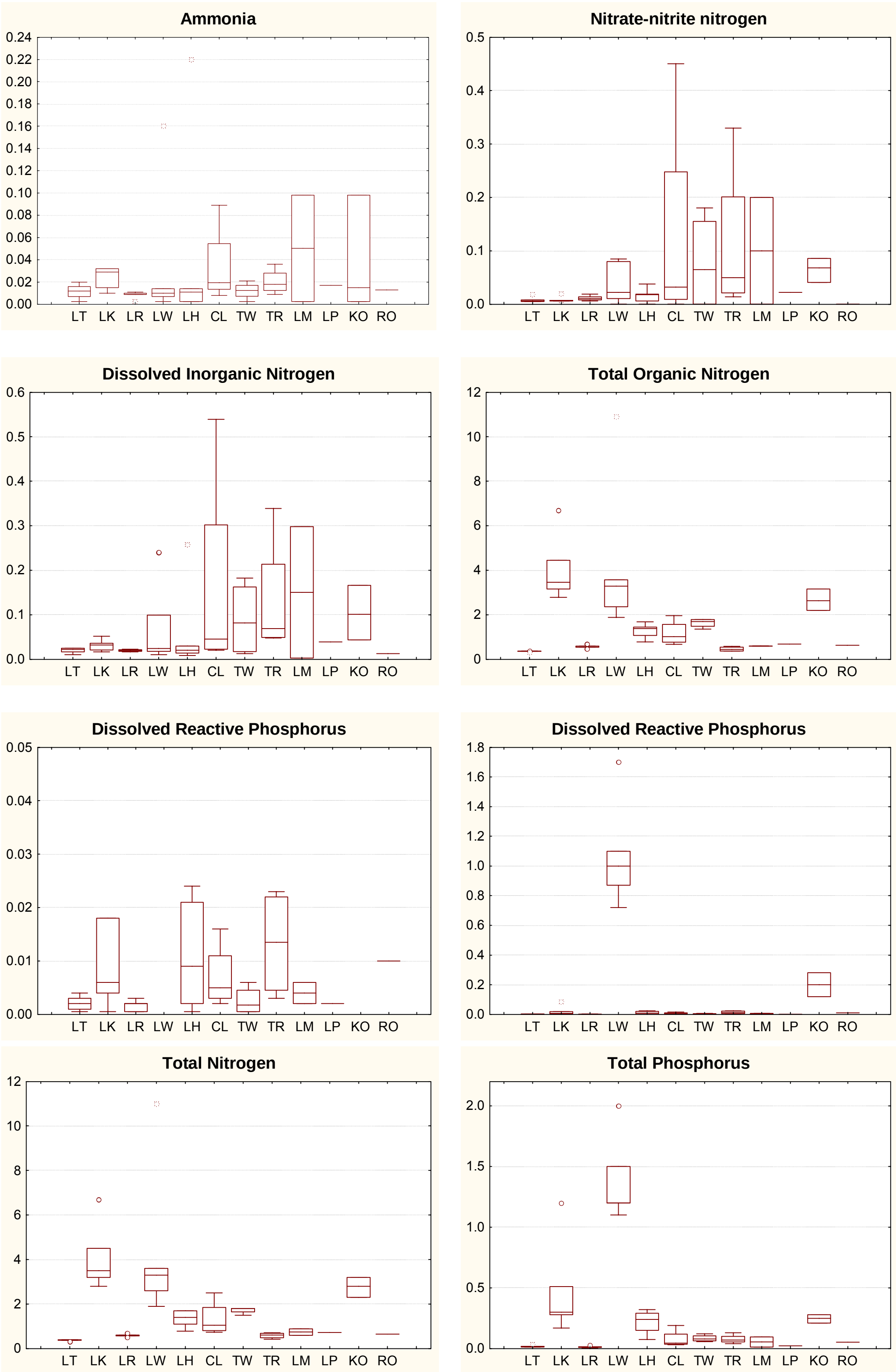


Figure 3.5 Nitrogen and phosphorus concentrations (mg/L) of twelve lakes on Chatham Island

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95% iles. Refer to Appendix 1 for site name list

3.2.2 Lake nutrient concentrations and trophic status

Lakes are generally considered to be particularly sensitive to quantities of soluble nutrients. Elevated concentrations of plant nutrients (nitrogen and phosphorus) can result in excessive growths of phytoplankton (algal) or macrophyte (plant) communities. The growth of these plant communities is an interaction between availability of nutrients, light, and water temperature, which help regulate photosynthetic production. This can be moderated by grazing pressure of zooplankton.

The 12 lakes varied greatly in their total nutrient concentrations (Figure 3.5, Table 3.2). The lakes were ranked according to nutrient concentrations (median TN, TP and chl-*a*) and then grouped by nutrient status category (defined for New Zealand lakes by Burns *et al.* 2000).

Lakes Kaingarahu and Wharemanu are in the highest group for each determinand (N, P, and Chl-*a*). Both were categorised as hypertrophic with very high median nitrogen and phosphorus nutrient concentrations and chlorophyll-*a* concentration. Amongst the other lakes, several had consistently elevated TN, TP and Chl-*a*. concentrations, often being ranked similar for each determinand (i.e. Causeway, Rangitai and Rotorua). However others were less consistent, often ranked high for one determinand, but low for others (i.e. Te Wapu and Koomutu). These latter examples can potentially illustrate nutrient limitation.

The lake trophic level index (TLI) provides a measure of overall nutrient status of Chatham Island lakes. It allows for reporting on individual lakes for management purposes, and lake condition over time. The lakes were graded into trophic level indices (TLI) for each determinand and averaged to produce an overall TLI following Burns *et. al*. (2000) (Appendix 6). Individual values of TLc, TLp and TLn and for the overall TLI are shown in Table 3.3. Note secchi depth was not measured; hence the overall lake trophic status was calculated by averaging 3 rather than 4 TLI components. For comparative purposes this should still adequately represent the differences in trophic status between the Chatham Island lakes, and allow comparison with other lakes in New Zealand.

Nine of the 12 lakes had high nutrient status, and are therefore potentially capable of high plant productivity. Not surprisingly Kaingarahu and Huro with their high nutrient concentrations and persistent year-round green algal blooms were amongst the three lakes categorised as hypertrophic (the highest possible category). Lakes Causeway, Koomutu, Te Wapu and Rotorua were all graded as supertrophic (the second to highest category). That is, they are susceptible for producing high amounts of algae, and blooming during warm settled periods. The remaining 5 lakes were either eutrophic or mesotrophic (of high and moderate nutrient enrichment respectively). Lake Rangitai, which supplies water to Kaiangaroa, was categorised as having the second lowest (meso) trophic state of all lakes sampled in the monitoring programme.

Table 3.2 Lake trophic level grades sorted by median chlorophyll-*a*, TN and TP (mg/m^3) concentrations

Lake	CHL A.	Lake	TN	Lake	TP
Lake Kaingarahu	0.110	Lake Kaingarahu	3.500	Lake Wharemanu	1.200
Lake Wharemanu	0.094	Lake Wharemanu	3.300	Lake Kaingarahu	0.300
Lake Huro	0.034	Lake Koomutu	2.800	Lake Koomutu	0.250
Causeway Lakes	0.017	Lake Te Wapu	1.800	Lake Huro	0.240
Lake Rotorua	0.014	Lake Huro	1.400	Lake Te Wapu	0.080
Lake Te Wapu	0.005	Causeway Lakes	1.000	Lake Te Roto	0.070
Lake Te Roto	0.004	Lake Marakapia	0.745	Lake Marakapia	0.054
Lake Marakapia	0.002	Lake Pateriki	0.720	Lake Rotorua	0.052
Lake Pateriki	0.002	Lake Rotorua	0.650	Causeway Lakes	0.045
Lake Koomutu	0.001	Lake Te Roto	0.615	Lake Pateriki	0.022
Lake Rangitai	0.001	Lake Rangitai	0.570	Tennants Lake	0.017
Tennants Lake	0.001	Tennants Lake	0.380	Lake Rangitai	0.011

red = hypertrophic, pink – supretrophic, orange = eutrophic, green = mesotrophic

Table 3.3 Trophic level indices and overall Trophic Level Index (TLI) (Burns *et al*, 2000)

Lake	TLn	TLp	TLc	overall TLI
Lake Wharemanu	7.0	9.2	7.2	7.8
Lake Kaingarahu	7.1	7.5	7.4	7.3
Lake Huro	5.9	7.2	6.1	6.4
Lake Koomutu	6.8	7.2	2.4	5.5
Causeway Lakes	5.5	5.0	5.3	5.3
Lake Te Wapu	6.2	5.8	3.9	5.3
Lake Rotorua	4.9	5.2	5.1	5.1
Lake Te Roto	4.8	5.6	3.7	4.7
Lake Marakapia	5.0	5.3	3.0	4.4
Lake Pateriki	5.0	4.1	2.6	3.9
Lake Rangitai	4.7	3.3	2.3	3.4
Tennants Lake	4.2	3.8	1.7	3.2

red = hypertrophic, pink – supretrophic, orange = eutrophic, green = mesotrophic

The data were also assessed to determine potential for lake nutrient limitation (Table 3.4). As both nitrogen and phosphorus nutrients are fundamental requirements for plant growth, the ratio of these nutrients can indicate if one is limiting for plant growth. This can be analysed for either Total nutrients - that reflect the total nutrient pools within the lake, or as soluble nutrients - that reflect the quantity and therefore ratio of soluble nutrients available for stimulating additional plant growth. Dissolved inorganic nitrogen (DIN) is a measure of the soluble nitrogen available to plants and is the sum of concentrations of nitrate and nitrite nitrogen and ammonia nitrogen. Dissolved reactive phosphorus (DRP), is a measure of the various forms of dissolved phosphate. It is generally considered that there is an optimal ratio of N/P in the range of approximately 10 – 20 (Redfield ratio), and outside this range plant growth may be either phosphorus (P) limited (ratio >20) or nitrogen (N) (ratio <10) limited.

Phosphorus originates from naturally derived sources from sediment deposits in the catchments, or from agricultural sources (fertilizers or animal effluent). Significant quantities of phosphorus may be present due to guano (faeces deposited by burrowing or roosting seabirds over thousands of years) that are present within peat soils overlying areas of sand dune and marine sediment on Chatham Island. These sediments can be rich in phosphorus and other minerals, and are readily dissolved into water groundwater, or in run-off to lakes and streams. Some natural rock types on Chatham Island can also be relatively rich in P and release phosphorus as a result of natural weathering (Campbell et al 1993). Conversely, nitrogen is generally derived only from plant and animal material rather than from natural geological sources.

Total nitrogen concentrations were generally high. However, concentrations were mostly as organic nitrogen (TON), and soluble nitrogen concentrations (DIN) were very low, such that 71 - 79% of total nitrogen was generally in the organic (TON) form (lakes Te Roto and Marakapia), and 94 - 99.5% was in organic form in the remaining ten lakes. These complex organic nitrogen compounds may be of limited availability for plant growth, and may confuse the analysis of TN/TP ratios.

Soluble (DIN/DRP) ratios indicate half of the lakes (6) are in nutrient balance, and the other half are either N limited (4 lakes) or P limited (2 lakes) (Table 3.4). Lakes Huro, Rangitai, Tennants, Causeway, Te Roto and Pateriki all had ratios in the 10 – 20 range, so were neither N nor P limited. In the case of Rangitai, Tennants and Huro this was due to very low DIN and DRP concentrations (medians 0.02 mg/L and 0.002 mg/L [Rangaitai and Tennants], and 0.02 mg/L and 0.009 mg/L [Huro] respectively). These lakes may therefore also be considered co-limited rather than just in balance. No obvious excessive algal biomass, and relatively high clarity readings, at Tennants and Rangitai (Tennants recording the highest clarity reading of all sites monitored), and low chlorophyll-*a* concentrations, suggest these two lakes are stable and free from excessive plant and algal growth. Low DIN and DRP values in Rangitai, Tennants, and Pateriki suggest these lakes are likely to have greater sensitivity to nutrient inputs than lakes Causeway and Te Roto.

The high chlorophyll-*a*, low clarity, and average TLI value of 6.4 at Lake Huro indicate this lake is in a phytoplankton dominated state where submerged macrophytes are suppressed or eliminated by poor light penetration. The high biomass also ensures that soluble nutrients are largely used as rapidly as they become available (leading to the low soluble concentrations).

Lakes Causeway and Te Roto had high concentrations of DIN and DRP (0.046 mg/L and 0.005 mg/L, 0.069 mg/L and 0.014 mg/L respectively) which were higher than at Pateriki (median 0.039 mg/L and 0.002 mg/L respectively). All three of these lakes appear to be in true nutrient balance, with appreciable available nutrients, but not in obvious algal bloom.

Of the lakes classed as N limited (Lakes Wharemanu, Koomutu, Kaingarahu and Rotorua), the dystrophic peat lakes Wharemanu and Koomutu had lowest nutrient ratios – less than 1. Median DRP concentrations were 3 and 5 times higher in Koomutu and Wharemanu respectively (0.101 mg/L and 1 mg/L) than in other N limited lakes. Low clarity and high DOC concentrations may help control phytoplankton biomass by limiting light penetration, however the high chlorophyll-*a* concentrations in Wharemanu suggests these lakes are responding to their nutrient concentrations with appreciable algal production already.

In contrast, Lakes Kaingarahu and Rotorua had significantly lower concentrations of DRP and/or DIN (0.0345 mg/L, 0.006 mg/L and 0.02 mg/L and 0.01 mg/L DIN and DRP respectively) and are likely to be sensitive to increases in nutrient inputs. High TLc (7.4), low clarity and median TLI (7.3) at Lake Kaingarahu indicates that this lake (as also with Lake Huro) is strongly in a stable phytoplankton dominated state.

Table 3.4 Median lake DIN/DRP ratios ranked and grouped by nutrient limitation category

Lake	TN:TP ratio	Lake	DIN:DRP ratio
lake Rangitai	51.8	Lake Te Wapu	39
Lake Pateriki	32.7	Lake Marakapia	26.1
Lake Te Wapu	22.5	Lake Pateriki	19.5
Tennants Lake	22.4	Lake Te Roto	12.2
Causeway Lakes	23.2	Causeway Lakes	11.9
Lake Marakapia	13.8	Lake Tennants	11
Lake Rotorua	12.5	Lake Rangitai	10.8
Lake Kaingarahu	11.7	Lake Huro	10.3
Lake Koomutu	11.2	Lake Kaingarahu	5.3
Lake Te Roto	8.8	Lake Rotorua	1.6
Lake Huro	5.8	Lake Koomutu	0.5
Lake Wharemanu	2.8	Lake Wharemanu	0.03

P limited (>20), not limited (10 – 20), N limited (<10)

Two lakes (Te Wapu and Marakapia) are considered P limited, that is, they (unusually for Chatham Island) have a surplus of nitrogen compared to phosphorus. Nitrogen commonly originates from nitrogen fixing plants, nitrogenous fertilisers, stock urine and effluent, human wastes and municipal / commercial wastes. Both lakes had a high proportion of NNN, with appreciable maximum concentrations 0.2 mg/L and 0.180 mg/L (Marakapia and Te Wapu respectively). Nitrogen fertilizers are seldom used on the Chatham Islands, and nitrogen-fixing plants are not abundant. Municipal waste in the Kaingaroa rubbish dump is possibly a significant source of nitrogen (leachate) to Lake Te Wapu. Lake Marakapia has a catchment of highly developed pastures, and so has moderate to high livestock densities. However, it was also suggested that it has a history of disposal of fish factory carcasses in trenches within its catchment. Both of these could contribute the elevated nitrogen loads or accumulation seen in this lake.

All lakes monitored had high total organic nitrogen (TON) (calculated as the difference between total nitrogen and DIN) concentrations. TON represents the fraction of nitrogen bound up in algae, bacteria and organic compounds. Significant amounts of TON can indicate accumulation and breakdown of plant material (i.e. peat material).

3.2.3 Grouping by Lake Type

Lakes can be grouped into distinctive types based on either their geomorphic types (‘bottom up’ analysis) or on the basis of similar chemical or biological attributes (‘top down” analysis). The Chatham Island lakes appeared to be of a number of ‘types’, but such delineation needs to be useful and measurable. Therefore a ‘top down’ analysis of lake chemistry was undertaken to see how many natural or logical groupings of lakes there were.

The determinands DO, pH, HCO3, conductivity, clarity, DOC, Chlorophyll-*a* TN, DIN, DRP, TP and SO4 were use to produce a cluster diagram and MDS ordination plot of the lake water quality sampling of all lakes and samples. From the diagram and plot it is possible to investigate similarity in water quality between lakes and between sampling times in each lake. Cluster analysis of all samples of (1 to 5) from the 12 lakes indicates there are 4 major groupings (Figure 3.6), with one sample from Lake Wharemanu on its own (Cluster 0). These groups are shown on the MDS ordination plot (Figure 3.7).

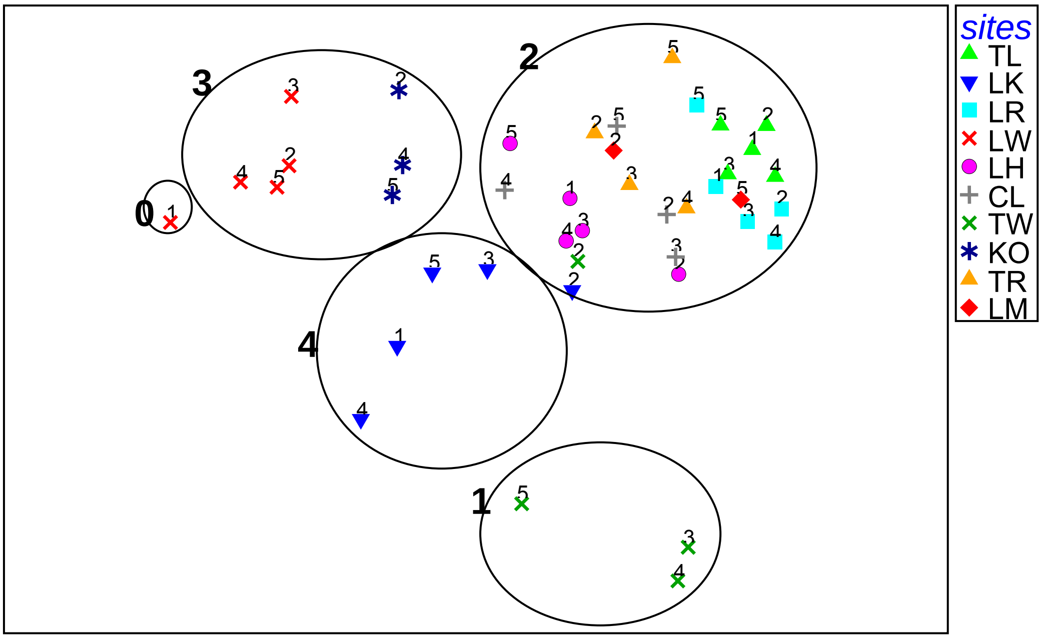
Water quality at lakes Wharemanu and Koomutu were generally similar (close together on the MDS plot) with water quality within each lake more similar than to the water quality between the two lakes). Lake Wharemanu had one replicate sample that differed somewhat from the other samples collected at the site.

Water quality signatures at LakeTe Wapu was quite distinct from the other lakes monitored on three of the sampling occasions (Figure 3.6), but similar to that in other lakes on one occasion. The variation in Lake Te Wapu samples indicates that the water quality in this lake is quite variable over time, and generally dissimilar to the other lakes.

Lakes Huro, Tennants, Rangitai, Causeway, Te Roto, Marakapia and Pateriki are all quite similar, with most samples from each site close together with overlap between samples of different sites. The water quality characteristics within each site were generally more similar than to the water quality in other lakes - particularly at Tennants, Rangitai and Huro. The single sample at Lake Rotorua, located to the top right of the plot, is separated from other sites, which indicates the water quality characteristic of Lake Rotorua is reasonably dissimilar to other lakes.

Lake Kaingarahu was distinct from the other lakes on four sampling occasions, but similar to other lakes on one of the sampling occasions. Again, this indicates that Lake Kaingarahu may be a dissimilar type to the other lakes, but that the water quality at this lake can also be variable over time.

Overall, most of the lakes on Chatham Island cluster together as one type on a ‘top down’ analysis. This is not surprising given they are all shallow, at low altitude, in a similar landscape, and in a similar climate. However, individual lakes in the north-east of the Island appear to cluster separately. Lakes Wharemanu and Koomutu are obviously different being heavily influenced by deep raw peat swamps. Lake Te Wapu’s separation may be influenced by contaminant levels produced by the nearby rubbish dump. The separation of lakes Rotorua and Kaingarahu are less easily explained. Lake Kaingarahu is one of a chain of ‘necklace lakes’ along the eastern margin of Te Whanga, and so may be one of a distinct type of dune-lake along this coast. Lakes in the north–east of Chatham Island may therefore warrant closer scrutiny as a range of different lake types to those on the rest of the Island.



Group 0 Lake Wharemanu, Group 1 Lake Te Wapu, Group 2 all other lakes, Group 3 Lakes Wharemanu and Koomutu, Group 4 Lake Kaiangahu

Times of sampling (1,2,3,4,5)

Figure 3.6 Cluster analysis dendrogram showing grouping of replicate samples at different similarity levels (Y axis) from all lake monitoring sites on Chatham Island based on water quality characteristics

NOTE: grouped numbers (in red) indicate clusters discussed in text. Green line defines the cut off point in Euclidian distance.

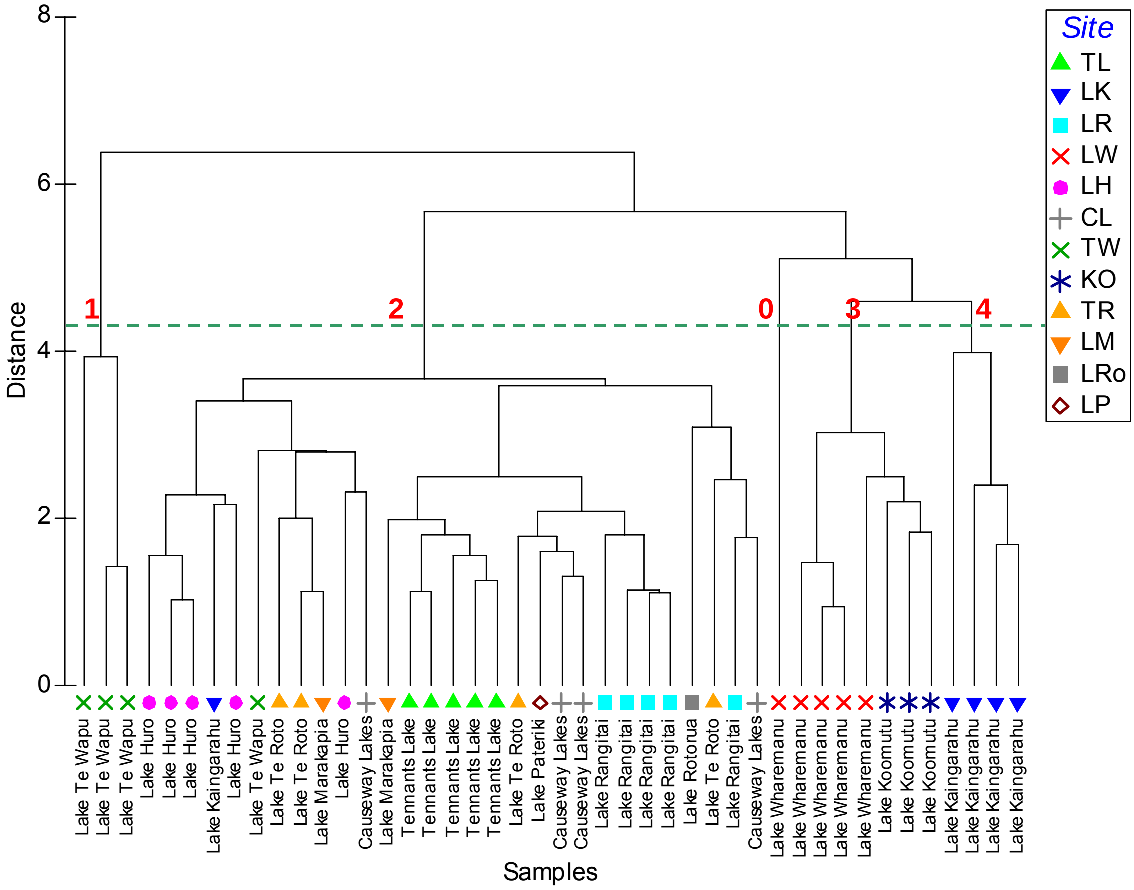


Figure 3.7 Multidimensional scaling plot of similarities between replicates sampled from all lake sites monitored on Chatham Island based on water quality samples (stress = 0.12)

3.3 Stream Results

Twenty five streams were sampled (mostly quarterly) from April 2005 to June 2006. Of the streams monitored: seven flowed into Te Whanga; sixteen flowed straight to sea; and two were tributary streams of larger rivers (Figure 2.1, Appendix 1).

Samples were analysed for nutrients (nitrogen and phosphorus in their various forms), a range of physical and chemical water quality determinands (Appendix 3) and invertebrate communities (Appendix 5.). Details of the sites including physical characteristics and general field observation are given in Table 3.6. Summary water quality and invertebrate statistics are presented in Appendices 4 and 5 respectively.

There are large numbers of water quality guideline values, nationally and internationally, against which results can be compared. The ANZECC 2000 guidelines are some of the most recent New Zealand guidelines, and contain a range of ambient ‘trigger level’ guidelines from slightly disturbed ecosystems, and effects based guideline values based on NOEC (no effect), LOEC (least or chronic effect) values. Earlier guidelines generally used lethal effect (LC50) type guidelines with built in safety margins. All are valid, but are used differently. ANZECC 2000 provides a range of ambient ‘trigger level’ guidelines against which to compare results from ‘slightly disturbed’ New Zealand ‘Lowland’ or ‘Upland’ rivers. These are derived from data from a range of New Zealand rivers and streams, and represent a guideline of high water quality attributes for 'similar types' of rivers. They are the only reference values for New Zealand rivers, but are considered 'interim values' that are designed to be replaced by more appropriate localized regional datasets. These ANZECC interim trigger values are presented in Table 3.5 to allow comparison with the Chatham Island dataset. However, as described earlier, the Chatham Island environment is very different to much of mainland New Zealand, and so comparisons may not always be particularly useful or relevant. Other effects based guidelines include microbiological indicators for 'contact recreation' (MfE 2003), nutrient guidelines for 'Periphyton growth (Biggs 2000), and colour and clarity guidelines (MfE 1994). A selection of these "effects based" guidelines is also included in Table 3.5.

Table 3.5 Guideline values for selected determinands of significance to the Chatham Island surface water quality monitoring programme

Parameter	Water Use/Value	Guideline value	Reference
Dissolved Reactive Phosphorus (DRP)	Lowland river default trigger value Estuarine water default trigger value (SE Australia)	0.01 mg/L 0.01 mg/L	ANZECC (2000) ANZECC (2000)
Dissolved Inorganic Nitrogen (DIN)	Lowland river default trigger value Estuarine water default trigger value (SE Australia)	0.44 mg/L 0.03 mg/L	ANZECC (2000) ANZECC (2000)
Nitrate N Toxicity (NNN)	Livestock water supply Aquatic ecosystem (95% protection) Potable water	90 mg/L 7.2 mg/L 11.3 mg/L	ANZECC (2000) ANZECC 2000 Addendum Memo (2005) MOH (2000)
Ammonia Toxicity (Total ammonia) (NH4N)	Aquatic ecosystems	Calculated toxicities 0.9 mg/L at pH 8.0 2.18 mg/L at pH 7.0 2.56 mg/L at pH 6.0	ANZECC (2000)
Chlorophyll-*a*	Estuarine water default trigger value SE Australia	4 ug/L	ANZECC (2000)
Clarity	Lowland river default trigger value	80 cm	ANZECC (2000)
Diurnally variable parameters			
Dissolved Oxygen (DO)	Aquatic ecosystems Estuarine water default trigger value (SE Australia)	6 mg/L 80-90 % saturation 80% - 110%	ANZECC (1992) RMA (1991) ANZECC (2000)
pH	Aquatic ecosystems Estuarine water default trigger value (SE Australia)	6.5-9.0 7.2-7.8 6-9 7 – 8.5	ANZECC (1992) ANZECC (2000) RMA 1991 ANZECC (2000)
Temperature	Aquatic ecosystems	Seasonal max 20°C Max 25°C, 3°C increase	RMA (1991)

On-site observations during sampling indicated streams were not 'unimpacted' or 'pristine', and most exhibited signs of livestock access, with eroded banks, pugging, compaction and increased sediment in the stream channel (Figure 3.8). Several streams also exhibited a high incidence of casualty stock carcases at times within the stream channel.

Figure 3.8 Obvious signs of stock access Matakatau Stream (left) and stream bank erosion Port Hutt Stream (right)

3.3.1 Stream temperature

Median daytime water temperature ranged between 11°C and 17.4 °C (Figure 3.9). Streams exhibited a moderate degree of seasonal variation with temperatures typically twice as high in summer (December / March) compared to winter (June). Highest water temperature was recorded in December at Mangape and Oringi Creeks (21.1°C and 21.2°C respectively); with the average maximum temperatures at most other streams being approximately 4°C lower (~17 °C). Lowest recorded water temperature was at Waihi River (6°C), which compared to 8-9° C at most other streams. Therefore stream temperatures were well buffered by groundwater temperatures and did not show any high or low temperature extremes.

3.3.2 Dissolved oxygen concentration and % saturation

Median dissolved oxygen concentrations ranged from 7.6 - 9.9 mg/L, and remained high at most sites throughout the sampling period (Figure 3.9). Overall, dissolved oxygen concentrations were generally above the general guideline values of 6 mg/L. The corresponding oxygen percentage saturation values were in the range of 80 - 90 % for many but not all sites (Figure 3.9) and so was generally above RMA (schedule 4) guideline values also. Therefore, despite streams draining organic peat basins, most streams maintained high oxygen concentrations at levels required to sustain even sensitive aquatic fish and macroinvertebrate species. However, supersaturated concentrations greater than 110% were recorded on occasions at 4 streams (Awamata, Waihi, Te One and Waitamaki). These were likely to be associated with observations of high growths of algae and aquatic plants associated with lower flows in these streams.

Three streams to the northwest of the Island (Washout, Waihi tributary and Whangamoe) recorded very low median % saturation concentrations (27.5%, 52.9% and 22% respectively). Such concentrations are indicative of the more sluggish, meandering streams (Washout and Waihi tributary), and blocked river mouths (Whangamoe), and are the result of high oxygen demand of particulate and dissolved peat components, and little physical reaeration.

3.3.3 Stream pH and alkalinity

Stream pH values varied widely from pH 4.8 - 8 (Figure 3.9). This indicated contrasting drainage sources and an influence of the different Island geology. Streams located to the central north of the Island, along Air Base and North Roads, had alkaline pH values (median range pH 8.0 - 8.2) generally higher than streams located to the south of the Island (median range pH 5.2 - 7.6) and to the north west (median range pH 4.6 - 6.6). Both Waihi and Waitangi West streams had alkaline pH of (pH 8.7 and 8 respectively) – although they also exhibited some saline interference. pH measurements also varied within sites over time. Streams located in the south of the Island that drained the southern volcanic tablelands exhibited the greatest pH range (variance of 2 - 3 pH units). pH also varied considerably at Waitangi West. The remaining streams exhibited less of a range within sites (variance of 0.5 - 1.5 pH units) and so could be considered to be well buffered against pH variation.

Correspondingly, stream alkalinity values showed similar patterns to pH values (Figure 3.9). Streams close to Te Whanga, and near the north/central part of the Island, appeared to be more influenced by limestone deposits and exhibited median alkalinity in the range of 89 - 235 mg/L. To the south of the Island, the majority of streams drain volcanic catchments and exhibited lower alkalinity (median range from 2 - 39 mg/L). Streams to the northwest of the Island also exhibited lower median alkalinity concentrations (2 - 54 mg/L) similar to southern streams. Alkalinity was also significantly higher at Waihi and Waitangi West streams (median concentrations 319 and 190 mg/l respectively) but may be due to saline (seawater) interference rather than limestone geology.

3.3.4 Stream conductivity/salinity

Stream conductivity values reflect overall concentrations of soluble salts. Stream conductivity values were generally lowest, and of a smaller range in the southern part of the Island (15 - 55 mS/m), compared to stream conductivity values to the north. Streams in the north-west (i.e. along Port Hutt and Waitangi West Roads) exhibited higher median conductivities (31 - 81 mS/m; Figure 3.9). Streams along North Road and Airbase Rd exhibited similar median conductivity (38 - 70 mS/m) to those in the north west of the Island, but exhibited greater ranges within sites. Again, conductivity values for Waitangi West and Waihi River were distorted by a tidal saline influence, particularly at the Waihi River, which recorded median conductivity value of 870 mS/m. The consistently higher results at streams in the central north of the Island reflect a predominance of hard limestone waters (high Ca, Mg), arising from groundwater seepage associated with the limestone based catchment surrounding the western side of Te Whanga. Similarly, streams to the north/ northwest that run through areas with clay (Rekohou Ash) and peat soils also had high conductivity values associated with materials washing out of the richer peat and ash.

Table 3.6 Physical characteristics of twenty-five Chatham Island streams monitored from April 2005 – June 2006

Ref ID	Waterbody	Sediment Type	Surrounding land use
AC	Awatotora Creek	Cobbles and gravel	Native bush - extensive stream cover
AWS	Awamata Stream	Cobbles and large boulders	Open grassland - sheep grazing
MC	Matakatau Creek	Sediment – mud/clay	Pine forest and open grassland – mixture of sheep and cattle farming
MP	Mangape Creek	Sediment – mud/clay	Open grassland – extensive sheep farming, some cattle (stream drains into Lake Huro)
TAR	Te Awainanga River	Cobbles, boulders and gravel	Secondary scrub intermixed with native trees
MAS	Mangahou Stream	Cobbles and gravel	Secondary scrub (tributary stream of Te Awaninga River)
KC	Kahiti Creek	Cobbles and gravel	Secondary scrub and areas native bush/trees
GC	Gillispie Creek	Cobbles and gravel	Open grassland – primarily sheep farming with some cattle
TOC	Te One Creek	Boulders, cobbles and gravel	Open grassland with sheep farming
HC	Hawaiki Creek	Cobbles and gravel	Secondary scrub
WTC	Waitamaki Creek	Sand, silt and peat	Secondary scrub
OC	Oringi Creek	Sand, silt and peat	Open grassland – cattle farming
WMC	Waimahana Creek	Cobbles and gravel	Mixture of open grassland and secondary scrub
BJ	Blind Jims Creek	Sand, gravel and silt	Open grassland – cattle and sheep farming
WAS	Waipapa Stream	Sand, gravel silt	Open grassland
WC	Waitaha Creek	Sand, gravel, silt	Scrub and patches of open grassland
TDR	Rakautahi Stream Trib	Cobbles, gravel and silt	Lower catchment - open grassland with cattle farming. Upper catchment – secondary growth
SC	Stoney Creek	Rocks, cobbles and boulders	Secondary scrub
WHS	Whangatete Inlet Stream	Stony	Secondary scrub, open grassland with cattle farming in lower catchment.
WIS	Whangamoe Inlet Stream	Sand and peat	Secondary scrub – some cattle farming but no open grass areas
PHS	Port Hutt Stream	Stony and mixture of clay/mud	Mixture of scrub and gorse with some grass land for cattle farming.
WAC	Washout Creek	Peat and sand	Mixture of scrub and gorse with some grass land for cattle farming
WST	Waihi Stream Trib	Peat	Secondary scrub
WWC	Waitangi-West	Sand	Sand dune vegetation and secondary scrub
WR	Waihi River	Sand	Sand dune vegetation and secondary scrub

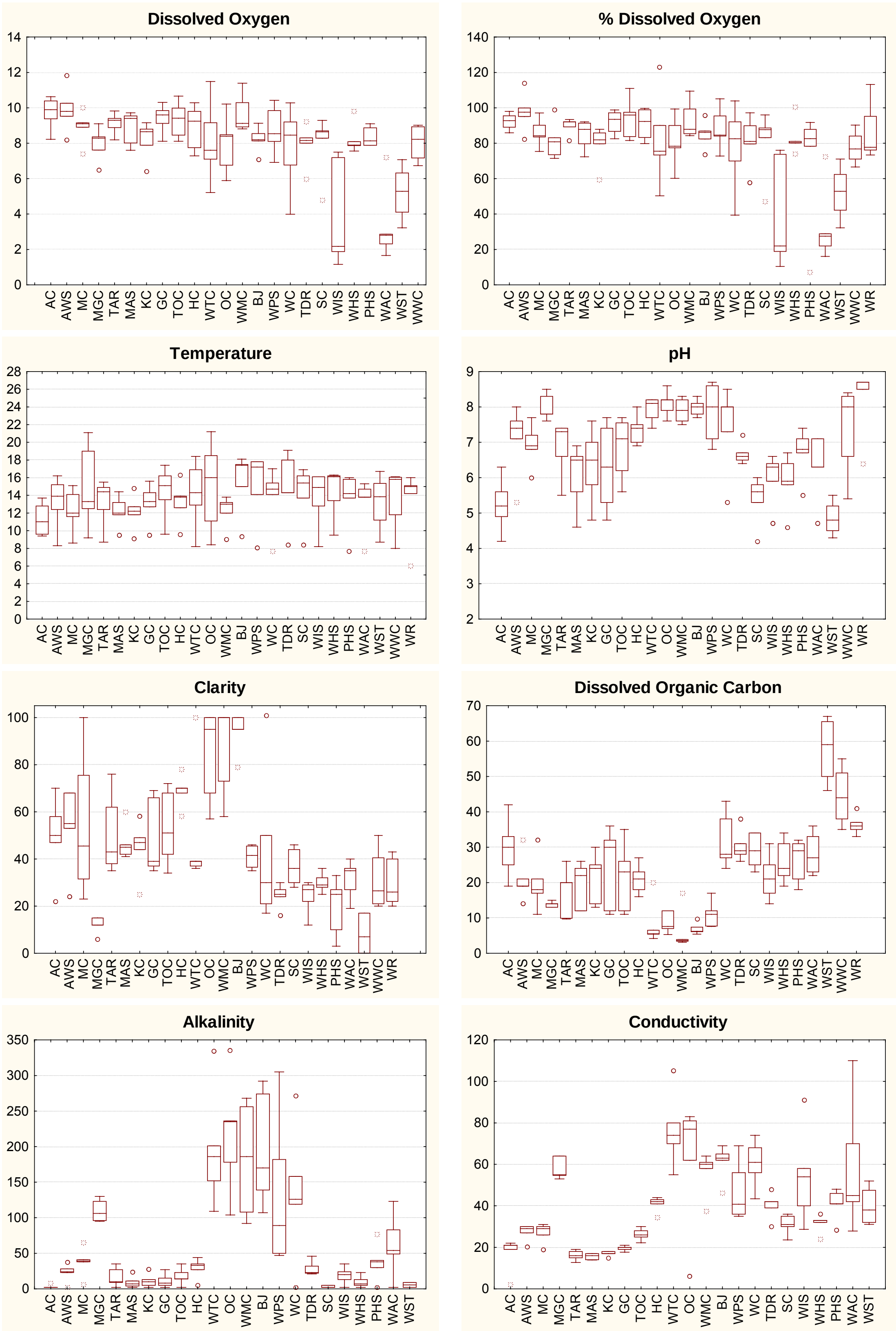


Figure 3.9 Box plots of physical and chemical concentrations of dissolved oxygen, temperature, pH, alkalinity, conductivity, salinity, clarity and dissolved organic carbon

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95% iles

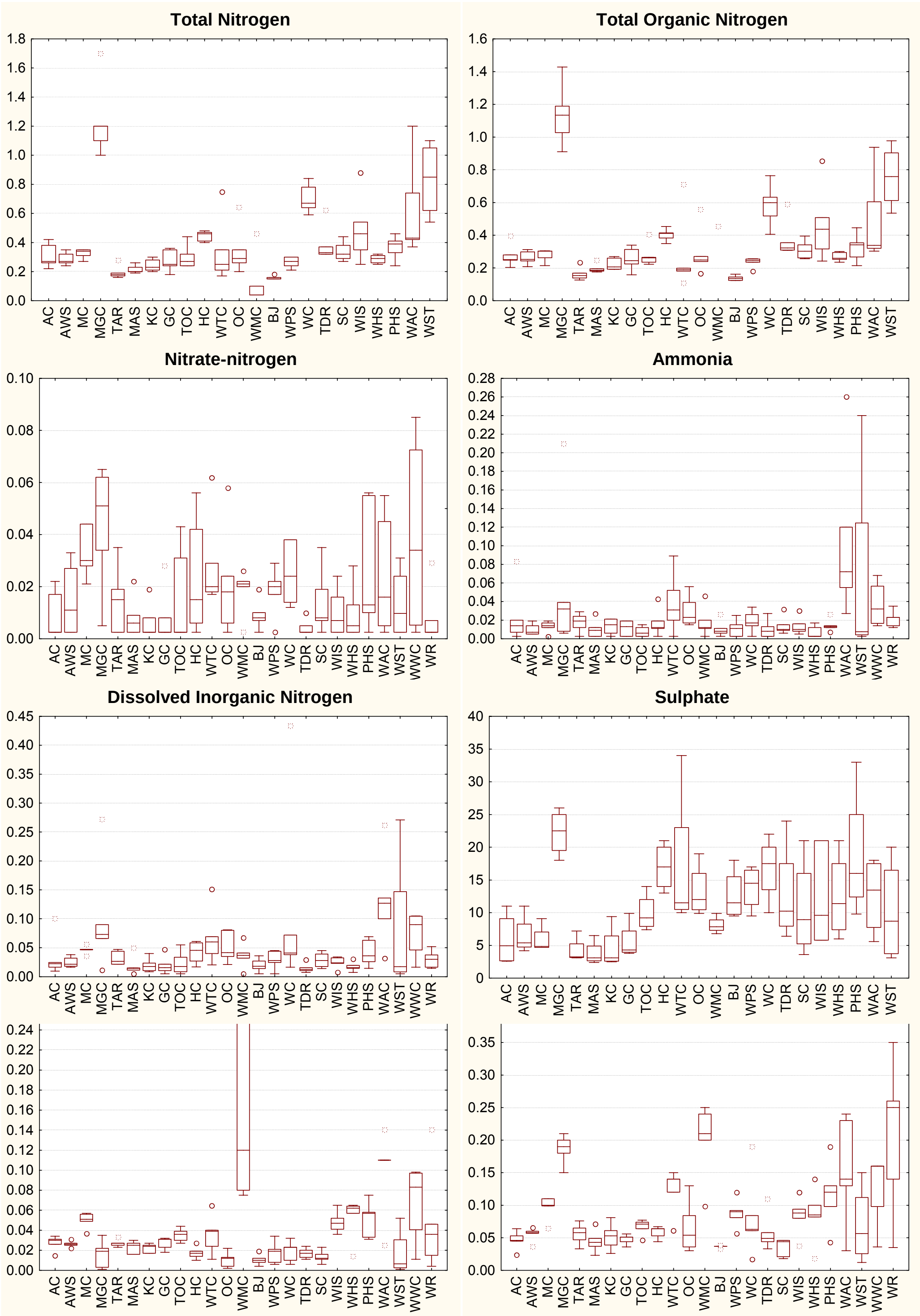


Figure 3.10 Box plots of nutrient nitrogen, phosphorus and sulphate concentrations at twenty-five stream monitoring sites on Chatham Island

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95% iles

3.3.5 Stream colour and clarity

Many Chatham Island streams are highly coloured with intense and distinctive 'rose/red' and 'brick/brown' tannin staining. These are derived from the peat materials that were high in reduced and leachable organic carbon. The very distinctive 'rose-red' colouration of many streams (particularly along Tuku Road, and most observable under high sunlight) are characteristic of the unusual 'Dracophyllum' vegetation that was dominant in the formation of much of the Chatham Island peat. Most other New Zealand peat was formed from rush and sedge swamps, and produce less colourful 'brown' water.

Field observations indicate under low flow conditions the peat staining was more intense, and the visual clarity was low. That is, the peat [dis]colouration is a significant component of the low water clarity, as against light scattering and absorption by organic and inorganic particles in the water column. Streams that exhibited the least tannin staining occurred along Airbase and North Rd, and tended to exhibit a light yellow/brown colouration (under conditions of low flow) that changed to briefer periods of rose/red colouration during periods of high recharge following intense rainfall (Figure 3.11). Streams to the south and north west of the Island imparted a deep rose/red to brick/brown hue that was consistent throughout the monitoring period.

Figure 3.11 Changes in colouration and visual clarity at Blind Jims Creek. From left (March 2006) to right (June 2006) >100 cm and 77 cm respectively

The ANZECC (2000) water clarity default trigger values in lowland streams (streams below 150 m elevation) are 80 cm (Black disk visibility). Field observations suggested most Chatham Island streams were considered to exhibit clear (although often 'coloured') water most of the time, and only 4 were categorised as 'opaque' on more than two out of five sample visits. Highest water clarity occurred at Waimahana, Oringi and Waitamaki creeks (median clarity 95 cm, 95 cm and 100 cm (SHMAK clarity tube) respectively) (Figure 3.9). Lowest water clarity occurred at Mangape and Waihi tributary streams (median clarity 6 cm and 9 cm respectively) (Figure 3.9). Of the other Chatham Island streams, those on the southern part of the Island generally exhibited clarity between 40 and 70 cm, while those of the northern areas showed clarity between 20 and 40 cm (Figure 3.9). Therefore, clarity of Chatham Island streams is generally considerably poorer than in mainland New Zealand. This is not surprising given the effects of natural 'colour' on clarity readings, but may also be implicated by some effects of farming and stock access. The reduced clarity of Mangape Creek, in particular, may be partially a result of stock access and stream bank erosion/pugging, however the algal blooms in Lake Huro will also be a contribution to the low stream clarity.

3.3.6 Dissolved organic carbon concentrations

Dissolved organic carbon (DOC) concentrations are usually very low (<3) in mature hard rock catchments in New Zealand. Increases in dissolved carbon concentration usually indicate sources of organic pollution or areas of waterlogged soils. The exception to this is in areas of extensive peat basins where organic soils are persistently wet. This is the case for most Chatham Island catchments, and is most similar to areas of the West Coast of the South Island of New Zealand, or parts of the Waikato Region. The resulting streams often contain appreciable concentrations of DOC that are mostly made up of humic acids, tannins and lignins.

DOC concentrations in most Chatham Island streams ranged from 20-30 mg/l (Appendix 4, Figure 3.9). Exceptions to this were the north eastern streams along Airbase and North Roads (4-11 mg/l) where water may be filtered through extensive sand geology below the peat. Mangape Stream also had lower than expected DOC (14 mg/l) and this may be a result of this being a lake fed stream with more opportunity for the carbon compounds to settle, oxidise or complex. Conversely streams in the north-west near Waitangi west had particularly high DOC concentrations (36-60 mg/l) and these may be associated with water leaching from the least developed (raw) peat basins.

3.3.7 Nutrient status

Elevated concentrations of plant nutrients, (nitrogen and phosphorus) can have a range of in-stream effects including generating excessive growths of algal or macrophyte (plant communities). Excessive growths of filamentous and mat forming algae smother streambeds and rock surfaces reducing the potential habitat for macroinvertebrate organisms and fish, increasing the potential for diurnal variations in dissolved oxygen concentrations and pH, and generally reducing the aesthetic appeal and recreational uses. Excessive growths of submerged and emergent macrophytes choke stream channels, also smothering stream beds and reducing available aquatic habitat, causing diurnal water quality (DO, pH) fluctuations, and recreational opportunities. They also impede channel flood capacity, lead to flooding impacts and culvert blockage.

There were examples of stream channels with abundant (emergent) macrophyte growth in the north and northwest parts of Chatham Island, where plants had established, proliferated and choked stream channels. With the absence of exotic submerged ‘oxygen weed’ species on the Island, submerged macrophyte growth in streams was not currently an issue. Field observations indicate emergent macrophyte growth is generally not a widespread issue in Chatham Island streams, although exotic watercress has become established in some streams.

Periphyton (algal growths) is an important part of stream ecosystems but at times can proliferate under stable flow, high light, and nutrient enriched conditions. One of the major controlling factors in periphyton growth is the hydrological regime of a stream, in particular the frequency of flood events, water velocity and depth. Where nutrients are not limiting, small streams with stable flows are more likely to develop a large periphyton biomass than larger, frequently flooded rivers. Conversely where soluble inorganic nutrients concentrations are high, nutrient availability is unlikely to limit productivity. Hard bottomed streams (those with gravel, cobble, or bedrock beds) generally support more abundant growths of periphyton, compared to sand/mud/silt bottomed streams, although periphyton can also grow as nuisance ‘epiphytic’ growths on the surfaces of stable stream plants. Chatham Island streams do not generally grow abundant periphyton, although growths were observed under periods of stable low flow in several gravel and bedrock bed streams of central and southern Chatham Island (Figure 3.12). In particular nuisance ‘epiphytic’ growths appeared to be smothering the stable moss growths in many streams on occasions on the streams along Owenga Road.

Figure 3.12 Accumulations of excess periphyton – Te One stream, Chatham Island

Most streams monitored were predominantly lowland streams sourced from groundwater seepage and groundwater fed springs. Therefore, ANZECC (2000) default trigger values based on dissolved inorganic nitrogen (DIN), total nitrogen (TN) and dissolved reactive phosphorus (DRP) for New Zealand lowland streams can be used for evaluating Chatham Island stream nutrient status. A summary of these default trigger values are detailed in Table 3.5. Overall, the concentrations of dissolved inorganic nitrogen (DIN) were generally below the trigger value (Figure 3.10), whilst dissolved reactive phosphorus (DRP) concentrations were above trigger values in nearly all samples at most sites (Figure 3.10). Nutrient enrichment is common for most lowland streams that flow through areas of intense agricultural activity. This is primarily because of the lack of adequate buffering of streams from surrounding land use activities.

3.3.8 Ammonia nitrogen

Ammonia generally originates from fertilizers, animal urine, or from reduction of nitrogen compounds under stagnant or anoxic conditions. Excess concentrations are most frequently an issue from livestock effluent or effluent treatment system discharges. Ammonia is the nitrogen nutrient most preferentially taken up by plants, but can also be toxic in relatively low concentrations. The toxicity of ammonia is dependent on the concentrations of the undissociated form (NH_3), which is controlled by the pH of the solution. The guideline value for total ammonia concentrations for the protection of fish in water at pH of 8.0 is 0.9 mg/L, and at a pH of 7.0 is 2.18 mg/L.

Ammonia concentrations do not appear to be a significant contaminant in Chatham Island streams (Figure 3.10), and median concentrations suggest they were unlikely to cause toxicity problems to fish. Highest concentrations of ammonia-N occurred on 2 occasions at Washout (Figure 3.10), and Waihi tributary, and Mangape streams during periods of brief rainfall activity (Figure 3.10). These are also catchments with appreciable cattle grazing. These concentrations remain below the toxicity trigger values for fish and as there are no direct discharges of effluent into these streams, diffuse sources from run-off and stock access are the likely sources.

3.3.9 Nitrate+Nitrite Nitrogen (NNN)

Concentrations of NNN in streams were low (Figure 3.10) with nearly all streams recording NNN values below laboratory detection limits on at least one occasion. Highest median NNN concentration was in Mangape Stream (0.051 mg/L), Waitangi-west Stream (0.034 mg/L), and Matakatau Stream (0.031 mg/L). Nearly half of the streams in the southern part of the Island recorded NNN concentrations below detection limit on 3 out of 5 samples. Median NNN concentrations were below the detection limit in Awatotora, Waihi, Rakautahi tributary, Kahiti, Gillespie and Te One streams.

Therefore, in contrast to pastoral streams in mainland New Zealand, there was minimal nitrate present, and therefore minimal leaching of nitrate into Chatham Island streams.

Available dissolved inorganic nitrogen (DIN) is the sum of the ammonia and NNN nitrogen, and so is the total concentration of plant available nitrogen. Median concentrations of DIN did not exceeded the New Zealand lowland stream default trigger value of 0.44 mg/L (Table 3.5) in any Chatham Island streams (Figure 3.10). Overall, median DIN concentrations were highest at Washout, Mangape and Waitangi West streams (0.086 mg/L, 0.083 mg/L and 0.066 mg/L respectively) and lowest at Whangatete and Te One streams (0.06 and 0.09 mg/L respectively). These concentrations would suggest that nitrogen leaching from Chatham Island stream catchments is currently not a significant issue, and that stream plant and algal growth is likely to be, more often than not, nitrogen limited.

Developed and undeveloped peatland soils have a very high carbon content (>90%) and low mineral content, and are often outside optimal soil pH ranges. They are commonly acidic and nitrogen deficient and strongly dependent on farm management practices i.e. lime addition and nitrogen fertiliser application (Environment Waikato, n.d.). The low DIN concentrations in Chatham Island streams, compared to New Zealand lowland streams, reflects the predominance of peat soils, naturally low nitrogen content, and lack of nitrogen based fertiliser addition in soils overlying much of the Island.

Examination of the relative proportions of ammonia-N and NNN making up total DIN, showed that streams that had high median DIN concentrations, (Mangape and Washout), had ammonia concentrations that made up to 90% of the DIN. Three other streams had median ammonia concentrations between 30 - 60% of total DIN. This is very high compared to common New Zealand pastoral streams which have close to 100% of DIN as fully oxidized nitrate. This further illustrates that most nitrogen leached from Chatham Island stream catchments is in a chemically reduced form and so either originated from direct unoxidised urine, or from anoxic peat sources.

3.3.10 Total organic nitrogen (TON).

Total nitrogen (TN) concentrations are measured to determine the total nitrogen pool, and to determine the partitioning of stream nitrogen concentrations between the dissolved plant available inorganic nitrogen (DIN = NNN + ammonia-N), and total organic nitrogen (TON; that is bound up in algae, bacteria and organic compounds such as proteins). TON can also include urea, and uric acid from animal and bird urine, and pelletised fertilizers (where applied). The organic fraction can indicate significant nitrogen concentrations that have already been utilised and bound up in cells, and/or nitrogen that may subsequently break down and contribute to the pool of plant available nutrients.

Percentage TON typically made up 80 - 90% of TN in all streams. The exception was Waimahana stream (17.5%). Some spatial pattern existed to show that there was higher total and %TON in streams located to the northwest of the Island. In contrast, lower concentrations tended to occur in central and southern streams (Figure 3.10). This pattern closely matched the extent of drained peat basins and concentrations of dissolved organic carbon (DOC). Streams that had lower concentrations of DOC also showed lower concentrations of TON (Figure 3.10). This pattern is presumably associated with dissolved and particulate peat compounds containing both carbon and nitrogen components, but that are relatively inert and largely unavailable for stimulating aquatic plant growth.

However, while peat components largely make up the concentrations of TON at most sites, local land use activities and salinity interference may also have increased concentrations at some sites. Median TON concentration in Mangape (1.1 mg/L) was up to 8 times higher than that of other streams monitored, and indicates the impact of local land use farming activities on stream water quality. High median TON concentrations at Waihi and Waitangi West indicate organic nitrogen associated with deep peat soils (Figure 3.10). At Waimahana the exceptionally low median TON (0.0007 mg/L) that made up only 17.5% of TN, suggests catchment geology had a marked effect on water quality in this stream.

3.3.11 Phosphorus

Phosphorus and nitrogen are the two dominant plant nutrients required for aquatic plant growth. Dissolved reactive phosphorus (DRP) is the soluble plant available form of phosphorus in stream water.

The concentrations of DRP in streams were quite variable but were consistently high (Figure 3.10) compared to the default trigger value (0.01 mg/L) for slightly disturbed lowland streams in New Zealand. DRP concentrations were also above aquatic ecosystem guideline values (Table 3.5) for managing nuisance algae instream growths. Highest median DRP concentrations were found in Waimahana (0.120 mg/L), Washout (0.110 mg/L) and Waitangi West (0.083 mg/L) creeks (all in the northern part of the Island). All other streams had median DRP concentrations between 0.01 - 0.062 mg/L. Waihi tributary was the only site to have a DRP median concentration (0.007 mg/L) below the trigger value. Therefore, Chatham Island streams can be considered to be particularly phosphorus rich in a New Zealand context, and sensitive to degrees of corresponding nitrogen enrichment.

DRP concentrations as a percentage of total phosphorus (TP) concentrations (%DRP), ranged from 10 – 79%. Four streams had DRP over 60% of TP, 11 streams had DRP concentrations < 40% of TP, the remaining streams had DRP concentrations that ranged from 40 - 60% of TP. This indicates that phosphorus is split approximately equally (50:50) between bound and soluble phosphorus in the phosphorus cycle in most Chatham Island streams.

Seasonal patterns of DRP concentrations indicated highest concentrations occurred in late summer/autumn, and lowest concentration occurred in winter/early spring in most streams. This is opposite to the patterns normally found in intensive pastoral streams in New Zealand, and is driven by local rainfall patterns rather than the fertilizer application patterns often implicated in New Zealand. Interestingly, Waimahana Stream had exceptionally high variation (greater than 3 fold) between samples - the highest concentration occurred on two consecutive sample periods (Dec / March 2005/06) and lowest in April 2005. These are unexplained.

Total phosphorus concentrations tended to follow the same seasonal pattern as DRP where lowest concentrations occurred in winter 2006, and highest concentrations in spring/summer 2005. The close match of TP and DRP concentration patterns suggest that both soluble and particulate phosphorus is likely to result from leaching or washout of both sediments and soluble P from a similar origin. The median concentration varied greatly between streams (0.037 mg/L - 0.25 mg/L), and the variability within streams was observed to increase more so in the far northwest of the Island along Waitangi West Road (Figure 3.10). Overall the TP concentrations of Chatham Island streams were considered to be relatively high for flowing waters.

3.3.12 Sulphate

Sulphate concentrations are not a routine water quality determinand in water quality monitoring programmes, but are useful in categorising water chemistry in novel environments such as the Chatham Islands. Sulphur is another important soil nutrient for maintaining soil health and productivity, and so can be commonly present in appreciable quantities in pastoral drainage water.

Sulphate concentrations were measurable and relatively consistent in Chatham Island streams. Concentrations generally varied between 3 and 20 mg/l. Streams on the southern part of the Island had lowest sulphate concentrations (generally 3-5 mg/l) and they were higher on the northern part of the Island (10-16 mg/l in north western streams and 8-17 mg/l on north eastern streams) (Appendix 4; Figure 3.10). Mangape and Hawaiki Streams had consistently high sulphate concentrations (medians of 22 and 17 mg/l respectively). Higher sulphate may be associated with limestone geology or areas where soils have been lime fertilised from locally mined sources.

3.3.13 Nutrient ratios

Median soluble nutrient ratios (DIN/DRP) were very low (<4) at all streams (Table 3.7). It is generally considered (Borchardt 1996, Biggs 2000) that the ratio of DIN/DRP is optimal in the range of 10 - 20. Such low ratios, frequently less than 2, indicate these streams are very nitrogen deficient (and/or phosphorus rich) and therefore plant and algal growth in streams is likely to be strongly nitrogen limited. This is in contrast to mainlandv lowland New Zealand streams that are usually most strongly phosphorus limited (ratios >20).

Total nutrient ratios (TN/TP) were higher, but still strongly indicates a nitrogen poor environment at most sites. All streams but Waihi tributary and Waitaha Creek had ratios of less than 10, and the majority of streams had total nutrient ratios of 5 or less. Comparison of the soluble and total ratios indicates a considerable influence in the amount of organic nutrient bound up in streams. This is likely to be associated with soil compounds that can be higher in phosphorus. These can be attributed to either the high carbon content peat material, or historic guano deposits being slowly leached to streams. It is likely these nutrients are relatively inert and therefore unavailable to directly stimulate plant growth. In general, where soluble inorganic concentrations of phosphorus are very high, then low nitrogen availability is likely to limit stream primary productivity.

Table 3.7 Median stream DIN/DRP and TN/TP ratios ranked and grouped by nutrient limitation category

STREAM	DIN/DRP		TN/TP
Mangape Creek	4.4	Waihi Stream Trib	15
Oringi Creek	3.4	Waitaha Creek	10.6
Waihi Stream trib	2.7	Waitangi West Creek	9.7
Waitaha Creek	1.8	Waihi River	7.6
Waipapa Stream	1.6	Stoney Creek	7.3
Blind Jims Creek	1.6	Hawaki Creek	7.2
Hawaki Creek	1.6	Un-named northern trib drain	6.7
Stoney Creek	1.5	Mangape Creek	6.3
Waitamaki Creek	1.3	Awatotara Creek	5.9
Te Awainanga River	1.3	Oringi Creek	5.4
Matakatau Creek	0.9	Whangamoe Inlet Stream	5.2
Washout Creek	0.8	Gilliespie Creek	4.9
Waitangi West Creek	0.8	Awamata Stream	4.7
Kahiti Creek	0.7	Mangahou Stream	4.7
Waihi River	0.7	Kahiti Creek	4.3
Awamata Stream	0.7	Blind Jims Creek	4.1
Un-named northern trib drain	0.6	Te One Creek	3.8
Mangahou Stream	0.6	Whangatete Inlet Stream	3.4
Awatotara Creek	0.6	Matakatau Creek	3.4
Gilliespie Creek	0.5	Port Hutt Bay Stream	3.3
Port Hutt Bay Stream	0.5	Te Awainanga River	3.1
Whangamoe Inlet Stream	0.4	Washout Creek	3.1
Waimhana Creek	0.3	Waipapa Stream	3
Te One Creek	0.2	Waitamaki Creek	1.8
Whangatete Inlet Stream	0.1	Waimhana Creek	0.2

not limited (10 – 20), N limited (<10)

3.3.14 Grouping by Stream Type and Cluster Analysis

As with the lakes, streams can be grouped into distinctive types based on either their geomorphic types ('bottom up' analysis) or on the basis of similar chemical or biological attributes ('top down' analysis). The Chatham Island streams are all low elevation 'lowland' streams, but also appear to represent of a number of 'types' based on their geology, appearance, and specific chemical characteristics. Therefore a 'top down' analysis of stream chemistry was undertaken to see how many logical groupings there were.

Differences between total stream nutrients, physical properties and nutrient ratios suggests Chatham Island streams can be grouped into clusters of similarity based on water quality. A multi-dimensional scaling ordination (MDS) of sites was based on the water quality characteristics of DO, pH, HCO3, conductivity, clarity, DOC, NH3N, NNN, TN, DIN, DRP, DRP and TP. Overall, the plot (Figure 3.13) shows streams in the central north of the Island as located in the upper right of the MDS plot, streams of the southern Chatham Island as tightly packed in the middle right of the plot, and streams located to the northwest of the Island generally dispersed along the central bottom of the MDS plot. Therefore there initially appear to be three logical groupings of streams.

Closer analysis of the clusters indicates nearly two thirds of the streams monitored occupy the centre right of the MDS plot (Figure 3.13). Within this grouping, water quality characteristics were generally more similar between streams of a similar geographic location. That is, streams along Waitangi Wharf - Owenga Road occupy the upper middle area of the cluster, streams along Waitangi West Road occupy the lower central area and streams along Tuku Rd occupy the middle area of the cluster. Overall the water quality of this group was characterised by higher similarity in alkalinity, ammonia, nitrate-nitrogen and TN concentrations compared to other Island streams monitored.

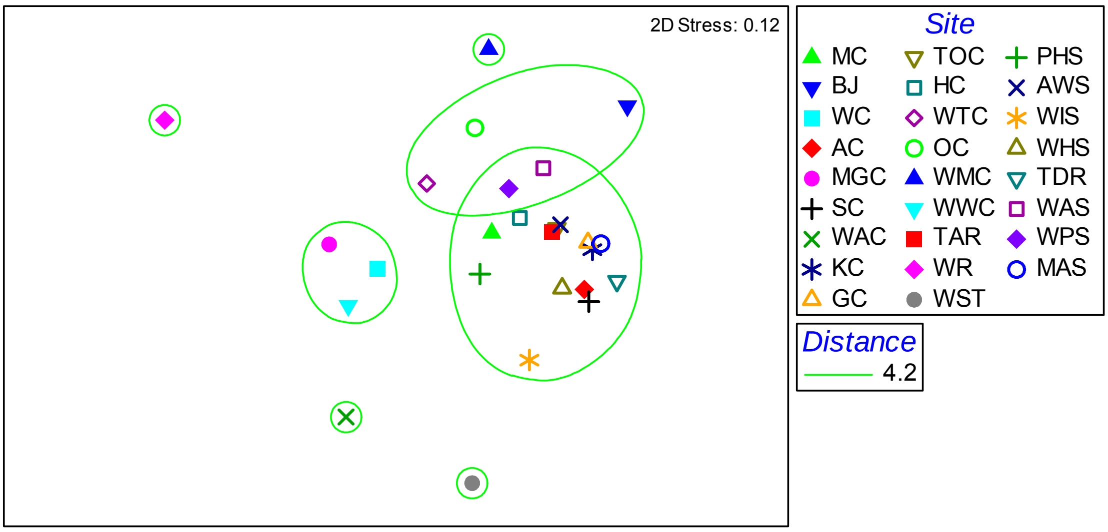


Figure 3.13 Multidimensional scaling plot of similarities between replicate samples from all stream sites monitored on Chatham Island based on water quality samples (stress = 0.12)

Streams located in the central north east of Chatham Island (Waimahana, Oringi, Waitamati, Waipapa and Blind Jims Creeks) occupy the upper middle right of the MDS plot (Figure 3.13). Streams in this grouping were characterised by high similarity in alkalinity, clarity and DOC. Differences in nutrient concentrations have created either a horizontal or vertical dispersion on the plot.

Mangape, Waitaha and Waitangi West streams were loosely packed in the centre of the MDS plot (Figure 3.13). These streams share high similarity in DIN, NNN and TP concentrations. The remaining streams occupy a dispersed space to the lower half (Whangamoe, Waihi tributary and Washout) and upper left (Waihi) of the MDS plot. Waihi was characterised by distinctive alkalinity, conductivity, TON and TP concentrations, whereas streams in the lower part of the plot were generally characterised by distinctive DO, clarity and conductivity concentrations.

Cluster analysis taken from the average of all water quality samples, comprising 1 to 5 samples from all 25 stream sites indicates that at a similarity (Euclidean) coefficient of 4.2 there are 7 clusters at of sites (Figure 3.14). These groupings are consistent with the MDS grouping of averages taken of replicate samples from these streams.

Therefore for management purposes streams could be grouped (and managed) as anything from 3 to 7 groups of similar streams.

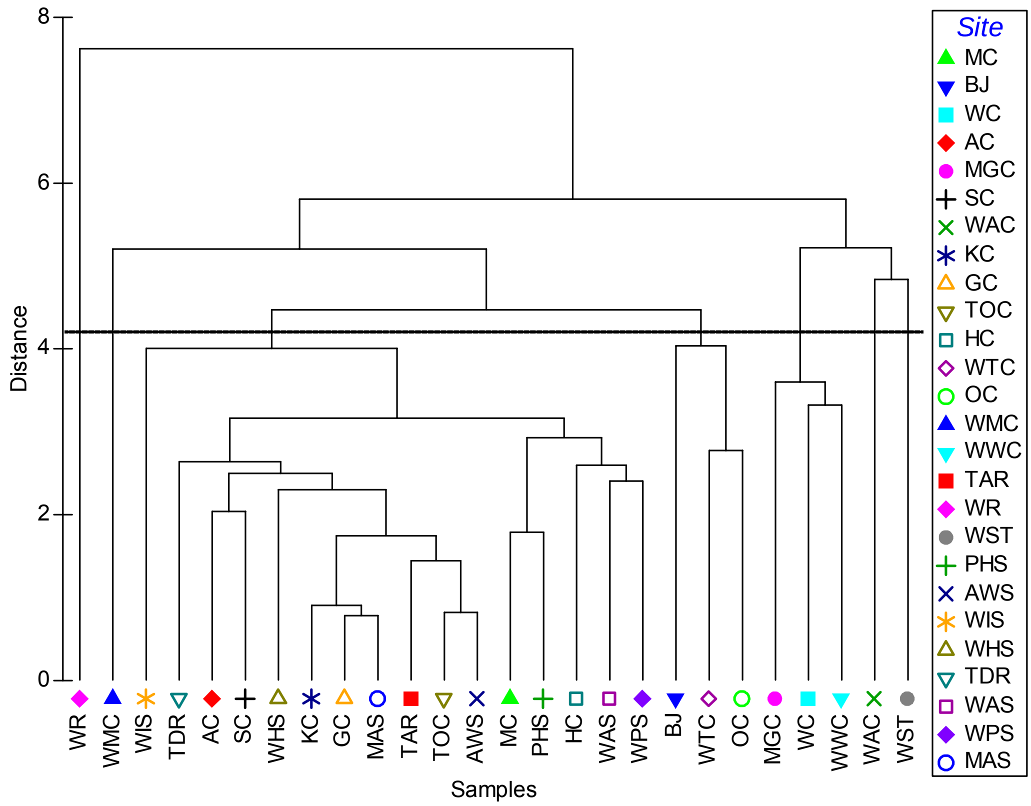


Figure 3.14 Cluster analysis dendrogram showing grouping of replicate samples at different similarity levels (Y axis) from all stream monitoring sites on Chatham Island based on water quality characteristics

3.3.15 Biological sampling

Biological sampling was undertaken at 19 stream sites. Sampling comprised composite samples of all available aquatic habitats, including large areas of bedrock, dense bryophyte (moss) covered rock surfaces, gravel and cobbles (when present), areas of organic and silty sediment and detritus, and riparian aquatic vegetation. The stream bed was frequently not visible due to the high colouration and/or poor clarity of the waters, so that sampled materials could not always be well characterised or scored for habitat assessments. Loose sediments ranged from sand and gravel, both loose and consolidated peat materials, and woody detritus. Subsequently, a 'Bathyscope' viewer has been sourced for future viewing of sampled streambeds.

Macroinvertebrate communities from all sites were composed of very similar and simple (low taxa diversity) communities. In particular, the common 'sensitive stream insect taxa' (EPT) were either absent (mayfly larvae (Ephemeroptera) and stonefly larvae (Plecoptera), or in the case A caddisfly larvae (Tricoptera) were represented by few taxa and were not abundant.

The most abundant insect taxa were Diptera (true winged flies, represented by the chironomid 'midge' subfamilies (*Chironominae* and *Orthocladiinae)*, and the algal piercing Trichopteran (*Oxyethira).* The molluscan snail *Potamopyrgus* was also common (Figure 3.15, Appendix 5). Crustaceans were also frequently present, and in 4 streams the freshwater shrimp *Paratya curvirostris* was a conspicuous and abundant macro species.

The Chatham Island streams therefore do not contain classically diverse macroinvertebrate communities found elsewhere in New Zealand. Foodwebs appear to be represented by simple browser or shredder based food webs, composed of crustaceans or midges. These are more commonly associated with soft sediment and 'macrophyte dominated' habitats, or still waters. Even in streams with extensive areas of bedrock or gravel, the usual EPT taxa were absent. This is therefore consistent with Chatham Island macroinvertebrates being more similar to off-shore islands in general (Collier 1993) and Campbell Island in particular (Joy and Death 2000).

Extensive bryophyte (moss) areas adhering to bedrock, also had low macroinvertebrate taxa diversity. Suren (1993) considered macroinvertebrate communities associated with bryophytes in New Zealand alpine areas were dominated by Nematoda, Chironomidae, Oligochaeta, and Copepoda. He considered this to be fundamentally different from the bryofauna outside New Zealand, and may reflect the absence of certain bryophyte-dwelling families of Trichoptera, Plecoptera, and Ephemeroptera from New Zealand.

The reasons for such simple food webs could include geographical isolation, short geological history, the acidic nature of the environments, and/or the poor clarity. These may all be affecting the overall type and abundance of the primary production of these ecosystems.

The consequence of this low macroinvertebrate diversity are that:

1. macroinvertebrate communities may not be particularly useful as monitoring tools or indicators of the health or change in health of Chatham Island streams.
2. Chatham Island streams have a range of vacant niches in stream communities that could easily be colonised by a range of more specialist mainland and exotic invading taxa.

Fisheries surveys were not specifically conducted, but specimens of resident fish were frequently encountered in the biological samples. Fish species identified from these samples included bullies (*Gobiomorphus sp., Gobiomorphus huttoni*.), elvers (*Anguilla spp*.), Galaxiids (*Galaxias fasciatus, Galaxias brevipinnis), and Smelt (Retropinna retropinna).*

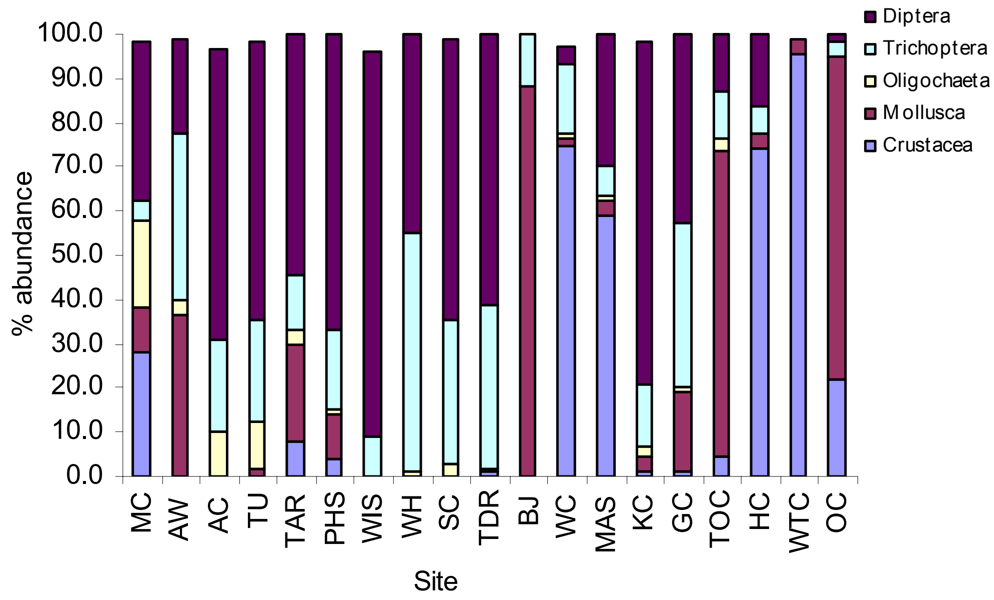


Figure 3.15 Abundance (%) of main taxonomic groups found in 19 Chatham Island streams

3.4 Te Whanga Results

Five sites were sampled from April 2005 to June 2006 (Figure 2.1, Appendix 1). Four were monitored quarterly, while the southern basin site near to the Hikurangi Channel was only sampled once in June 2006. Samples were taken by wading into Te Whanga to approximately knee depth at all of the northern sites, and a sample grabber was used to sample from deeper water at the southern site. Dissolved oxygen, % oxygen saturation, conductivity, salinity, pH and temperature were measured in the field. Nutrients and a range of chemical determinands were analysed from collected water samples. TN, DRP, and chlorophyll-*a* were compared to trigger values for southeast Australian estuarine and marine ecosystems (ANZECC, 2000).

Te Whanga water quality results are summarised in Figure 3.17 and 3.19. Summary water quality statistics are presented in Appendix 4.

3.4.1 Te Whanga characteristics

Over 2005/06, the Hukurangi channel, which connects Te Whanga to the sea, remained closed. Under these conditions Te Whanga effectively behaves as a large shallow lake (Goring, 2004). Water levels are known to respond largely to wind fetch and freshwater inflow when the mouth is closed. Salinity is generally uniform or changes slowly, and the water balance is dominated by recharge from rainfall runoff (70%) and the Te Awainanga River (30%) (Goring 2004).

During the September and December 2005 monitoring visits, the northern basin was effectively dewatered by a northerly wind flow over the Island. The resulting wind fetch increased water levels in the southern half of Te Whanga and drained the shallow northern basin. Figure 3.16 illustrates the influence wind direction and speed has on water levels on a day-to-day basis. Wind arriving from the north or south of the Island has the most impact on Te Whanga water levels (Figure 3.16, left photo). This is due to a longer fetch i.e. the longer the distance the wind acts over. Westerly winds are also important - but they have a comparatively much shorter fetch (Figure 3.16, right photo). Water samples were unable to be collected from the North Road site in both September and December 2005 due to a northerly wind flow over the Island at that time.

Figure 3.16 Water levels at Te Whanga northern basin under a northerly wind December 2005 (left), and under a westerly wind June 2006 (right)

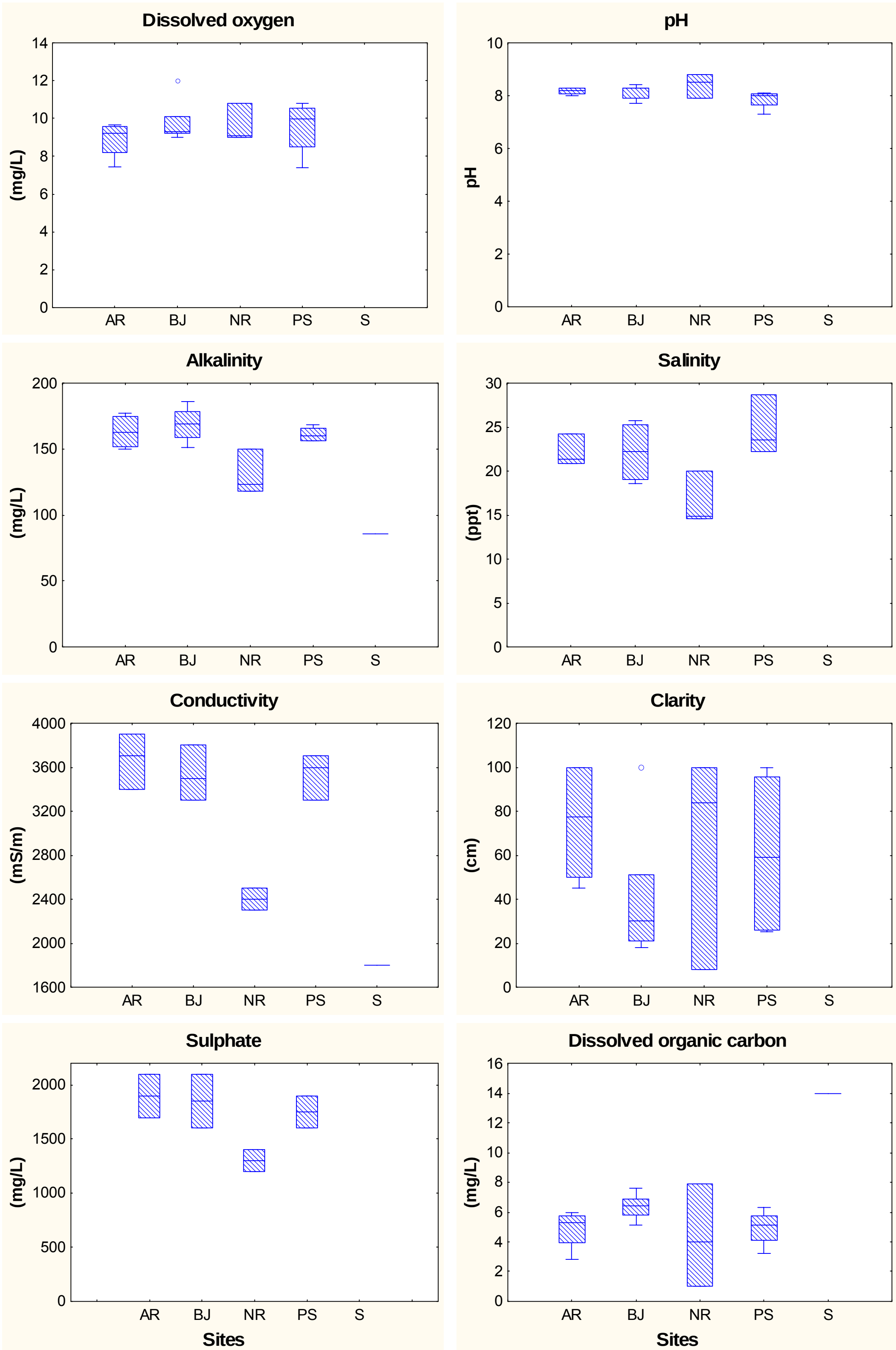


Figure 3.17 Dissolved oxygen, pH, alkalinity, salinity, conductivity, clarity, sulphate and dissolved organic carbon at five Te Whanga monitoring sites on Chatham Island

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95% iles

The water within Te Whanga is saline (Figures 3.17 and 3.18). A maximum salinity (28.7 ppt; 82% seawater) was recorded at the 'Pat Smith's' site in April 2005, and a minimum salinity (14.6 ppt; 42% sw) was recorded in the northern basin (North Road site) in March 2006. Median salinity at north and west central basin sites ranged between 14.9 to 22.2 ppt (Figure 3.18). Salinity in the central basin at Airbase Rd and 'Pat Smith's' remained consistently above 20 ppt (57% sw), with median concentration of 22.2 and 23.5 ppt respectively. The lower conductivity/salinity at the southern site confirm a freshwater influence from the Te Awainanga River, observed by Goring (2004) as equal to almost one third of total recharge.

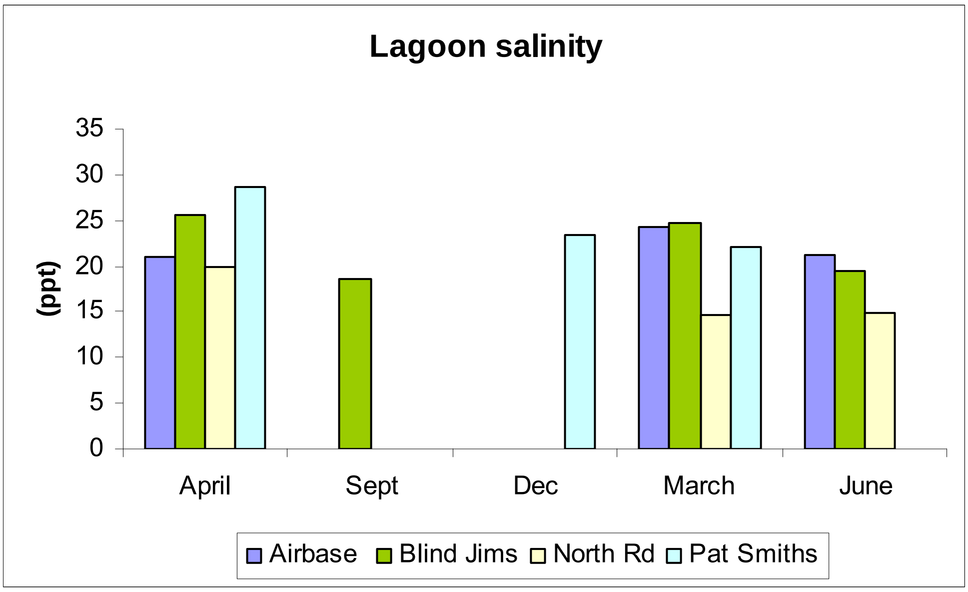


Figure 3.18 Salinity concentrations at north and west central basin sites, Te Whanga, 2005 – 2006, Chatham Island

All sites were slightly alkaline with a median pH of 8 - 8.5 (Figure 3.17). Alkalinity was influenced by limestone to the west of Te Whanga, and the carbonaceous (cockle shell) material on the bed and western beaches. Te Whanga temperature was generally in equilibrium with air temperature. Dissolved oxygen and percent oxygen saturation was generally above 8 mg/L, and above the guideline value of 80% saturation (Figure 3.17).

Chlorophyll-*a* concentrations varied considerably within and between sites (Figure 3.19). Concentrations were exceptionally high in March and June (2006) at Pat Smith's (117 ug/L and 64 ug/L respectively), at North Road (62.5 ug/L) in June 2006 and Blind Jims (31 mg/L) in March 2006. A strong onshore wind predominated over the two sample periods. Under these conditions wave action had significantly stirred up the bed thereby reducing water clarity because of high concentrations of suspended organic matter. A significant quantity of the plant *Ruppia megacarpa* had been deposited along the western shores within 100 m from land, and is likely to have influenced the chlorophyll-*a* results.

3.4.2 Te Whanga nutrient limitation

Nitrogen is generally the most common limiting nutrient in marine ecosystems. This is caused by constraints on nitrogen fixation and higher denitrification in marine sediments due to their anoxic state (Tomasky *et al,* 1999, Vince & Valiela, 1973). Conversely, phosphorus is generally abundant and conservatively maintained in marine systems.

However, when assessing ambient nutrient concentrations in estuarine waters, no nutrient and chlorophyll-*a* water quality trigger or guideline values are available for New Zealand marine waters. However, values do exist for marine and estuarine ecosystems in Southeast Australia that can be cautiously applied to New Zealand lagoon waters (ANZECC 2000) (Table 3.5). Over the monitoring period the mouth of Te Whanga was closed, therefore the trigger values established for (generally tidally flushed) estuarine ecosystems are not entirely suitable for use as an indication of water quality status.

Dissolved inorganic nitrogen concentrations (ammonia-N and NNN) were high compared to the ANZECC (2000) default trigger values (Table 3.5) at all central and northern basin sites. This is not surprising for what is essentially a partial freshwater environment. Nitrogen was predominantly present as TON rather than the inorganic fractions (Figure 3.19). The southern basin water quality differed from the other sites in that the inorganic nitrogen was slightly less than 50% of the total nitrogen. Total organic nitrogen (bound nitrogen) comprised over 90% of the measurable total nitrogen in the southern basin, and is probably associated with wind stirred sediment and algal biomass at the site.

Total nitrogen concentrations varied between sites and over time. Concentrations ranged from 0.38 - 0.69 mg/L at Airbase Road, 0.77 - 1.8 mg/L at Blind Jims, 0.74 - 2.8 mg/L at North Road, and 0.47 - 2 mg/L at Pat Smith's (Figure 3.19). In the one sample taken at the southern site the TN concentration was 0.76 mg/L.

Dissolved reactive phosphorus concentrations were also higher at all sites compared to the ANZECC (2000) default trigger values (Table 3.5). Particulate phosphorus (TP – DRP) made up 71 - 82% of the total phosphorus present at all four central and northern basin sites, indicating P was mostly bound up in algal biomass or sediment. Significantly less particulate phosphorus occurred at the southern basin site (only 53% of TP as TPP). Median total phosphorus concentrations at Blind Jims, North Rd and Pat Smith's were generally higher than those from Airbase Rd and the southern site (Figure 3.19). The total phosphorus concentration ranged from 0.046 - 0.17mg/L at the Airbase Rd, from 0.042 - 0.32 mg/L at Blind Jims, from 0.029 - 0.49 mg/L at North Rd, and from 0.03 - 0.33 mg/L at Pat Smith's. The southern site registered a TP of 0.028 mg/L.

Dissolved reactive phosphorus concentrations were of similar concentration to dissolved inorganic nitrogen such that soluble nutrients were either in excess or N:P ratios indicated nitrogen limitation at all sites except in the southern basin (Table 3.8). A higher soluble N:P ratio value at the southern basin indicates this site is possibly phosphorus limited.

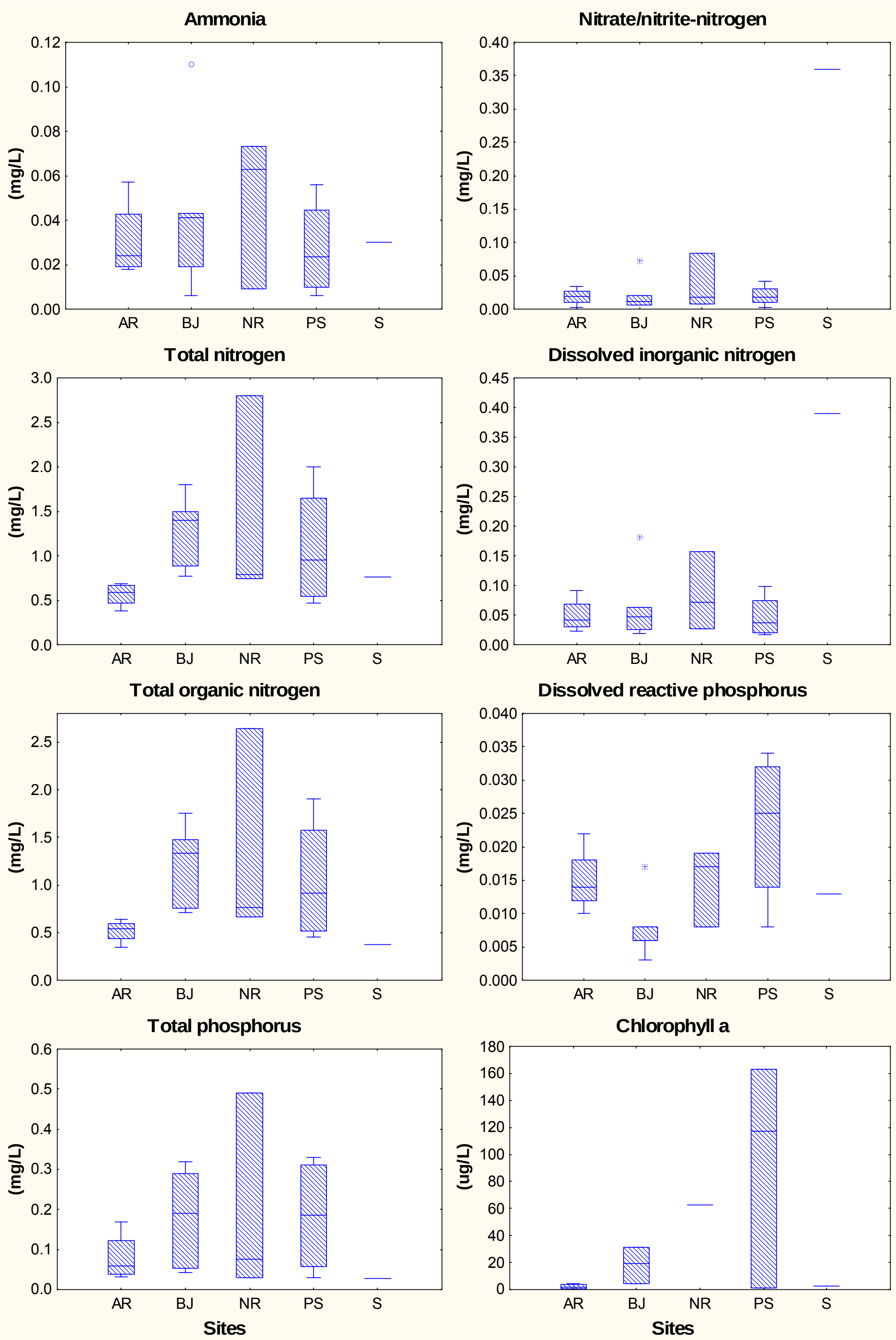


Figure 3.19 Box plots of nutrient nitrogen, phosphorus and Chlorophyll-*a* concentrations at five Te Whanga monitoring sites on Chatham Island

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95% iles

Table 3.8 Median DIN/DRP and TN/TP ratios ranked and grouped by nutrient limitation category, Te Whanga, Chatham Island

Site	DIN/DRP	Site	TN/TP
Southern	30.0	Southern	27.1
Blind Jims	7.8	North Rd	10.5
North Rd	4.2	Airbase Rd	10.0
Airbase Rd	3.0	Blind Jims	7.4
Te Matarae	1.5	Te Matarae	5.1
Te Awaninga River	1.2	Te Awaninga River	3.1

P limited (>20), not limited (10 – 20), N limited (<10)

4 Discussion

4.1 Lakes

The accessible Chatham Island lakes were all located in the central to northern region of the Island. They are shallow and low-lying (from 1 - 21 m above msl) with maximum known depths of less than 1.0 m (Huro) to 4 m (Tennants). Most are small (i.e. less than 100 hectares), and all are exposed to the prevailing winds. Coupled with shallow depth, this means that they are generally kept fully mixed and well aerated throughout the year. Lakes Rangitai and Huro, both formerly part of Te Whanga, were the largest of the lakes monitored (867 and 598 hectares respectively).

For the most part, they are set in amongst rolling landscapes upon dune complexes or overlying peat layers on top of basement schist and limestone. One of the most remarkable features of the Chatham Island lakes is the absence of exotic invasive aquatic plant species. This sets them apart from lakes in mainland New Zealand, and adds to their overall high conservation status. The reduced number of aquatic plant species also reflects the isolated nature of the Chatham Islands from New Zealand and the rest of the world, and the limited opportunities for plant introduction by natural mechanisms. Lake aquatic vegetation is therefore generally considered sparse and composed of low growing turf species. They therefore appear to be clear open water lakes, despite their shallow depth. Such lakes in mainland New Zealand have mostly reverted to a persistent turbid state associated with either high inorganic turbidity, persistent algal blooms or both. Most of these lakes are also highly visible from the roads, and so represent important landscape features.

Based on the lake classification system developed by Lowe and Green (1987), accessible lakes are described as being either ‘Dune’ lakes or ‘Peat’ lakes, or falling on a continuum somewhere between the two types. Dune lakes are characteristically fed by groundwater entering directly through the lake bed (along with rain on the lake surface), rather than through inflowing streams (e.g. Kokich 1991). Conversely, Peat lakes represent the infilling of peat in a high water table environment, whereby groundwater enters from around the margins and through the lakebed, and is typically acidic and darkly stained. The Chatham Island dune lakes mostly occur along the coastal fringe of northern Chatham Island (both the central northwest and central northeast) and overly catchments of consolidated quartz sands, with mixed layers of peat, mud and sand. However they also receive flow from streams draining elevated peat catchments. The sampled true peat lakes all exist in the north east of the Island around Kaiangaroa. Other peat lakes not sampled occur in the southern wilderness area.

Most of the lakes monitored were characteristically phosphorus rich. This contrasts markedly to lakes on mainland New Zealand that (when enriched) tend to be nitrogen rich with excessive N:P ratios. The lower nitrogen concentrations on Chatham Island can be easily explained by local farming practices that don't involve applying nitrogen fertilizer, and with relatively low livestock densities as well as low human population densities . Few farmers apply any phosphatic fertilizer either, so the nutrient status of many of the lakes may be considered a consequence of natural processes. The primary determinant of most of the lakes’ trophic states would be delivery of phosphorus from the immediate catchment and internal cycling of nutrients within the lakes. Possible sources of the naturally elevated phosphorus concentrations include:

- Guano deposition from widespread historic seabird burrowing and nesting across the Island
- Phosphorus rich volcanic sediments from both local and distant (Taupo) origin ash fall
- High P content in natural volcanic and oceanic sediments uplifted in natural Chatham Island geological formations (Campbell et al. 1993)

Other natural features that have a significant influence on Island lake trophic levels are lake depth and lake hydraulic flushing rates. Shallow lakes typically have less volume to dilute nutrients, so have higher concentrations of nutrients and algae, and thus greener, more eutrophic water. Light limitation is also seldom an issue in shallow lakes. They are also more likely to become stirred by wind energy, consequently nutrients are prone to become resuspended in the water column and are repeatedly made available for algal growth (as observed in lakes Kaingarahu and Huro).

Water residence time, or flushing rate also influences the time available for nutrients to be actually used for algae growth. Most of the lakes monitored do not have defined outlet streams, and therefore, they have a very slow hydraulic flushing rate, and/or can accumulate nutrients and other contaminants over time. As a consequence, algae and plants have plenty of time to use the nutrients.

The history of development across the Island also suggests lake trophic status is possibly affected by anthropogenic sources. Most of the lakes monitored are in private ownership and none are well protected from grazing livestock, especially cattle, which have well documented impacts on lake health trophic status and vegetation state (Jowett 1997, Rowe and Dean 1998). Noticeable stock impacts observed during the monitoring period were erosion, pugging and/or compaction of lake margins, resuspension of lake sediments, and consumption of aquatic plants. Significant nutrient and bacteria addition by animal faeces and urine are also highly probable. Adverse effects from livestock, a loss of natural habitats, and disappearance of some indigenous plant species, have consequently left some lakes more exposed to the wind and wave action. This can trigger increased sediment resuspension and lead to turbidity and algal blooms that can become a detrimental stable state.

The extent of ‘natural’ lake eutrophication, before land clearance and catchment development is not easy to ascertain, but prior to people arriving to Chatham Island, the lakes would have been in a natural ‘pristine’ state. The lakes will have sustained effects of both Moriori and Maori population growth, prior to European arrival. Further nutrient addition and bacterial contamination would certainly have increased post European settlement. The overall TLI scores suggest these lakes are surprisingly eutrophied, and hinge between moderate to high productivity. They are largely devoid of excessive nuisance plant, algal growths. There are also very few introduced adventitious aquatic macrophytes that could exploit currently observed or future enrichment of nutrient conditions (Champion and Clayton 2004). These features all lead to conclusions that the lakes should be in a steady or near natural state.

The trophic state assessments may be an over-estimate of the true trophic state of these lakes. The equations in Burns et al. 2000, were generated from a subset of monitored New Zealand lakes. Few of these were shallow lakes, and/or peat affected. As such, the index may not be well calibrated for these lake types. This is also illustrated by assessments of the trophic state of the shallow Canterbury lakes (Ellesmere and Forsyth) being considered an overestimate of their true trophic state.

Dune lakes along the western sand spit displayed particularly high water quality/clarity, as did Lake Rangitai in the north-east of the Island. These are contrasted with lakes Kaingarahu and Huro, which displayed excessive algal blooms throughout the monitoring period from April 2005 - June 2006. Lake Kaingarahu’s algal bloom that was also noted in 2003 by Champion and Clayton (2004). The cause of the sustained bloom, or likely source of nutrients (particularly nitrogen) driving the bloom is unknown. The extent of the bloom is such that a large source of nutrients would have been required to initiate and then maintain the sustained bloom. Many possible sources of this nutrient addition could be hypothesized, from historic or recent aggregations, or deaths, of seabirds or waterfowl, exposure of a strata representing historic shellfish beds, or strandings of marine fish or cetaceans, loss or disposal of livestock., to name a few. There is no evidence to support any theory, other than to illustrate that the lake continues to cycle a large internal nutrient load.

In contrast, Lake Huro is a very shallow lake (< 0.5 m depth) surrounded by well-developed pasture, a small amount of human dwellings with the catchment, an eroding shoreline and little riparian margin or protection. It is likely that domestic and agricultural sources have contributed the increased nitrogen loads into the lake catchment, such that the lake has reached a critical threshold of sustained blooms.

The visual and chemical degradation of water quality in both lakes clearly illustrates the sensitivity and risk of degradation of other Chatham Island lakes. In particular, lakes with low dissolved nitrogen and phosphorus ratios are likely to be highly sensitive to any increase in nutrients, and similar changes in state.

The distinctive rich ‘red brown’ colouring and high organic content of the peat lakes, Wharemanu and Koomutu, signals they receive large amounts of their organic (and nutrient) supply from allochthonous sources of peat material that covers much of the catchment basin. Both lakes had relatively high naturally occurring DIN and DRP concentrations, but did not exhibited visible algal productivity due to both restricted light penetration and acid conditions probably inhibiting the extent of algal growth. These ‘dystrophic’ lakes are unlikely to be sensitive to further trophic changes, as there is limited capacity to ‘develop’ their catchment areas, they are largely in DOC control, and their existing water quality is probably highly stable. Therefore, monitoring lake water quality in these dystrophic lakes will only be necessary if there is a significant change in catchment land use, or if a deterioration in the lakes physical condition is observed.

Deterioration in lake water quality in most other lakes could result from a change in land use activity or other nutrient addition that stimulates increased leaching of nitrogen into the surface water environment. Algal blooms that may result may be followed by excessive blooms of a wide collection of common aquatic plants and algae. As with Lakes Huro and Kainagarahu, such blooms can become a stable though undesirable state.

The greatest risk to lake water quality is if there is a change of trend in Chatham Island farming activity that promotes importation of nitrogen based fertilizers. Nitrogen fertilizers could assist farmers to increase pasture production and extend their productive growing season, or allow them to broaden their farming practices into cultivation of horticultural crops. However this increases the risk of N losses and leaching to surface water bodies.

Lake Management issues

The key water quality issues affecting lake water quality and ecosystem health are related to: nutrient addition, invasion by exotic aquatic plants, and erosion from a lack of riparian protection. These are correspondingly most likely to be affected by changes to agricultural activities, and activities within and alongside lakes. Other important management issues include:

Change in disposal of municipal and commercial wastes on the Island

The current system of solid waste disposal is located along the coastal fringes (e.g. Te One, Owenga and Kaingaroa). Any moves to promote land disposal technologies, (such as disposal of waste onto inland catchments) could greatly increase soluble nitrogen leaching to inland surface waters. This includes increased yields of soluble nitrogen from municipal wastes, landfills and fish processing factory waste.

Potable water supply sources – particularly Lake Rangitai

The clear lakes represent some of the most easily accessible water sources for potable water supplies. Currently, Lake Rangitai is the predominant source of treated water for Kaiangaroa township, and other lakes are used as private supplies. Surface waters are generally considered insecure and therefore potentially contaminated and requiring a high standard of treatment. Microbial and nutrient contamination from stock access and wild bird populations generally compromise potable uses, and can contribute to algae growth and poor water quality.

In particular, the water supply value of Rangitai could be compromised at times due to stock access if the supply did not continue to be appropriately treated as for the seafood processing factory. Should the local Kaingaroa community want to continue to source their drinking water from this lake without the factory based treatment, they would still need to consider treatment options to reduce the level of micro-organisms. Monitoring for E.*coli* bacteria as an indicator organism of faecal contamination (from stock and birds) is recommended for future inclusion in the long term monitoring programme.

4.2 Streams

Chatham Island streams sampled are mostly small and independent from one another. They vary in width from 0.5 m to 4 m, and are distinguished by their dark tannin stained waters that overlie catchments of peat soils (up to 10 m in depth) and mixed geology. One of the most notable features of Chatham Island streams is the absence of exotic predatory fish on native fish species. Impacts from channelisation, water abstraction and drainage are minor, however most streams meander through farmland and consequently are exposed to grazing stock. In several streams, small dams and culverts have been constructed without provision for the passage of indigenous fish, and road metal quarries adjoin some waterways.

Stream recharge is predominantly from groundwater seepage associated with the gently undulating and semi drained pakihi swampland of Chatham Island. Most streams have a relatively stable flow regime that increases over the wetter months of the year. Some streams are also part augmented by spring recharge. All streams monitored are classed as lowland streams i.e. much of their catchment occurs between 0 - 150 m above sea level.

In general the biological community is a simple “filter and collector browser” food web with most insects feeding on small organic matter or grazing on algae (depending on what is available). In streams that are highly coloured, light penetration is low and hence photosynthesis and algae production is low. In these streams organic matter leached from the surrounding soils and leaves from riparian vegetation are the basis of the food web. The crustacean based biota observed in these streams mirror those observed in the NZ subantartic Campbell and Auckland Islands and Stewart Island (Collier, 1993; Joy and Death 2000). The reasons for such simple food webs may be many, but could include geographical isolation, short geological history, the acidic nature of the environments, and/or the poor clarity. These may all be affecting the overall type and abundance of the primary production of these ecosystems.

Southern tableland streams (Tuku Road)

Streams form a characteristically well developed drainage pattern that flow westwards from hills located in the southern tablelands (Whakamarino and Oehau) to the coast near Point Durham. They are distinguished by their moderately steep gradients, short length (up to 5 km), cobble / stony bottoms and relatively narrow incised channels.

Land use includes extensive pastoral farming (sheep and cattle) on less fertile peat soils and distinctive remnants of mixed hardwood tarahinau forest secondary growth, and semi drained pakihi swampland. The dominant geology influencing these streams is the coastal belt of calcareous tuffs / pillow lavas and hard basalt basement rock. Awatotora and Awamata streams have significant portions of basalt lava in their upper reaches compared to Matakatau stream.

Awatotora stream appeared to be in an attractive and healthy state, with good riparian vegetation, resulting in clear water, little sediment, low periphyton / macrophyte growth and good bank stability. However, Awamata and Matakatau were poorly protected and large parts meandered through grazed pastures, which generally lack fencing to keep stock out of the waterways. There is often no riparian vegetation along these streams, and stream banks showed signs of erosion from stock access.

Nutrients concentrations were generally low, especially DIN concentrations, which met the periphyton guideline values and were well within the range of those typically found in Chatham Island streams. Dissolved reactive phosphorus concentrations were also within the range typically found in the volcanic based geology catchments of Chatham Island, though were high when compared to the trigger guideline values for slightly disturbed lowland streams for New Zealand. Matakatau Stream had consistently high NNN concentrations, and higher DRP concentrations (than in other streams from the southern tableland region), which indicates impacts from land activities. Excessive periphyton growth was noticeable in Awamata and Matakatau over the summer lower flow period.

Sedimentation of the streambed in Matakatau was consistently observed. As with many lowland streams in farmed areas, sedimentation of poorly protected streams results in loss of aesthetic and biodiversity values.

Southern tableland streams (Waitangi Wharf - Owenga Roads)

The streams of southeast Chatham Island flow from the south over a relatively open, extensive flat plateau and undulating country to Hanson Bay. They are distinguished by their long linear gradients (up to 20 km in length); rocky and stony bottoms that sometimes drop steeply near the coast to form highly visible chutes and waterfalls. They have relatively stable channels and well developed drainage patterns that respond quickly to rainfall events. These streams generally have greater flows than streams bisecting Tuku Road. The Te Awainanga is the largest river of the southern plateau and drains close to one third of the southern tableland region. Its substantial volume and fall have lead to the Te Awainanga being considered as a potential source of electricity for Chatham Island.

Calcareous marine volcanic sediments, hard basalt basement rock and quartz sands are the dominant catchment geology. Te One and Gillespie catchments were part dominated by pastoral farming (mainly sheep with some cattle), whereas Mangahou, Te Awainanga and Hawaiki catchments were mostly dominated by secondary scrub and semi drained pakihi swampland, interspersed with pockets of native forest. As with many other streams flowing through pastoral land, Te One and Gillespie streams generally lacked riparian protection, and stream margins exhibited signs of grazing stock. Casualty stock (dead carcases) were observed in Mangahou and Te Awaninanga streams.

The water quality data show moderate to high water quality. Streams were characteristically cool and well oxygenated and conductivity concentrations were low and reflect the dilution capacity of streams. The low alkalinity and widely fluctuating pH values suggest some influence from the volcanic geology, however nitrogen concentrations (typically high in volcanic dominated catchments) were low at all sites.

The stable flow regime and stony/rocky streambed means these streams are susceptible to occasional excessive peripyton growth. This is likely to occur under times of settled weather, over a warm summer period.

Mangape Creek

Mangape Creek flows through a relatively wide open, extensively farmed lowland plain. It is characterised as an outflow stream of Lake Huro, and is distinguished by its sluggish and stagnant nature. Soft flats historically formed by Te Whanga, swampland and high peat soils are the dominant geology.

The streambed is largely unprotected from surrounding grazing sheep and cattle and in many areas stock have unrestricted access to the streambed. Casualty stock were a common feature of this stream. Consequently poor clarity, high turbidity, high nutrients, microbial contamination and sedimentation is a feature of Mangape. It is considered likely that the poor water quality of Lake Huro is contributing to poor water quality in this stream.

Central North Streams

Streams in the central north flow east through areas of undulating landscape before entering the central and northern basin of Te Whanga. The geology is mixed and quite varied, but generally consists of layers of sand, peat and soft flats bounded by a band of exposed limestone cliffs around the edge of Te Whanga.

Streams are distinguished by their low-lying nature and narrow stony or sandy beds. The catchments are generally small, and streams have relatively short gradients (up to 4 km in length). Generally, streams that bisect Airbase Road tend to be deeper and slower moving with streambeds comprised of silt and sand. Those further north, which drain into the northern basin are shallower and tend to be more oxygenated, but with lower flows, and rocky/gravel beds.

Land use in the central north consists of smaller more intensive farming (mostly cattle) on fertile limestone soils, areas of scrubland and some quarrying. The high alkalinity and conductivity concentrations and low amounts of dissolved organic carbon measured in these streams are as expected for catchments that overlie a mixture of hard and soft limestone deposits. For the most, stream clarity is very good and likely to be influenced by the lower amounts of dissolved organic carbon in the water column. Waitaha stream is particularly susceptible to inputs of sediment from the Waitaha volcanic quarry during periods of rainfall activity.

During low summer flows, Waipapa and Waimahana streams do not flow continuously; rather they become a series of discontinuous ponds. Under these conditions water quality is likely to be lowered from a combination of soft sedimentary geology, stagnant water during summer low flows and inputs of contaminants from adjacent land activities.

High amounts of phosphorus are not unusual in Chatham Island streams but the elevated concentrations at Waimahana suggest considerable phosphorus input from soft marine sediments in the catchment. Nitrogen concentrations were typically low at most sites, which indicates these streams are classically phosphorus rich and nitrogen limited. High concentrations of dissolved nitrogen at Waitaha indicate impacts from land activities.

Port Hutt / Waitangi West streams

The northwest peninsula of Chatham Island consists of a large, slightly tilted peneplain set in amongst low relief. From Tawirikoko to the west the peninsula is covered in extensive areas of semi drained pakihi swampland, and secondary scrub, which contain large volumes of water. Catchment land use activity is generally limited to extensive tracts of scrubland, cattle farming and isolated areas of horse grazing and pig farming.

Waitangi West, Washout, Waihi tributary and Waihi creeks have low-lying catchments that meander up to 6 km across the peninsula before emptying into the ocean on the northern coastline. Streams are generally well distinguished by their wide, deep incised channels, acidity, dark staining and stagnant / slow moving water. Consequently poor clarity, low dissolved oxygen, high DOC and high organic nutrients are a common feature of these streams

Further east, the dominant geology consists of schist and layers of peat and dune bedded quartz sand. Streams are distinguished by their shorter gradients (up to 2 km in length) and small catchments, which flow to the south coast of the peninsula. Streams drain land extending south from Mt Diffenbach to Rakautahi, and for the most have narrow, incised channels and cobble / stony beds. These streams share similar physical water quality characteristics to streams in the northwest of the peninsula, however nutrient concentrations are generally lower. Under periods of low recharge Port Hutt, Stony and Rakautahi tributary streams run dry.

The nutrient data show streams are largely nitrogen limited, whilst dissolved reactive phosphorus concentrations were above the trigger values for lowland streams across New Zealand. High dissolved organic carbon and elevated phosphorus concentrations in streams were largely due to catchment geology. The high concentrations of dissolved reactive phosphorus and dissolved inorganic nitrogen indicate impacts from land activities.

Unrestricted stock access to streams and a lack of riparian protection are major factors contributing to poor water quality. In many reaches streams show signs of sedimentation from stock access - as seen in Port Hutt and Rakautahi tributary streams. The incidence of casualty stock is also a feature of these streams.

The blocked river mouth of Whangamoe and slow moving stagnant nature of Washout causes these streams to have exceptionally low concentrations of dissolved oxygen. It is unlikely these streams are able to support a diverse instream ecosystem.

Management issues

The key water quality issues affecting stream water quality and ecosystem health are related to affects from agriculture i.e. changes to physical habitat and water quality and reduced streamside riparian cover. Other important management issues include:

Culvert design and the passage of fish / invertebrates

Culverts are designed to carry stream flows with maximum efficiency, but with little regard for habitat continuity and the passage needs of fish / invertebrates. Culvert design has an important influence on the upstream migration of fish. Several culverts were observed to have excessive slope (high water velocities, or a drop at their downstream end, both of which make passage for fish difficult. There are several new large ARMCO culverts being installed on the Island, and represent an opportunity to address some current poor culvert placement with respect to fish passage requirements.

Changes in land use activity

A change in land use activity may increase the amount of nitrogen leached into surface water. Increases in soluble N may come about by a move from farmers to use nitrogen-based fertilisers, which will promote eutrophication and intensify stream deterioration caused by excessive plant and algal production.

Adverse environmental impacts associated with major development projects.

Mitigating against adverse environmental impacts associated with major developments such as proposals to: dam the Te Awainanga River for power supply; relocate municipal and commercial waste inland; harvest sphagnum moss; and mining for peat.

4.3 Te Whanga

Te Whanga is New Zealand's largest shallow saline lake/lagoon, and is considered locally as part of the freshwater resources, but by the NZ government as marine and therefore part of the Coastal Marine Area (CMA). It is a dominant feature of the Island landscape, and consists of a unique mix of truly marine and largely freshwater fish and shellfish species. Moriori and Maori highly prize Te Whanga for its abundant supply of mahinga kai, patiki (flounder), tuna (eels), inanga (smelt-whitebait) and a variety of native duck, which could be collected in almost total safety. Today Te Whanga is used by local families for swimming, boating, fishing and gathering swan eggs, and remains highly regarded for its cultural, historic and botanical values.

On the north and east sides Te Whanga is bounded by long low-lying sand bars. The northern bar is older and covered for the most part with peat swamp. The eastern sand bar stretches from Okawa Point almost to Owenga, a distance of 44 kilometres. Te Whanga is formed by the eastern sand bar, which intermittently encloses a coastal embayment resulting in rising water levels and decreasing salinity during periods of enclosure (Goring, 2004).

Occasional dense sea grass beds occur around the perimeter of Te Whanga to a depth of 0.5 m, and in deeper water, sparse assemblages of marine red algae occur (Champion and Clayton, 2004). The bottom is typically sandy and covered in loose organic floc, or encrusting algae. In the parts visited, some marginal vegetation had been cleared, land reclaimed (particularly in the northern basin area) and converted to pasture/grass for sheep and cattle grazing. Land use impacts surrounding Te Whanga are comparable (though not as severe) to impacts on similar mainland habitats - for example Te Waihora (Lake Ellesmere) and Coopers Lagoon in Canterbury, Lake Wairarapa (Wellington) and shallow Waikato lakes.

The water quality data show that Te Whanga is a saline environment typified by high soluble nitrogen and phosphorus concentrations, spiked concentrations of chlorophyll-*a* and sporadic low clarity.

In general the highest salinity occurred in the central and southern basins and the lowest salinity occurred in the northern basin. This indicates that seawater is restricted from penetrating into the northern basin by the submerged shelf of hard limestone that extends from Korowaipuna to Kahupiri Point. The conductivity and high dissolved organic carbon (double the northern sites) at the southern site, indicates the Te Awainanga River can have a significant influence on southern basin water quality.

The nutrient water quality is such that Te Whanga is classed as moderately to highly nutrient enriched, and is predominantly nitrogen limited. That is, plant growth is limited by n variability while p concentrations are in excess to plant needs. Most of this phosphorus is in organic form, i.e. bound to carbon, and is likely to be derived from carbonaceous material and from waters flowing into Te Whanga. The organic dominated environment also reflects the process by the mineralised nutrient is rapidly taken up by plant growth. However, whilst dissolved inorganic nitrogen concentrations are low, dissolved reactive phosphorus concentrations are high in comparison to mainland New Zealand waters (Waters of New Zealand, 1992; R Hoare and L Lowe.; Meredith and Hayward; 2002)

One consequence of high nutrient status is that Te Whanga will be very sensitive to any changes in nitrogen state i.e. from inert organic nitrogen to soluble nitrogen, and any overall increases in nitrogen. Chlorophyll-*a* concentrations that peaked at Pat Smith's, North Road and Blind Jims monitoring sites indicate Te Whanga suffers from excess plant productivity and algal blooms on occasion. How often TeWhanga is in bloom is unknown. If blooms become more frequent, then the composition of the plant community structure, fish and shellfish species in Te Whanga is likely to change over time. If the blooms occur longer and more frequently there will be a move from vascular plants (seagrasses and saltmarsh), which assist with nutrient absorption, to an eventual dominance by bloom forming phytoplankton and reduced water clarity (higher turbidity).

Overall Te Whanga is the dominant receiving environment for land runoff, stream inflow and groundwater seepage on Chatham Island. The water resource constitutes a potential sink for contaminants because of its enclosed nature, restricted tidal range and limited flushing capability. These characteristics emphasize the susceptibility of Te Whanga to changes and deterioration in water quality.

Protection of Te Whanga and its associated landscape, historic, wildlife, cultural and botanical values is needed to safeguard it from development and pollution. This is particularly important for controlling excessive proliferations of weed and algae, and is likely to be successful if efforts were concentrated on restricting nutrients and contaminants from land-based enterprises to water.

Management issues

The key water quality issues affecting Te Whanga are related to affects from agriculture and changes in nutrient status. Other important issues likely to affect the water quality of Te Whanga include:

Decreasing freshwater flows and flushing rates

Decreasing freshwater inputs could tend toward a more saline environment with increased concentrations i.e. less dilution of nutrients. In turn, this could result in blooms of a wide suite of common aquatic plants and algae. Investigations into large scale projects that alter freshwater inflows to Te Whanga should be closely scrutinised to allow consideration and management of the consequences on functioning and status.

Manual openings

There is a limited understanding of the flow of nutrients between land and sea, and the impacts artificially opening has on nutrient cycling and overall trophic status.

Contamination from land based activities

The semi-enclosed nature and limited flushing capability places Te Whanga at risk of contamination from land based activities such as septic tank and sewage discharges to rivers and streams. Long-term sampling is therefore critical, and its comprehensive coverage in each compartment necessary if changes in water quality are to be effectively identified.

5 Conclusion

The water resources of Chatham Island occur on flat to rolling land set in amongst thick peat soils overlying a mixed geology. They have formed in isolation, and since the last glaciation, under a cool, moist environment. These features are particularly unique, and provide a regional pattern of water quality and physical characteristics that draw similar parallels to streams and lakes found in the southern South Island and subantartic Islands. They are easily distinguished by their highly tinted 'rose red' colouration, which contrasts to other mainland pakahi/peat waters of a 'yellow brown' colouration.

Overall the water quality is relatively good, especially in the water bodies that are less modified. The life supporting characteristics (dissolved oxygen, temperature and pH) fit mostly above or within national guideline values. Therefore, the water of most streams, lakes, and Te Whanga, are considered capable of sustaining aquatic ecosystems. Invertebrate analysis shows that the streams support simple "filter and collector browser" food webs, and a range of native fish species. These species occur reasonably consistently across the range of stream habitat types (forested, high riparian cover, pastoral farmland or semi drained pakihi swampland), and are in response to the high organic matter and light properties of the water. Similarities in the food web structure of Chatham Island streams are drawn to the NZ subantaractic Islands, Stewart Island and Campbell Island. The reasons for such simple food webs may be many, but could include geographical isolation, short geological history, the acidic nature of the environments, and/or the poor clarity. These may all be affecting the overall type and abundance of the primary production of these ecosystems.

Nitrogen concentrations are low compared with water bodies on mainland New Zealand, and are reflective of the naturally low nitrogen content and lack of nitrogen based fertilizer addition in soils overlying much of the Island. Ammonia nitrogen in streams and lakes was appreciably lower than those that would cause toxicity to aquatic life, being well below the ANZECC (2000) water quality guidelines. However, despite little evidence of any phosphatic fertiliser additions, concentrations of dissolved reactive phosphorus were high. Total phosphorous concentrations in the streams indicate farming sourced phosphorus is probably swamped by phosphorus from natural sources such as natural geology and historical avian sources. As a result, most of the Islands water resources appear to be nitrogen limited and phosphorus rich. These features make the water resources of Chatham Island susceptible to impacts from the adjacent low to moderate intensity agriculture (predominantly drystock sheep and beef). Some water bodies show elements of a degraded aquatic environment associated with inputs and disturbance as a result of the adjacent land uses.

Where there is impact, it has resulted from a lack of adequate riparian cover and sedimentation of reaches. Livestock contribute to increased nutrients, destabilisation of banks, and mobilisation of fine sediment, leading to sedimentation in the water column, and reduced clarity. Casualty stock within streams and lakes has also led to a decline in water quality. Whilst these effects have not caused consistent reductions in reduced water clarity, they have resulted in poor quality habitats. Most streams also had culverts constructed without provision for the passage of indigenous fish, and several streams were straddled by road metal quarries. While the impacts of these activities are considerable, other adverse activities on stream habitat, such as channelisation, water abstraction, drainage have been less significant.

The significance of nutrient enrichment in streams is that during long periods of stable low flows prolific periphyton biomass may develop. This was observed over the summer lower flow period, when significant growths of filamentous green slimes were observed on mosses colonising bare rock surfaces in several streams. The consequence of such change to a phytoplankton dominated environment on the current animal food webs in Chatham Island streams is, at this stage, unknown. As the food webs are primarily crustacean based, they may currently rely on stable detrital and moss based primary production. These systems could easily be destabiliised by shift to a periphyton or aquatic macrophyte dominated system. Such shifts will also cause adverse consequences to existing biological communities and natural biodiversity.

Given the importance of endemic biodiversity to the Chatham Islands environment, and limited understanding of the biological components of the Islands freshwater ecosystems, it is appropriate to include long-term assessment (5 yearly) of fish community presence and abundance at selected monitoring sites. In this environment they may be more sensitive than the limited macroinvertebrate community, and may more closely represent values for which the aquatic resources are being managed. From the results, it is likely that stream invertebrate communities are very resilient unless dramatic change is seen in water quality and habitats.

Of the lakes monitored, most are considered to be in a steady state. They are largely devoid of excessive nuisance plant and algal growths, and very few introduced adventitious aquatic macrophytes that could exploit the currently observed or any future enrichment of nutrient conditions (Champion and Clayton 2004). Although lake TLI scores indicate the lakes hinge between moderate to extremely high productivity, it is likely naturally high nutrient levels load these values. Productive dune lakes formed in the western sand spit displayed particularly high water quality, as did Lake Rangitai in the east of the Island. However, lakes Kaingarahu and Huro were constantly in major algal bloom and are indicative of an altered system.

Te Whanga is the dominant receiving environment in the flow of nutrients between land and sea. Community interest in Te Whanga is high; it is a unique ecosystem and valued asset that Chatham Islanders identify with strongly. Therefore, it is important that land use activity and environmental impacts from major development projects are viewed very carefully against likely environmental responses on the water resources of Chatham Island. In particular, municipal wastes, landfills, and fish processing wastes probably constitute the greatest potential sources of contamination. Proposals to increase any of these should be viewed very carefully against likely environmental responses. This is particularly important for controlling excessive proliferations of weed and algae, and is likely to be successful if efforts were concentrated on restricting nutrients and contaminants from land-based enterprises to water. Accordingly the sampling programme should be maintained to collect further data relating to environmental variables that affect eutrophic blooms and the life sustaining characteristics of the Islands water resources.

A further report summarising the water quality trends and instream habitat values of the selected long term monitoring sites will more conclusively discuss whether particular monitoring sites contain significant values that necessitate greater attention. The current limited understanding of the biological components of Chatham Island water resources suggests it is possible unknown fish and invertebrate species occur. Through determination of key aquatic habitats and fish spawning areas it is possible to then put in place management techniques to assist in promoting restoration/protection of identified water resources.

6 Recommendations

Current water quality monitoring (quarterly) is sufficient to maintain a watching brief on the state of the water quality of the Islands freshwater resources. Following the initial period of quarterly sampling and analysis, we recommend the following changes be made to further strengthen the monitoring programme:

1. The core number of sites are consolidated to a manageable number of sites representing the major identifiable lake and stream types identified in this report (Appendix 7) and

determinands monitored are extended to include sedimentation, stream habitat composition and abundance field observations.

2. Water bodies are assessed by their beneficial uses to identify existing quality and issues with reference to national guidelines. This includes:
   - Recreation water quality monitoring at popular swimming sites in Te Whanga and the Nairn River;
   - Potable water quality monitoring of Lake Rangitai;
   - Stock water quality monitoring of streams and lakes.

3. Further investigation into baseline assessment of fish and invertebrate community composition and abundance are completed and selected sites are repeated 5-yearly.

4. Opportunities to obtain samples from unsampled areas of the Island be taken when possible utilising cooperation with other parties (DOC, locals etc.). These could include southern lakes and streams in the wilderness areas, flowing reaches of the Nairn and Tioriori Rivers, and other inaccessible areas.

5. Sampling of streams on Pitt Island to compare water quality and stream types with those of the main island.

7 Acknowledgements

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Appendix 1 Details of the sampling sites included in the monitoring programme for Chatham Island

	Ref ID	Waterbody	Site Description	Site No.
Lakes	LT	Lake Tennants	North east shore off Port Hutt Rd	CRC304842
	LK	Lake Kaingarahu	North east lake margin off Taia-Hapupu Rd	CRC304845
	LR	Lake Rangitai	Eastern shore off Taia-Hapupu Rd	CRC304846
	LW	Lake Wharamanu	Northern shore off North Rd	CRC304847
	LH	Lake Huro	Western shore, south of School	CRC304859
	CL	Causeway Lakes	Northern shore off causeway	CRC304886
	TW	Lake Te Wapu	Northern shore off Kaingaroa Road	CRC304887
	TR	Lake Te Roto	North east shore off Port Hutt Road	CRC304892
	LM	Lake Marakapia	North west shore off Admirals Farm	CRC304893
	LP	Lake Pateriki	Southeast shore off Kaingaroa Road	CRC304889
	KO	Lake Koomotu	Northern shore off North Rd	CRC304890
	RO	Lake Rotorua	Northwest shore off Kaingaroa Road	CRC304888
Lagoon	PT	Te Whanga Lagoon	Lake edge at Pat Smiths	CRC304833
	LW	Te Whanga Lagoon	Lake shore at Waitamaki Ck Beach	CRC304861
	LN	Te Whanga Lagoon	Northern shore off North Rd	CRC304848
	LB	Te Whanga Lagoon	beach 300m north of Blind Jims Creek	CRC304843
	LO	Te Whanga Lagoon	Hikurangi Channel	CRC304850
Rivers / Streams	MC	Matakatau Creek	Upstream Tuku Road	CRC304800
	AWS	Awamata Stream	Upstream Tuku Road	CRC304829
	AC	Awatotara Creek	Upstream Tuku Road	CRC304830
	TAR	Te Awainanga River	Downstream Waitangi Wharf – Owenga Road	CRC304832
	HC	Hawaiki Creek	Downstream Waitangi Wharf – Owenga Road	CRC304858
	TOC	Te One Creek	Upstream Waitangi Wharf – Owenga Road	CRC304857
	GC	Gillespie Creek	Upstream Waitangi Wharf – Owenga Road	CRC304856
	KC	Kahiti Creek	Upstream Waitangi Wharf – Owenga Road	CRC304855
	MGC	Mangape Creek	Upstream Waitangi Wharf – Owenga Road	CRC304851
	MAS	Mangahou Stream	Downstream Waitangi Wharf – Owenga Road	CRC304854
	WR	Waihi River	Hurikia Beach	CRC304835
	WWC	Waitangi-West Creek	Hurikia Beach	CRC304891
	WST	Waihi Stream Trib	Downstream Waitangi West Road	CRC304836
	PHS	Port Hutt Bay Stream	Downstream Waitangi West Road	CRC304837
	WIS	Whangamoe Inlet Stream	Downstream Waitangi West Road	CRC304839
	WHS	Whangatete Inlet Stream	Downstream Waitangi West Road	CRC304838
	SC	Stoney Creek	Upstream Waitangi West Road	CRC304840
	TDR	Rakautahi Stream Trib	Upstream Waitangi West Road	CRC304841
	WTC	Waitamaki Creek	Downstream Airbase Road	CRC304860
	OC	Oringi Creek	Downstream Airbase Road	CRC304862
	WMC	Waimahana Creek	Downstream North Road	CRC304863
	BJ	Blind Jims Creek	Downstream North Road	CRC304844
	WPS	Waipapa Stream	Upstream North Road	CRC304850
	WC	Waitaha Creek	Upstream North Road	CRC304849
	WAC	Washout Creek	Downstream Waitangi West Road	CRC304834

Appendix 2 Photographs showing the range of stream and lake types, including habitat and morphology

Photo A Lake Wharamanu
Photo B Causeway Lakes
Photo C Lake Rangitai
Photo D Lake Kaingarahu
Photo E Lake Te Wapu
Photo F Lake Tennants

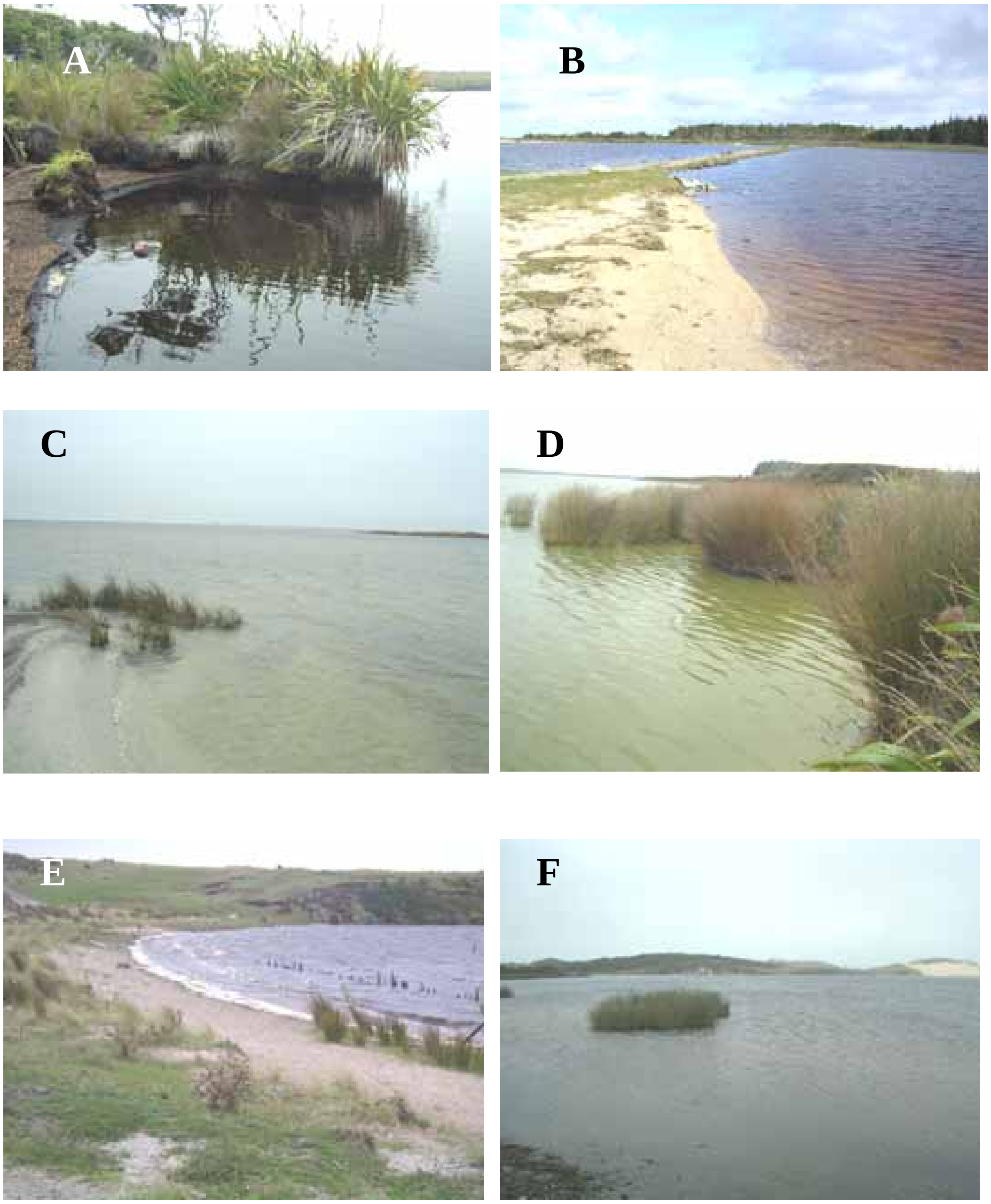

Photo G Matakatau Stream
Photo H Awamata Stream
Photo I Mangape Creek
Photo J Te Awaninga River
Photo K Te One Stream
Photo L Kahiti Stream

Photo M Waimahana Creek
Photo N Blind Jims Creek
Photo O Oringi Stream
Photo P Whangamoe Inlet Stream
Photo Q Port Hutt Bay stream
Photo R Washout Creek

Photo S Te Whaanga Lagoon – Airbase Road
Photo T Te Whaanga Lagoon – Te Matarae Point
Photo U Te Whaanga Lagoon – North Road
Photo V Te Whaanga Lagoon – Blind Jims

Appendix 3 Details of determinands and analyses included in the Environment Canterbury Chatham Island surface water quality monitoring programme

Determinand	Type of Measurement	Method	Detection Limit	Units
Dissolved Oxygen (DO)	Field measurement	NI-YSI 55 DO Meter – EMQ D7	0.5	mg/L
DO % Saturation (%SAT)	Field measurement	NI-YSI 55 DO Meter – EMQ D7		%
Temperature (TEMP)	Field measurement	NI-YSI 55 DO Meter – EMQ D7		°C
pH	Field measurement	NI-YSI pH 100 Meter – EMQ P2		pH
Salinity field (SAL)	Laboratory analysis (ECan)	NI-YSI/30 SCT Meter – EMQ S7		pH
Conductivity (COND)	Field measurement	Hach One pH/ISE meter		mS/m
	Laboratory analysis (ECan)	APHA 2510 B (20 Ed) - meter	2	mS/m
Clarity	Field measurement	SHMAK clarity tube	100	cm
Dissolved Organic Carbon	Laboratory analysis (ECan)	APHA 5310 C (20^{th} Ed) uv-persulphate		mg/L
Chlorophyll a. *	Laboratory analysis (ECan)	APHA 10200 (20 Ed) - Fluorimetry		ug/L
Nitrate/nitrite nitrogen (NNN)	Laboratory analysis (ECan)	APHA 4500 NO_3-F (20^{th} ED)	0.010	mg/L
Total ammonia-nitrogen (NH3N)	Laboratory analysis (ECan)	APHA 4500 NH_3-F modified (20^{th} ED)	0.005	mg/L
Dissolved inorganic nitrogen (DIN)	Calculation (NNN +NH3N)			mg/L
Total organic nitrogen (TON)	Calculation (TN - DIN)			mg/L
Total nitrogen (TN)	Laboratory analysis (ECan)	APHA 4500 N C (20 Ed) modified		mg/L
Dissolved reactive phosphorus (DRP)	Laboratory analysis (ECan)	APHA 4500-P B F (20^{th} Ed)	0.003	mg/L
Total phosphorus (TP)	Laboratory analysis (ECan)	APHA 4500 P B5 (20 Ed) - Autoanalyser		mg/L
Alkalinity (HCO3)	Laboratory analysis (ECan)	APHA 2320 B (20 Ed) – Titration to pH 4.5		mg/L
Sulphate (SO4)	Laboratory analysis (ECan)	APHA 4110 B (20 Ed) IC	0.008	mg/L

Appendix 4 Summary statistics of the lake, stream and lagoon water quality data collected from Chatham Island

LAKES		DO	DO SAT	TEMP	pH	HCO3	COND	CLARITY	DOC	CHL A	NH3N	NNN	TN	DIN	TON	DRP	TP	SO4
Tennants Lake	Minimum	8.12	80.4	9.2	7.8	65	43	80	11	0.4	0.003	0.005	0.330	0.011	0.308	0.001	0.014	7
	Median	9.1	91.7	14.6	8.3	98	48.8	91.2	12	1	0.012	0.008	0.374	0.020	0.364	0.002	0.020	7.65
	Maximum	10.2	103.9	17.9	8.8	115	52	100	14	2.3	0.020	0.018	0.400	0.025	0.390	0.004	0.036	8.4
	Count	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4
Lake Kaingarahu	Minimum	8.61	72.8	7.4	7.9	62	65	3	33	25.8	0.010	0.003	2.800	0.017	2.783	0.001	0.170	15
	Median	9.8	96.4	15.5	8.6	90	74	9	40	110.4	0.029	0.007	3.500	0.035	3.464	0.006	0.300	22
	Maximum	12.4	127.6	16.9	9	115	82	11	58	252.2	0.032	0.020	6.700	0.052	6.679	0.086	1.200	26
	Count	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	4
Lake Rangitai	Minimum	7.49	75.3	7.4	8.2	92	86	38	7.6	0.5	0.003	0.006	0.490	0.017	0.467	0.001	0.004	24
	Median	9.22	94.6	15.8	8.2	117	93	100	7.8	1.1	0.009	0.011	0.570	0.020	0.550	0.002	0.011	28
	Maximum	10.1	101.3	17.6	8.7	147	99	100	9.3	1.4	0.011	0.019	0.700	0.023	0.683	0.003	0.027	31
	Count	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4
Lake Wharemanu	Minimum	8.79	90	8.1	4.3	2	87	0	67	10.2	0.003	0.003	1.900	0.013	1.882	0.720	1.100	30
	Median	9.12	91	15.9	4.4	2	92	0	73	93.7	0.010	0.022	3.300	0.025	3.288	1.000	1.200	39
	Maximum	9.61	96.2	18.7	4.5	2	110	2	80	99.8	0.160	0.085	11.000	0.240	10.901	1.700	2.000	48
	Count	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	4
Lake Huro	Minimum	8.29	83.1	11.3	8.3	74	50	7	12	18.1	0.003	0.003	0.790	0.009	0.782	0.001	0.076	18
	Median	9.08	95	15.2	8.5	93	54	11	16	33.9	0.011	0.018	1.400	0.021	1.380	0.009	0.240	21.5
	Maximum	9.67	99.3	20.1	10	122	61	24	17	95.3	0.220	0.038	1.700	0.258	1.684	0.024	0.320	26
	Count	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4
Causeway Lakes	Minimum	7.71	78.4	8.8	8.1	95	62	16	11	9	0.008	0.003	0.740	0.023	0.675	0.002	0.032	17
	Median	9.7	95.75	14.95	8.3	117	94	46	14	17.25	0.020	0.032	1.045	0.046	1.021	0.005	0.045	21
	Maximum	10.01	105.3	17.9	9	154	100	70	24	23.3	0.089	0.450	2.500	0.539	1.961	0.016	0.190	21
	Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
Lake Te Wapu	Minimum	8.46	86.8	7.8	7.7	49	79	10	35	1.6	0.003	0.003	1.500	0.016	1.358	0.001	0.057	73
	Median	9.275	93.75	14.8	8.25	152	530	25	38.5	4.8	0.013	0.066	1.800	0.083	1.697	0.002	0.080	240
	Maximum	9.68	97.7	16.9	8.5	189	610	42	40	9.1	0.021	0.180	1.800	0.183	1.785	0.006	0.120	260
	Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
Lake Koomutu	Minimum	7.69	76.2	8.3	5.9	21	78	0	78	0.5	0.003	0.041	2.300	0.044	2.199	0.120	0.210	20
	Median	8.9	90.2	13.8	6.1	22	79	6	80	1.25	0.015	0.068	2.800	0.101	2.634	0.200	0.250	27
	Maximum	9.83	99.4	15.9	7.1	38	100	10	90	2	0.098	0.086	3.200	0.166	3.157	0.280	0.280	34
	Count	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3
Lake Te Roto	Minimum	7.97	81	9.8	7.4	95	45	36	2.3	1.3	0.009	0.014	0.420	0.048	0.370	0.003	0.041	15
	Median	9.14	92.4	15.6	8.15	127.5	55.5	64	15.5	3.9	0.018	0.050	0.615	0.069	0.442	0.014	0.070	16
	Maximum	9.63	99.9	17.3	8.6	165	61	67	31	8.3	0.036	0.330	0.710	0.339	0.582	0.023	0.130	20
	Count	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
Lake Marakapia	Minimum					118	61		16	1.4	0.003	0.003	0.600	0.005	0.592	0.002	0.013	11
	Median	9.52	94.6	14.3	8.2	125.5	63	60	16.5	2	0.050	0.101	0.745	0.152	0.594	0.004	0.054	11.5
	Maximum					133	65		17	2.6	0.098	0.200	0.890	0.298	0.595	0.006	0.095	12
	Count	1	1	1	1	2	2	1	2	2	2	2	2	2	2	2	2	2
Lake Pateriki	Median	9.55	98.8	13.8	8.1	103		61	22	1.5	0.017	0.022	0.720	0.039	0.681	0.002	0.022	44
	Count	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lake Rotorua	Median	6.16	58.8	13.6	6.7	90	60	54	18	13.5	0.013	0.003	0.650	0.016	0.635	0.010	0.052	20
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

STREAMS		DO	DOSAT	TEMP	PH	HCO3	COND	CLARITY	DOC	SAL	NH4N	NNN	TN	DIN	DRP	TP	SO4
Matakatau Creek	Min	7.4	75.4	8.6	6.0	6	19	23	11.0	0.1	0.003	0.021	0.270	0.024	0.037	0.064	4.7
	Median	9.1	84.2	12.0	6.9	39	29	46	18.0	0.1	0.014	0.030	0.340	0.044	0.051	0.100	4.9
	Max	10.02	97.1	15.1	7.7	65	30	100	32.0	0.1	0.019	0.044	0.350	0.063	0.057	0.110	9.1
	Count	5	5	5	5	5	5	4	5	2	5	5	5	5	5	5	4
Awamata Stream	Min	8.2	82.2	8.3	5.3	2	21	24	14.0	0.1	0.005	0.003	0.240	0.008	0.022	0.036	4.2
	Median	9.8	97.6	13.9	7.4	24	28	55	19.0	0.1	0.007	0.011	0.270	0.018	0.026	0.058	5.4
	Max	11.8	113.9	16.2	8.0	37	30	68	32.0	0.1	0.019	0.033	0.350	0.052	0.031	0.066	11.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Awatotara Creek																	
	Min	8.2	85.9	9.4	4.2	2	19	22	19.0	0.1	0.003	0.003	0.220	0.005	0.015	0.024	2.6
	Median	9.9	92.8	11.0	5.2	2	21	50	30.0	0.1	0.014	0.003	0.270	0.017	0.030	0.046	5.0
	Max	10.6	98.0	13.7	6.3	8	22	70	42.0	0.1	0.083	0.022	0.420	0.105	0.034	0.064	11.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Mangape Creek	Min	6.5	71.5	9.2	7.6	95	53	6	13.0	0.3	0.006	0.005	1.000	0.011	0.001	0.150	18.0
	Median	8.3	80.8	13.3	7.8	106	55	12	14.0	0.3	0.032	0.051	1.200	0.083	0.019	0.190	22.5
	Max	9.1	98.8	21.1	8.5	130	64	15	15.0	0.3	0.210	0.065	1.700	0.275	0.035	0.210	26.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Te Awainanga River	Min	8.2	81.3	8.7	5.5	2	13	35	9.7	0.1	0.003	0.003	0.160	0.005	0.023	0.033	3.1
	Median	9.3	92.1	14.4	7.3	10	15	43	20.0	0.1	0.019	0.015	0.180	0.034	0.027	0.058	3.3
	Max	9.8	93.4	15.5	7.4	35	19	76	26.0	0.1	0.029	0.035	0.280	0.064	0.033	0.076	7.2
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Mangahou Stream	Min	7.6	72.3	9.5	4.6	2	14	41	12.0	0.1	0.003	0.003	0.190	0.005	0.016	0.023	2.4
	Median	9.4	87.8	12.0	6.5	7	16	45	22.0	0.1	0.009	0.006	0.200	0.015	0.025	0.043	3.1
	Max	9.7	92.1	14.4	6.9	24	17	60	26.0	0.1	0.027	0.022	0.260	0.049	0.030	0.071	6.5
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Kahiti Creek	Min	6.4	59.4	9.1	4.8	2	14	25	13.0	0.1	0.003	0.003	0.200	0.005	0.017	0.026	2.5
	Median	8.7	81.9	12.2	6.5	10	17	47	24.0	0.1	0.015	0.003	0.230	0.018	0.024	0.053	3.1
	Max	9.2	87.9	14.8	7.6	28	18	58	30.0	0.1	0.021	0.019	0.300	0.04	0.027	0.081	9.4
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Gillespie Creek	Min	8.1	82.5	9.5	4.8	2	18	35	11.0	0.1	0.003	0.003	0.180	0.005	0.018	0.036	3.8
	Median	9.6	93.5	13.3	6.3	8	20	39	30.0	0.1	0.013	0.003	0.250	0.016	0.031	0.051	4.3
	Max	10.3	98.8	15.6	7.7	27	21	69	36.0	0.1	0.019	0.028	0.360	0.047	0.032	0.056	9.9
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Te One Creek	Min	8.1	81.6	9.6	5.6	2	22	34	11.0	0.1	0.003	0.003	0.240	0.005	0.027	0.046	7.4
	Median	9.4	95.9	15.1	7.1	14	25	51	23.0	0.1	0.006	0.003	0.270	0.009	0.036	0.071	9.2
	Max	10.7	111.0	17.4	7.7	35	30	72	35.0	0.1	0.015	0.043	0.440	0.058	0.044	0.077	14.0
	Count	5	5	5	4	5	5	5	5	2	5	5	5	5	5	5	4
Hawaiki Creek	Min	7.3	79.8	9.6	6.9	5	33	58	16.0	0.2	0.003	0.003	0.400	0.005	0.010	0.044	13.0
	Median	9.3	92.4	13.8	7.4	33	42	70	21.0	0.2	0.012	0.015	0.460	0.027	0.017	0.064	17.0
	Max	10.3	99.7	16.3	8.0	44	44	78	27.0	0.2	0.043	0.056	0.480	0.099	0.027	0.067	21.0
	Count	5	4	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Washout Creek	Min	1.7	16.1	7.7	4.7	2	28	19	22.0	0.1	0.027	0.003	0.370	0.0295	0.025	0.030	5.6
	Median	2.8	27.5	13.8	6.3	54	45	35	27.0	0.2	0.072	0.016	0.430	0.088	0.110	0.140	13.5
	Max	7.2	72.5	15.3	7.1	123	110	40	36.0	0.2	0.260	0.055	1.200	0.315	0.140	0.240	18.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Waihi River	Min	7.8	73.4	6.0	6.4	21	37	20	33.0	0.2	0.012	0.003	0.560	0.0145	0.004	0.035	10.0
	Median	8.8	77.7	15.0	8.7	319	870	26	36.0	5.5	0.023	0.003	1.900	0.026	0.036	0.250	34.0
	Max	11.4	113.2	16.0	8.7	446	1700	43	41.0	10.7	0.035	0.029	2.900	0.064	0.140	0.350	760.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	3

STREAMS		DO	DOSAT	TEMP	PH	HCO3	COND	CLARITY	DOC	SAL	NH4N	NNN	TN	DIN	DRP	TP	SO4
Waihi Stream Tributary	Min	3.2	32.2	8.7	4.3	2	30	7	46.0	0.1	0.003	0.003	0.540	0.005	0.001	0.012	3.1
	Median	5.3	52.9	13.9	4.8	6	38	9	59.0	0.1	0.008	0.010	0.850	0.017	0.007	0.057	8.7
	Max	7.1	71.1	16.7	5.5	9	51	17	67.0	0.1	0.240	0.031	1.100	0.271	0.052	0.150	20.0
	Count	4	4	4	4	4	4	3	4	2	4	4	4	4	4	4	4
Port Hutt Bay Stream	Min	7.9	7.3	7.7	5.5	2	28	3	18.0	0.1	0.007	0.003	0.240	0.0095	0.031	0.043	9.8
	Median	8.1	82.6	14.2	6.8	38	41	25	29.0	0.2	0.013	0.013	0.390	0.026	0.057	0.120	16.0
	Max	9.1	91.7	16.0	7.4	77	46	33	32.0	0.2	0.026	0.056	0.460	0.082	0.075	0.190	33.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Whangamoe Inlet Stream	Min	1.2	10.4	8.2	4.7	2	27	12	14.0	0.1	0.005	0.003	0.250	0.0075	0.036	0.037	5.8
	Median	2.2	22.0	14.9	6.3	20	54	27	21.0	0.3	0.010	0.007	0.460	0.017	0.047	0.088	9.6
	Max	7.5	76.0	16.1	6.6	35	180	30	31.0	0.4	0.030	0.024	0.880	0.054	0.065	0.120	21.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	3
Whangatete Inlet Stream	Min	7.6	73.8	9.5	4.6	2	24	25	19.0	0.1	0.003	0.003	0.250	0.005	0.014	0.018	6.0
	Median	7.9	80.3	16.1	5.9	7	33	29	24.0	0.2	0.003	0.005	0.290	0.008	0.062	0.085	11.4
	Max	9.8	100.3	16.3	6.7	23	34	36	34.0	0.2	0.017	0.028	0.320	0.045	0.065	0.140	21.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Stoney Creek	Min	4.8	47.1	8.4	4.2	2	23	28	23.0	0.1	0.006	0.003	0.270	0.0085	0.006	0.018	3.6
	Median	8.6	87.7	15.4	5.6	2	31	36	29.0	0.2	0.010	0.008	0.320	0.018	0.012	0.044	9.0
	Max	9.3	96.0	16.9	6.0	5	35	46	34.0	0.2	0.032	0.035	0.440	0.067	0.023	0.046	21.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Trib draining Rakautahi	Min	6.0	57.8	8.4	6.4	21	30	16	26.0	0.1	0.003	0.003	0.320	0.005	0.011	0.033	6.4
	Median	8.2	81.0	14.3	6.6	23	40	25	29.0	0.2	0.008	0.003	0.330	0.011	0.017	0.049	10.3
	Max	9.2	97.2	19.1	7.2	46	42	30	38.0	0.2	0.027	0.010	0.620	0.037	0.024	0.110	24.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Blind Jims Creek	Min	7.1	73.6	9.3	7.7	107	36	79	5.4	0.2	0.003	0.003	0.150	0.005	0.004	0.033	9.5
	Median	8.2	86.1	17.4	8.0	170	62	95	6.2	0.3	0.008	0.008	0.150	0.016	0.010	0.037	11.5
	Max	9.1	95.7	18.1	8.3	292	65	100	9.6	0.3	0.026	0.019	0.180	0.045	0.019	0.038	18.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Waitaha Creek	Min	4.0	39.4	7.7	5.3	2	25	17	24.0	0.2	0.003	0.012	0.590	0.0145	0.006	0.017	10.0
	Median	8.5	82.5	14.7	8.0	126	56	21	28.0	0.3	0.017	0.024	0.670	0.041	0.023	0.063	17.5
	Max	10.3	103.9	17.0	8.5	271	74	50	43.0	0.3	0.034	0.420	0.840	0.454	0.032	0.190	22.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Waipapa Stream	Min	6.9	72.8	8.1	6.8	47	35	35	7.6	0.2	0.003	0.003	0.210	0.005	0.006	0.056	9.5
	Median	8.5	84.6	17.2	8.0	89	36	42	11.0	0.3	0.011	0.020	0.270	0.031	0.019	0.090	14.5
	Max	10.4	105.1	36.0	8.7	305	69	46	17.0	0.3	0.025	0.029	0.300	0.054	0.034	0.120	17.0
	Count	5	5	5	5	5	5	4	5	2	5	5	5	5	5	5	4
Waitamaki Creek	Min	5.2	50.3	8.2	7.4	109	43	36	4.2	0.4	0.003	0.017	0.170	0.0195	0.011	0.061	10.0
	Median	7.6	75.5	14.3	8.1	186	70	39	5.5	0.5	0.031	0.020	0.250	0.051	0.039	0.140	11.5
	Max	11.5	123.0	18.4	8.2	334	93	100	20.0	0.5	0.089	0.062	0.750	0.151	0.065	0.150	34.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Oringi Creek	Min	5.9	60.2	8.4	7.6	104	44	57	5.3	0.3	0.015	0.003	0.200	0.0175	0.002	0.030	9.9
	Median	8.4	78.3	16.0	8.2	235	62	95	7.6	0.4	0.023	0.018	0.290	0.041	0.012	0.054	12.0
	Max	10.2	99.3	21.2	8.6	335	83	100	12.0	0.4	0.056	0.058	0.640	0.114	0.022	0.130	19.0
	Count	5	5	5	5	5	5	5	5	2	5	5	5	5	5	5	4
Waimahana Creek	Min	8.8	84.3	9.0	7.5	92	36	58	3.1	0.2	0.003	0.003	0.040	0.005	0.075	0.098	6.8
	Median	9.1	87.9	13.0	7.9	186	58	100	3.6	0.3	0.012	0.021	0.040	0.033	0.120	0.210	7.9
	Max	11.4	109.4	13.8	8.3	268	61	100	17.0	0.3	0.046	0.026	0.460	0.072	0.250	0.250	9.9
	Count	4	4	5	5	5	5	5	5	2	5	5	5	5	5	5	4

STREAMS		DO	DOSAT	TEMP	PH	HCO3	COND	CLARITY	DOC	SAL	NH4N	NNN	TN	DIN	DRP	TP	SO4
Waitangi-West Creek	Min	6.7	66.6	8.0	5.4	2	24	20	35.0	0.3	0.014	0.003	0.930	0.0165	0.011	0.036	16.0
	Median	8.2	76.8	15.8	8.0	190	81	27	44.0	1.3	0.032	0.034	1.550	0.066	0.083	0.160	38.0
	Max	9.0	90.3	16.1	8.4	333	390	50	55.0	2.2	0.068	0.085	1.600	0.153	0.098	0.160	160.0
	Count	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	3

LAGOON		DO	DO SAT	TEMP	pH	HCO3	COND	CLARITY	DOC	CHL A.	NH3N	NNN	TN	DIN	TON	DRP	TP	SO4	SAL
Airbase Rd	Minimum	7.46	72.70	8.20	8.00	150	3400	45	2.8	0.6	0.018	0.003	0.380	0.023	0.343	0.010	0.031	1700	20.9
	Median	9.20	97.30	16.60	8.20	163	3700	78	5.3	1.9	0.024	0.019	0.595	0.042	0.538	0.014	0.060	1900	21.3
	Maximum	9.68	106.30	17.30	8.30	177	3900	100	6.0	4.5	0.057	0.034	0.690	0.091	0.644	0.022	0.170	2100	24.2
	Count	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	2	3
Blind Jims	Minimum	9.00	91.30	9.30	7.70	151	3300	18	5.1	4.7	0.006	0.006	0.770	0.018	0.708	0.003	0.042	1600	18.6
	Median	9.30	107.30	17.30	8.30	169	3500	30	6.4	19.6	0.041	0.012	1.400	0.047	1.337	0.006	0.190	1850	22.2
	Maximum	12.02	128.00	18.30	8.40	186	3800	100	7.6	31.1	0.110	0.072	1.800	0.182	1.753	0.017	0.320	2100	25.7
	Count	5	5	5	5	4	3	5	5	3	5	5	5	5	5	5	5	2	4
North Rd	Minimum	9.00	100.00	7.30	7.90	118	2300	8	1.0	62.5	0.009	0.008	0.740	0.027	0.669	0.008	0.029	1200	14.6
	Median	9.10	100.70	15.80	8.50	123	2400	84	4.0	62.5	0.063	0.018	0.790	0.071	0.763	0.017	0.075	1300	14.9
	Maximum	10.83	104.50	17.20	8.80	150	2500	100	7.9	62.5	0.073	0.084	2.800	0.157	2.643	0.019	0.490	1400	20.0
	Count	3	3	3	3	3	2	3	3	1	3	3	3	3	3	3	3	2	3
Te Matarae point	Minimum	7.40	84.20	9.20	7.30	156	3300	25	3.2	1.1	0.006	0.003	0.470	0.017	0.454	0.008	0.030	1600	22.2
	Median	9.95	95.45	14.85	8.00	160	3600	59	5.1	117.4	0.024	0.018	0.955	0.038	0.918	0.025	0.187	1750	23.5
	Maximum	10.79	105.00	16.00	8.10	168	3700	100	6.3	163.1	0.056	0.042	2.000	0.098	1.902	0.034	0.330	1900	28.7
	Count	4	4	4	4	4	3	4	4	3	4	4	4	4	4	4	4	2	3
Southern	Result					86	1800		14.0	2.7	0.030	0.360	0.760	0.390	0.370	0.013	0.028		
	Count					1	1		1	1	1	1	1	1	1	1	1		
		mg/L	%	°C	pH	mg/L	mS/m	cm	mg/L	ug/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ppt

Appendix 5 Taxa list for 19 streams and rivers on Chatham Island

	Site																		
Taxa List	MC	AWS	AC	TU	TAR	PHS	WIS	WHS	SC	TDR	BJ	WC	MAS	KC	GC	TOC	HC	WTC	OC
Trichoptera																			
Hydrobiosis	1		3	14	1			13		1			3	1	2				
Oecetis	1	1	10		5			3		1		1	4	9	2	1			1
Oxyethira	3	39	7	10	6	18	9	40	33	36	10	16	1	5	35	11	2		1
Paroxyethira											2								2
Triplectides					1														
Diptera																			
Ceratopogonidae							6								1				
Chironominae			18	2	13	53	73	35	21	54		2	22	68	8	2	5		2
Diamesinae																1			
Hexatomini													1						
Limoniinae				1															
Muscidae				1		1	1			1			2						
Orthocladiinae	37	23	43	60	44	13	3	11	42	5		1	7	7	36	11			
Paralimnophila				1															
Psychodidae								1	1										
Stratiomyidae														1					
Tanypodinae			3				4			3		1	2	5					
Hemiptera																			
Sigara												1							
Mollusca																			
Gyraulus													1						
Physa											1	1						1	1
Pisidium/Sphaerium	1																		4
Potamopyrgus	10	39		2	23	10					90	1	3	4	19	75	1	3	85
Crustacea																			
Amphipoda	6					4						1				1		14	9
Cladocera												13				1			
Isopoda	22											1				2			1
Ostracoda	1									1		64	3	1	1	1			15
Paratya curvirostris					8							1	65				23	99	2
Odonata																			
Xanthocnemis	1						4					2		2				1	
Nematoda									1										
Oligochaeta	20	3	10	11	4	1		1	3	1		1	1	2	1	3			
Acarina	1	1	3	2															

Appendix 6 Values of the variables defining the boundaries of the different lake trophic levels

The TLI scheme uses the following equations to determine each individual TL values for Chla (TLc), TP (TLp), SD (TLs) and Tn (TLn) to meet national lake status TLI protocol.

$TLc = 2.22 + 2.54\log(Chla)$ eqn. (1)
$TLp = 0.218 + 2.92\log(TP)$ eqn. (2)
$TLn = -3.61 + 3.01\log(TN)$ eqn. (3)
$TLs = 5.56 + 2.60\log(1/SD – 1/40)$ eqn. (4)

The average trophic level index for each lake can be calculated by:

$TLI = \Sigma (TLc + TLs + TLp + TLn)/4$ eqn (5)

Nutrient enrichment category	**Trophic state**	**Trophic level**	**Chla**	**Secchi depth**	**TP**	**TN**
			(mg/m^3)	**(m)**	**(mg/m^3)**	**(mg/m^3)**
Low	Oligotrophic	2.0 to 3.0	< 2.0	> 7.0	< 10	< 200
Medium	Mesotrophic	3.0 to 4.0	2.0 – 5.0	3.0 - 7.0	10 – 20	200 – 300
High	Eutrophic	4.0 to 5.0	5.0 – 15	1.0 – 3.0	20 – 50	300 – 500
Very high	Supertrophic	5.0 to 6.0	15-30	0.5 – 1.0	50 – 100	500 – 1500
Extremely high	Hypertrophic	6.0 to 7.0	> 30	< 0.5	> 100	> 1500

(Burns et al. 2000)

Appendix 7 Table of longterm water quality monitoring sites on Chatham Island

Ref ID	Site Name	Field Observations											Chemical Analyses									Micro - Biological Analyses	
		DISSOLVED OXYGEN	% DISSOLVED OXYGEN	TEMPERATURE	pH	CLARITY	CONDUCTIVITY	COLOUR	SALINITY	MACROPHYTES / PERIPHYTON	WEATHER OBSERVATIONS	SEDIMENTATION	CHLOROPHYLL A.	DISSOLVED ORGANIC CARBON	ALKALINITY	NITRATE-NITRITE NITROGEN	AMMONIA-N	TOTAL NITROGEN	DISSOLVED REACTIVE PHOSPHORUS	TOTAL PHOSPHORUS	SULPHATE	ENTEROCOCCI	E.COLI
STREAMS																							
AWS	Awamata	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
AC	Awatotora	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
MOC	Mangape	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
TAR	Te Awaninga	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
MAS	Mangahou	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
TOC	Te One	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
WAC	Washout	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
WIS	Whangamoe	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
TDR	Rakautahi trib	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
WMC	Waimahana	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
WPS	Waipapa	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
BJ	Blind Jims	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
WTC	Waitamaki	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
NR	Nairn																					x	x
LAKES																							
LR	Rangitai	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x			x
TW	Te Wapu	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x			
LT	Tennants	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x			
LH	Huro	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x			
LM	Marakapia	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x			
LAGOON																							
LW	@ Airbase Rd	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x		x	x
LB	@ Blind Jims	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x		x	x
LS	@ Southern site	x	x	x	x	x	x	x	x	x	x	x	x	x				x		x			