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Chatham Islands Freshwater Investigation – State of the Water Resources

Environment Canterbury

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Chatham Islands Freshwater Investigation – State of the Water Resources

∴ Prepared for

Environment Canterbury

∴ June 2020

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Limitations:

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Executive Summary

Environment Canterbury is contracted to provide regional council functions and advice to the Chatham Islands Council (CIC) and as such is required to review and report on the land, air, water and coastal resources in the area. As per the Resource Management Act (1991) (RMA) reporting on these matters is required at intervals no greater than 10 years.

Pattle Delamore Partners Ltd (PDP) has been engaged by Environment Canterbury to review data gathered and to report on the state of the water resources on the Chatham Islands. This report provides a review of available information and analyses on rainfall and evaporation, climate change, surface water quantity and quality and groundwater. This also includes a water balance, review of potential uses and abstractive pressures on the water resources and analysis of the suitability of water bodies for potable and domestic use. A summary of the review and analysis is provided as follows.

Rainfall and potential evapotranspiration

There is a wide variety of rainfall data available across Chatham Island. This has previously been used by NIWA to report on the climate and weather patterns of Chatham Island (Pearce 2016). Based on the available rainfall data, rainfall appears to be greater in the south of Chatham Island compared to the north and it is likely, although there are no rainfall stations present across the southern uplands, that rainfall at the most southern high points of the island are higher than elsewhere. In contrast, the available information suggests that potential evapotranspiration is generally more consistent than the rainfall between the stations at Waitangi and the airport.

Seasonally, rainfall is generally greatest in late autumn and winter, and generally lowest in late spring/summer. Long-term patterns of changes in rainfall are uncertain due to the lack of a consistent long-term record from any one rainfall site. The long-term record that can be derived from stations at Waitangi suggests that between 1990 and 2012, rainfall was generally greater than the long-term average. Based on recent data from the airport sites, the summers of 2017/2018 and 2018/2019 appear to have experienced relatively lower rainfall, but there is not sufficient data to determine a long-term trend to 2020.

A rainfall gauge should be re-established and maintained at Waitangi to ensure that a consistent long-term record is available at that site. The historic records at Waitangi are a valuable resource and continued rainfall gauging should be maintained. In addition, ideally a rainfall gauge could also be installed in the southern uplands to better understand the pattern of rainfall in that area, but the logistics of achieving this will need to be examined. If successful, this would lead to improved estimates of the water balance for the catchments that drain from the southern uplands.

Hydrology

There are four current and two historical continuous flow recorders on Chatham Island monitoring flow on most of the larger rivers on the island. The available information indicates that the rivers with a relatively large portion of their headwaters in the elevated parts of the southern hills have relatively high specific discharges at mean flow reflective of the likely relatively high rainfall in these areas. Flows during the summer low flow period are generally maintained in the larger rivers that drain these southern hills (Te Awainanga, Nairn and Tuku a Tamatea River), whereas the Awamata (at Old Hydro Intake), a relatively small watercourse in the south and the Tutuiri River (at Schist Outcrop) located in the northern part of the Island run dry during periods of extreme drought.

Analyses on the two long term recorder sites (Te Awainanga and Awamata) indicate no obvious increasing or decreasing trend in mean annual flow. There is no statistically significant difference in the mean annual flow between the last ten years of data (2010-2019) and the historical data (1986-2009) for these two watercourses.

In addition to the recorder sites, spot gaugings are available at a further 27 sites. Regression analyses with primary recorder sites indicate that the southern spot gauging sites generally correlated well with nearby primary sites in the southern hills. The sites in the northern part of the island generally correlated best with the Tutuiri River at Schist flow recorder although there are a significant number of sites in this area (especially the watercourses draining into Te Whanga Lagoon) that had either insufficient gauging data or did not show a clear correlation with any of the primary recorder sites. The majority of the spot gauging sites have insufficient gauging information at low flow. The reported 7DMALF estimates should therefore be used with caution.

The smaller streams in the northern half of the island are therefore likely to be of a different "stream type" to the recorder site rivers. They have also largely ceased to be gauged since 2014. Therefore, knowledge of the hydrology of these streams is poor, and not being kept up to date. This is an important omission, particularly as many of these streams drain into the very important and now co-governed Te Whanga Lagoon.

The results of the regression analyses indicate that the specific discharge at mean and median flow for the southern catchments tend to be higher compared to the northern catchments which is likely to be a reflection of relatively high rainfall and the low permeability of the underlying strata.

Based on our review and analyses of the available hydrological information it is recommended that:

- Flow recorder sites are more regularly gauged and maintained to ensure a reliable and continuous record is available for analyses.

- On the basis that the Nairn River correlates well with the other three continuous flow recorder sites in the southern part of the island it is recommended not to re-instate the Nairn River flow recorder. However, concurrent gaugings should be undertaken during both low and normal flow conditions with a focus on the flow range not covered by the current data.
- Further work be undertaken to improve flow estimates for the watercourses flowing into the north-western side of Te Whanga Lagoon and two other streams in the northern part of the island (Unnamed Stream and Whangamoe Creek). It is recommended to re-instate the recorder in Waitamaki Creek (at a suitable location) or another watercourse in the vicinity of Waitamaki Creek. It is crucial that a site is chosen that will provide a reliable continuous record and is gauged and maintained on a regular basis.
- Low flow gaugings be undertaken to improve knowledge of the low flow regime at spot gauging sites.

Groundwater, Water Balance and Abstractive Pressures

There is limited groundwater use across the island and overall, it is unlikely that total use is much greater than 250 m^3/day, which is relatively small scale in a national sense, but bulk water uses are largely absent from Chatham Island. Water balance estimates also suggest that groundwater recharge may be very limited. Further information regarding the groundwater resource and its potential for use is required, including development of a bore database, monitoring of groundwater levels in key locations and a survey of existing bores.

Climate Change

The Chatham Islands are projected to experience increased temperatures, increased rainfall and sea level rise as a result of climate change.

Although the projected atmospheric changes (temperature and rainfall) are expected to have limited effect on the overall water balance and potable water supplies, seasonal issues such as increased frequency, duration and intensity of drought periods may increase. A rise in sea level has the potential to impact the groundwater resource and in particular the community supply bore at Waitangi (depending on its depth). It would be prudent to undertake some assessment of the potential risk of saline intrusion at the community supply bore in Waitangi.

Sea level rise scenarios may also affect (increase) the connections of coastal lakes and lagoons to the sea. In particular the opening and closing regime of Te Whanga Lagoon may be adversely affected, and opening points to the north may become a potential risk and affect roading and access to Kaingaroa.

Water Quality

Chatham Island has a range of highly valued fresh waterbodies, including lakes, watercourses and lagoons. Many show high water quality values, especially those in less modified catchments; however, low impact agricultural land use (subsistence farming) has resulted in impacts to many of the fresh waterbodies on the island. These stem from livestock access to water bodies, vegetation clearance, and changes to stock density and stock type. While point source discharges do occur, they are rare and mostly located on the coastal fringes of the island. The primary nutrient input for waterbodies is non-point source discharge from land, and soil runoff and faecal contamination from stock.

A central government funded contract between Environment Canterbury and the Chatham Islands Council has allowed Environment Canterbury staff to carry out quarterly water quality monitoring since April 2005. Long term surface water quality monitoring data from 2005 to 2019 has been analysed in this report, to determine current state and temporal trends in waterbodies of the island and to compare current state data against national standards, where available.

Lakes

Lakes on the island can be characterised as either tannin stained peat lakes, or clear coastal dune lakes. Two of the monitored lakes on the island, Lake Huro and Te Wapu, show high levels of nutrient enrichment, with poor water quality and algal blooms. Trophic level index (TLI: a measure of the trophic or nutrient health of a lake) has improved at Lake Huro, moving from a hypertrophic state reported in 2007, to a eutrophic state as assessed in the last five years of data. The improvement at this lake corresponds to improving long-term trends in total nitrogen, total phosphorus, and chlorophyll-*a*. Overall, Lakes Marakapia, Rangitai and Tennant Lake have maintained long-term mesotrophic states (with some interannual variation reported), representative of moderate levels of nutrients and algae; however, recent (five year) trend analysis indicates increasing concentrations of nitrogen and phosphorus in Lake Marakapia, nitrogen in Lake Rangitai and phosphorus in Tennants Lake, which should be investigated to avoid degradation of these lakes.

Watercourses

Long term monitoring shows watercourses on Chatham Island have high variability in many water quality parameters; however, the majority are peat stained, with high alkalinity and are well oxygenated. The watercourses also frequently have high natural phosphorus concentrations. Small yet significant increasing trends in nitrogen are observed in many watercourses and although levels are far below nitrate and ammonia toxicity levels, many watercourses on the island are nitrogen limited. Many of these watercourses drain to Te Whanga lagoon or coastal lagoons, therefore current elevated nutrient levels and any future increases may lead to an increase in excessive macrophyte and periphyton growths in some watercourses and downstream lagoon waterbodies.

No systematic biological sampling (invertebrates or fish) has occurred since the 2007 SOE report. Communities are known to be a simple 'filter and collector browser' food web, with many common insect species from mainland New Zealand absent. While a recent systematic freshwater fish survey has not been conducted on the island, there are no known exotic species on the island and a variety of native freshwater species have been recorded by different agencies and during monitoring visits. Both natural and artificial fish passage barriers are common on the island and should be mitigated, where possible.

Te Whanga Lagoon

Te Whanga Lagoon is the largest waterbody on the island and is highly prized for its recreation and food gathering values, as well as having high cultural values. It is predominantly a brackish or saline environment, due to periodic openings to the sea.

It has moderate to high nutrient levels and is sensitive to changing nutrient state, as increases in nutrients could lead to more frequent and prolonged planktonic algal blooms, which can have adverse ecological effects. As many of the watercourses on the island drain to Te Whanga Lagoon, improved management of these catchments is important to reduce excessive nutrient inputs.

Planktonic algal blooms, suggested by high concentrations of chlorophyll *a*, have occurred periodically throughout the monitoring period, with peak concentrations in the northern end of the lagoon, likely as a result of low levels of flushing in that area during lagoon openings.

Te Whanga Lagoon Nutrient Flux

The nutrient flux analysis for the June 2011 to May 2012 period indicates that a significant proportion of the nutrient flux to Te Whanga Lagoon is generated from the southern contributing catchment areas. Approximately 80 to 85% of the total water flow and therefore nutrient load from the monitored sites enters Te Whanga Lagoon via the Te Awainanga River mouth.

In addition to the southern catchments, other localised 'hotspots' contributing high nutrient loads into Te Whanga Lagoon include Nikau Reserve Stream, Blind Jims (north) trib, Waitamaki Creek, and Matanginui Creek.

Review of different monitored water bodies suitable for or limiting potable and domestic use

The watercourses on Chatham Island with relatively large catchments generally have perennial (year round) flow and the quantities of water needed on Chatham Island for potable and domestic use are relatively small compared to flows in these waterways. From a water quantity perspective these relatively large rivers would be suitable for potable and domestic use, with no or a limited amount of storage. For smaller streams significant amounts of storage may be required to ensure reliability of supply for potable and domestic water use.

A review of the limited available water quality data indicates that there are no exceedances of the relevant drinking water standards for fluoride, chloride and the nitrogen species (nitrate, nitrite, nitrate-nitrite and ammoniacal-nitrogen). The GV for sulphate (250 mg/L) was exceeded during one sampling round for two watercourses and one lake site.

At times all watercourse and lake sites have recorded pH values outside the GV range (7.0 - 8.5) specified in the DWSNZ and with the exception of one sample in Lake Rangitai, the available water quality data indicates that *E. coli* was detected in all samples for the watercourses and lakes regularly being sampled. Based on these results it is considered that treatment will be required should any of these water bodies be used for drinking water.

Only a limited range of determinands has been sampled for and more comprehensive chemical analyses are required to determine the suitability of the monitored water bodies for potable and domestic use. This should include testing for heavy metals which may be present in the watercourses that drain the peat deposits on the Island.

The dark brown colour of most of the waterbodies on Chatham Island is caused by tannins and lignins leaching from the peat deposits. These can be removed by ultrafiltration, but this process is likely to be only viable for large community schemes and/or large commercial operations and may therefore not be feasible for the Chatham Islands. Therefore, should surface water be considered as a potable water source, further investigations should focus on rivers, streams, and lakes that are free of tannins and lignins leaching from the peat (i.e. avoid rivers with dark brown colours that are likely to drain peat basins). These clear water bodies may be a limited resource on the island and should be monitored and managed to avoid excessive utilisation.

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Appendices

1.0 Introduction

Environment Canterbury is contracted to provide regional council functions and advice for the Chatham Islands Council (CIC) and as such is required to review and report on the land, air, water and coastal resources in the area. As per the Resource Management Act (1991) (RMA) reporting on these matters is required at intervals no greater than 10 years.

Environment Canterbury entered into a contractual agreement with the Chatham Islands Council (CIC) in 2004, to establish baseline and trend monitoring of the water resources on Chatham Island. It was intended that this monitoring would begin to identify any current or potential water resource management issues and support the planning of water resource management as set out in the Chatham Islands Resource Management Document (CIRMD; CIC 2001, CIC 2018). A long-term monitoring programme has been operating since 2005, with monitoring data for freshwater (watercourses and lakes) and saline (Te Whanga Lagoon) surface water environments.

Pattle Delamore Partners Ltd (PDP) has been engaged by Environment Canterbury to review the existing data and report on the state of the water resources on the Chatham Islands. A State of the Environment (SOE) Report was completed in 2007 (Meredith and Croucher, 2007) and includes details of water quality monitoring and ecosystem health of the lakes, watercourses and Te Whanga Lagoon on Chatham Island. Annual Water Quality Summary memoranda were also prepared from 2014 to 2018 (ECan 2014, 2015, 2016; PDP 2018). A Chatham Island Water Resource Report was completed in 2010 (Ritson, 2010) which includes rainfall and evaporation data, river flow information and a water balance. The information presented in those earlier reports has been updated for this report but the review and analyses undertaken also cover additional matters as detailed below.

In summary this report covers the following:

- A review of rainfall and evaporation data;
- Flow statistics for monitored watercourses;
- A brief overview of the groundwater resources;
- A review of the abstractive pressure, consents and permitted activities;
- Water balance for monitored catchments;
- A summary of the key climate change projections;
- A review of watercourse, lake and lagoon water quality data including state and trend analysis;
- Nutrient flux analyses for Te Whanga Lagoon; and

- A review of different monitored water bodies suitable for or limiting for potable and domestic water use.
- An assessment of the monitoring programmes against national requirements.

This report details the results of our review and analyses of the most recent available information and (where possible) places these results within the wider temporal context of the longer-term monitoring data by assessing trends.

2.0 General Description – Chatham Island

Several reports provide a general description of the Chatham Islands covering the topography, main settlements, climate, geology, soils and the water resources of the Chatham Islands. The most notable reports include Meredith & Croucher (2007), Pearce (2016), Holt (2008), Goring (2004), Ritson (2010), Campbell (1993), Champion and Clayton (2000), and Chatham Islands Council (2018). The general description below draws on information from these reports.

The Chatham Islands form a small archipelago measuring 966 km^2, located approximately 800 km east of New Zealand's South Island. The archipelago consists of about ten islands within an approximate 60 kilometre radius. The largest two Islands are Chatham Island (900 km^2) and Pitt Island (6.3 km^2), as shown in Figure 1. Lakes and lagoons cover about a quarter of Chatham Island.

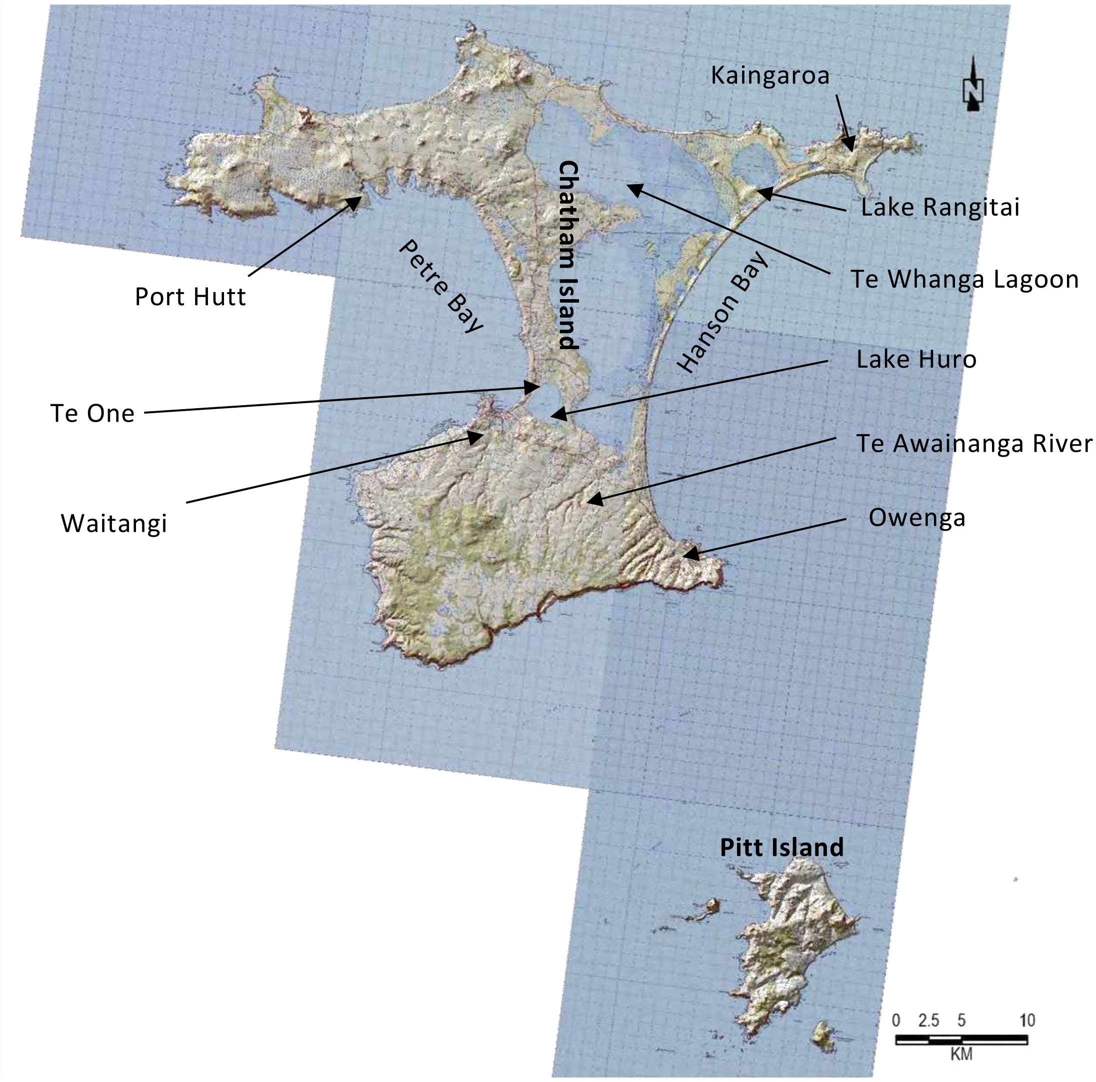


Figure 1: Chatham Island and notable locations

The islands sit on the Chatham Rise, a large submerged part of the Zealandia continent that stretches east from near the South Island. The Chatham Islands are the only part of the Chatham Rise above sea level. The islands can be regarded as the eroded remnants of Late Cretaceous oceanic islands. Pre-quaternary lithologies are dominated by mafic volcanics from three volcanic episodes during the Cretaceous and Tertiary, and by bioclastic Tertiary limestones. The Chatham Schist is believed to form the basement rock of the Chatham Rise. Following the schist in age on Chatham Island, are the Southern Volcanics which form the southern uplands. They are composed predominantly of mafic alkaline extrusive volcanics and were generated by a large shield volcano during the Late Cretaceous/Paleocene. After the cessation of the Cretaceous/Paleocene volcanism, crustal subsidence led to the Chatham Islands becoming submarine resulting in the bulk of the Late Cretaceous and Tertiary record being dominated by limestones. There are a number of different limestone units present on the island, the most extensive of which is the Te Whanga Limestone forming the main lithology in the central portion of the island. The geology of the Chatham Islands is illustrated in Figure 2. The Quaternary deposits on Chatham Island are dominated in volume and aerial extent by peat, and to a lesser degree aeolian sand. At least half the island is covered in peat, ranging in thickness from approximately half a metre to greater than ten metres.

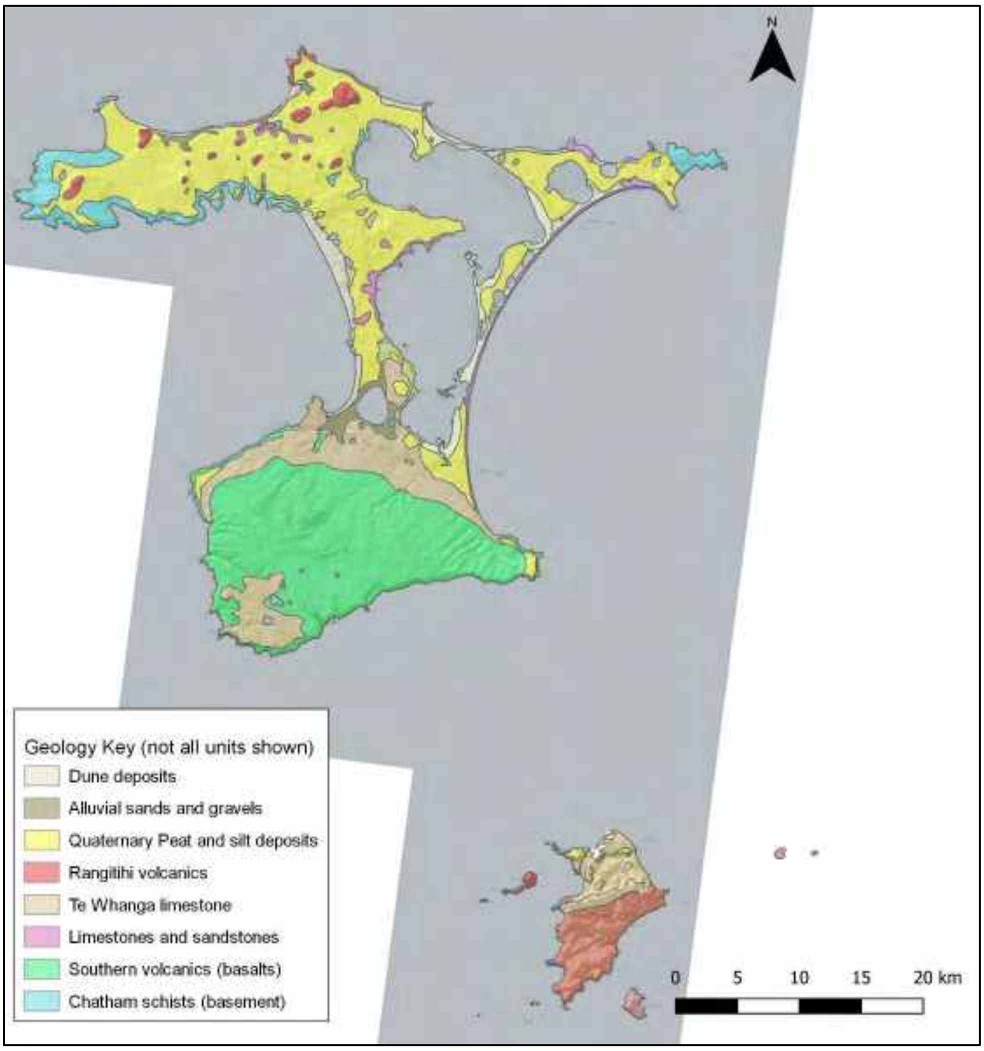


Figure 2: Geology of the Chatham Islands (Forsyth, 2008)

The geography of Chatham Island is dominated by three features: two bays and a lagoon. More than half of the west coast of Chatham Island is taken up by Petre Bay. On the east coast is the even larger Hanson Bay, which stretches almost the entire length of the island (35 kilometres). Much of the area between the bays is taken up by the large Te Whanga Lagoon, which currently drains to the sea to the east, into the southern half of Hanson Bay. This lagoon covers about 160 km^2 and drains several watercourses on Chatham Island including Te Awainanga River, the main river on the island that rises in the southern hills. The largest lakes are Rangitai (867 ha) and Huro (598 ha), respectively located northeast and southwest of Te Whanga (Champion and Clayton 2000).

The central and northern parts of Chatham Island are low undulating hills and basins, with altitudes ranging from typically a few metres on the northeast and centre to 50 m on the northwest, but with a few scattered limestone outcrops and volcanic cones. The southern part is higher, generally sloping down towards the north and west; about half of it is over 150 m above sea level. The south coast of the island is mostly cliffs 100 m high or more. The highest point of the island (299 m) lies close to its southernmost point.

The Chatham Islands have a mild oceanic climate and experience a mean annual rainfall between 800 and 1,000 mm in the lowland areas and up to 2,000 mm in the southern hills of the main island. Mean annual temperature for most of the land area on the Chatham Islands is between 11 and 12°C, with the southern highlands on Chatham Island slightly cooler with a mean annual temperature of between 10 and 11°C.

Chatham and Pitt Island are the only permanently inhabited islands with a total population of around 700. The town of Waitangi is the main settlement with approximately 200 residents. There are other communities such as Owenga, Te One, Kaingaroa and Port Hutt. The Chatham Islands Council provides a reticulated potable water supply to households in Waitangi and Kaingaroa. Drinking water for Waitangi is sourced from a bore and for Kaingaroa water is sourced from Lake Rangitai. All other residents on the island operate on rainwater collection and/or private bores for potable water supply and, if this is not sufficient (e.g. during extended dry periods), top up their supply from the Council’s public water tank in Waitangi or opportunistically from other surface water sources.

Much like mainland New Zealand, many of the natural resources on the Chatham Islands have been impacted by the presence of humans for many hundreds of years. Deforestation, urban development and agricultural land use practices have resulted in most waterways intersecting pastural land. The streams, lakes, and lagoons of the Chatham Islands are now subjected to the impacts of altered drainage patterns, burning and the clearing of vegetation, livestock grazing and small amounts of urban/industrial runoff/drainage.

3.0 Rainfall and Evaporation

3.1 Rainfall

Rainfall data is available from a variety of times at various sites across Chatham Island and Pitt Island. Figure 3 shows the times when rainfall data was collected from different sites.

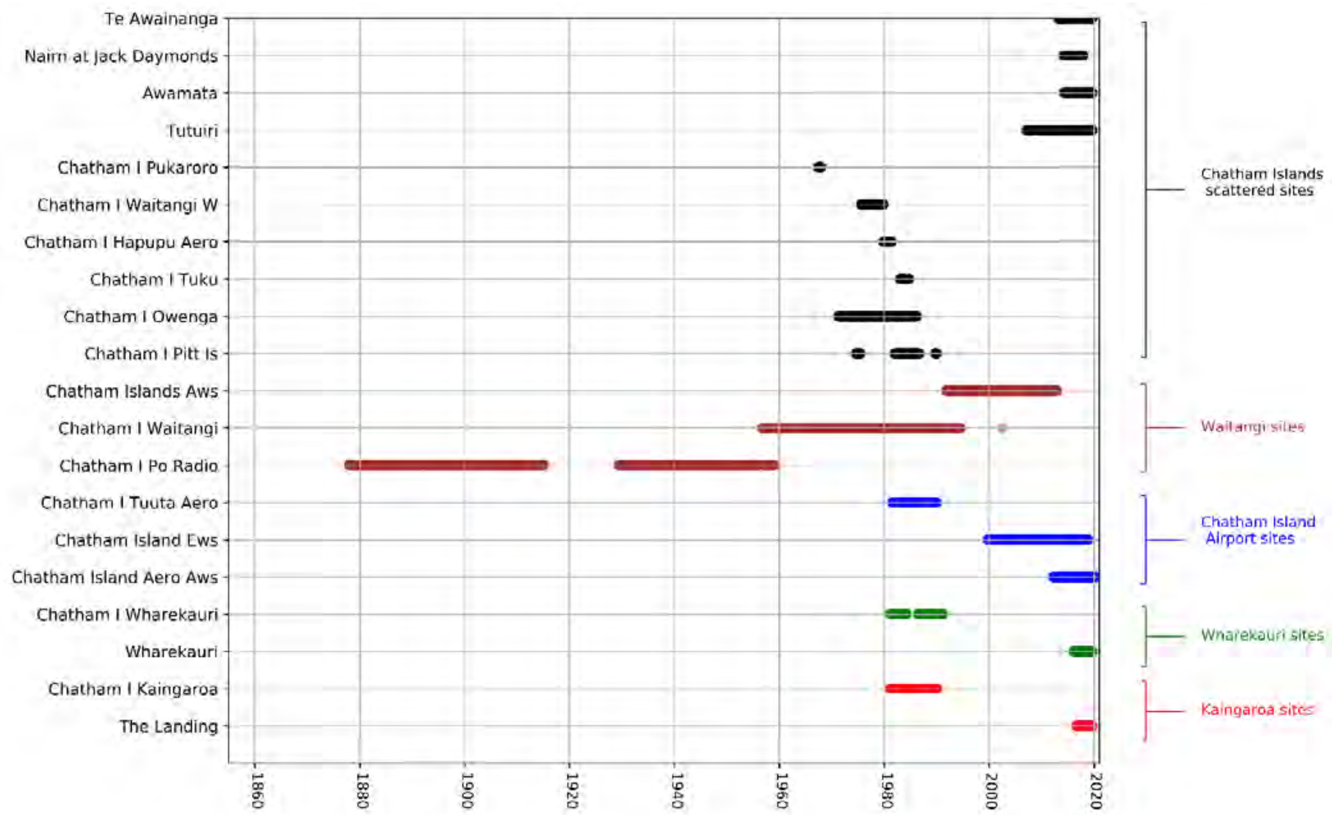


Figure 3: Rainfall data availability

The different colours in Figure 3 refer to different clusters of rainfall sites. This shows that the ECan sites (top four sites in black, plus Wharekauri (green) and The Landing (red)) have relatively up-to-date data, together with one of the NIWA sites (Chatham Islands Aero AWS). Otherwise most of the sites have been sporadic or are currently discontinued. A summary of the data at each of the currently operational sites, together with data from the gauge at Nairn at Jack Daymonds (discontinued in 2018) is provided in Table 1, and plots of the data are shown in Figure 4. The locations of all sites are shown in Figure 5.

There is an obvious gap where only one rainfall station was operating (Chatham Island AWS) in the late 1990s (refer to Figure 3). None of the groups of sites have a complete record that could be combined together to make a long-term record extending to the present day. This makes analysing long term changes in rainfall difficult or complex. The amount of rainfall at the different sites varies and generally, rainfall totals change across the island from south to north, with southern areas showing higher rainfall than northern areas.

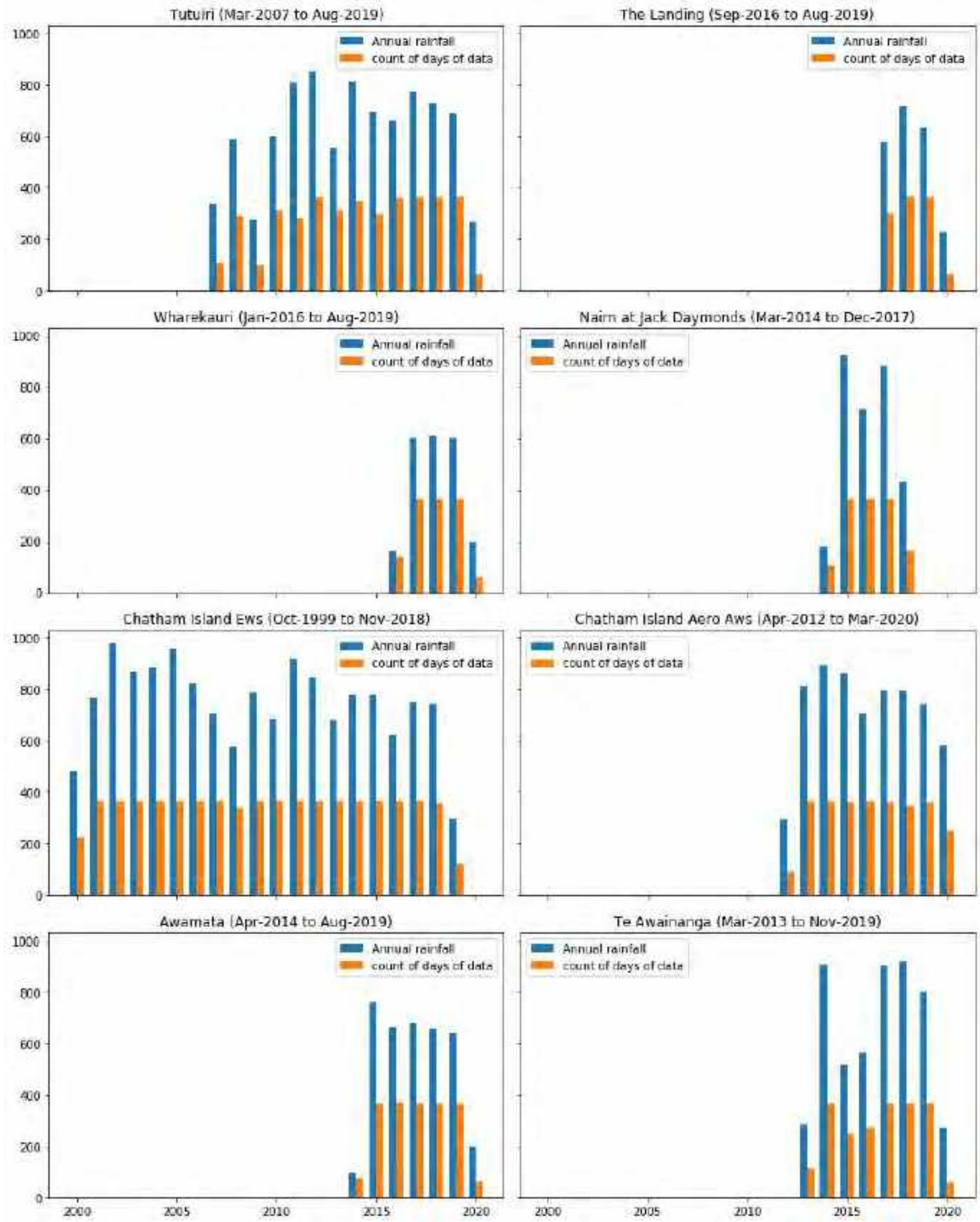


Figure 4: Annual rainfall data (mm) for current or recently operational sites

Table 1: Annual rainfall statistics for years with complete datasets (based on hydrological years)

Station Name	**Awamata**	**Chatham Island Aero Aws**	**Chatham Island Ews**	**Nairn at Jack Daymonds**	**Te Awainanga**	**The Landing**	**Tutuiri**	**Wharekauri**
Years of available data	2014-2019	2012-2020	1999-2018	2014-2017	2013-2019	2016-2019	2007-2019	2016-2019
Years of data with complete datasets	5	6	17	3	4	2	5	3
Average (mm)	680	803	799	841	881	673	741	606
Min (mm)	641	707	623	716	797	630	662	602
Lower Quartile (mm)	658	756	745	801	875	651	690	602
Median (mm)	662	805	780	885	904	673	730	602
Upper Quartile (mm)	678	852	867	903	910	694	772	608
Max (mm)	761	894	981	922	918	716	854	613

A brief summary of comments on the datasets is provided below. Note that this only covers the Environment Canterbury sites; the NIWA sites do not include QA coding so the quality of the information is not known.

- Awamata: This site shows a good record with no gaps. Generally good or satisfactory data quality.
- Nairn at Jack Daymonds: Good record, two gaps 26/6/2014 -2/7/2014, 28/8/2015 - 31/8/2015, Quality coding indicates that majority of the record is unreliable quality data.
- Te Awainanga: Reasonable record, one large gap 6/3/2015 to 2/10/2015, Quality coding indicates reliable/satisfactory data for most of the record period except for the first 15 months of data and Dec 2016-Feb 2017 (unreliable).
- Wharekauri: Good record, one gap 12/5/2016 - 29-5-2016, most of the data reliable or satisfactory quality data.
- The Landing: Good record, no gaps but poor quality data coding.

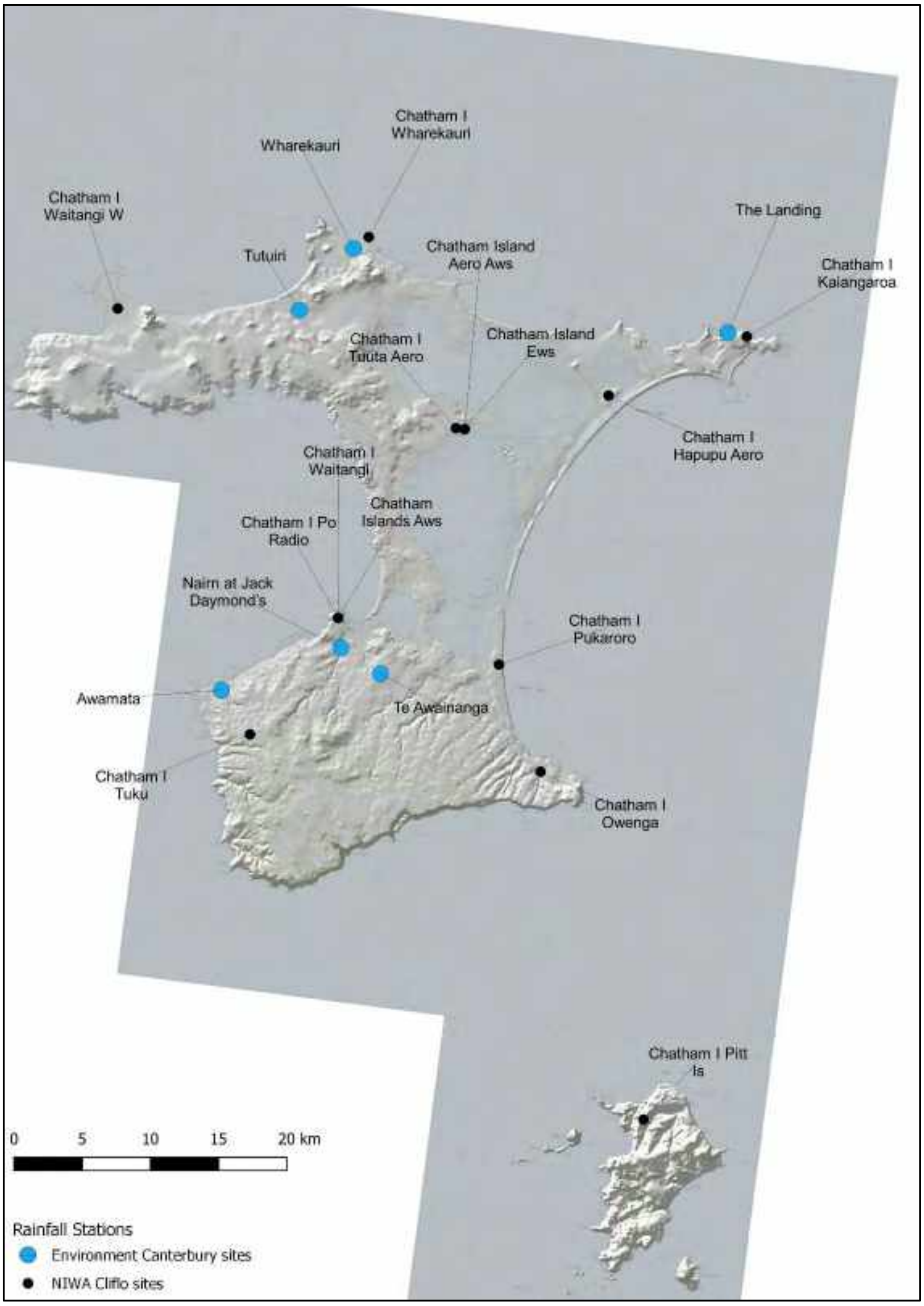


Figure 5: Rainfall gauging sites

Figure 6 shows the annual rainfall totals for the 2017/2018 hydrological year for sites where that data is available which gives an indication of the likely spatial distribution. Note that long term averages have not been calculated because of the incomplete nature of the available data.

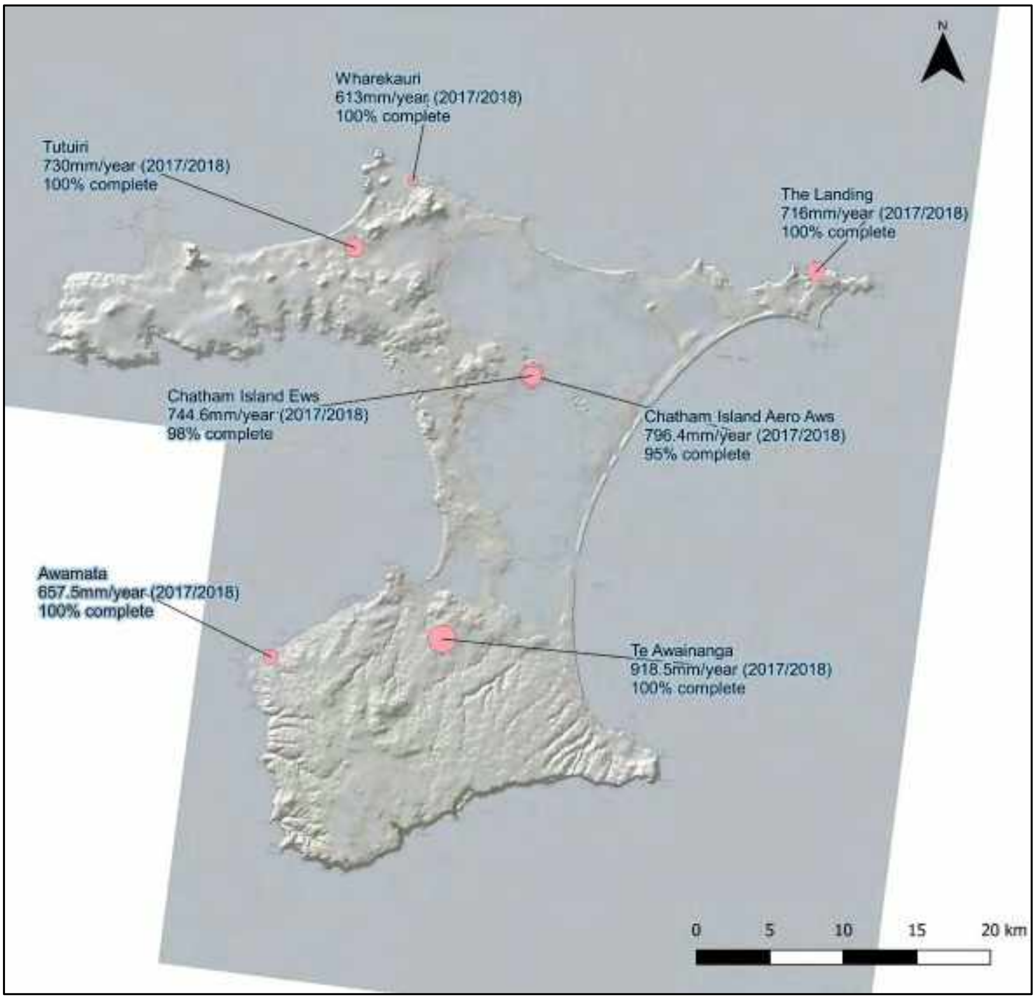


Figure 6: Rainfall distribution for 2017/2018 hydrological year

Rainfall at the Te Awainanga gauge in the south of the island was around 918 mm in the 2017/2018 water year and higher rainfall is likely to occur in the more elevated southern parts of the island (Pearce, 2016). However, in the northern part of the island rainfall rates are lower, ranging between 613 mm/year at Wharekauri and 796 mm/year at the airport gauging stations. Note that Nairn at Jack Daymonds is not included on the map as the record was only approximately 45% complete for the 2017/2018 hydrological year.

These estimates are generally in line with spatial rainfall estimates from Pearce (2016), repeated in Figure 7 below. However, Figure 7 highlights that rainfall across the Southern Uplands may be considerably higher than elsewhere on the island, with annual totals possibly up to 2,000 mm/year.

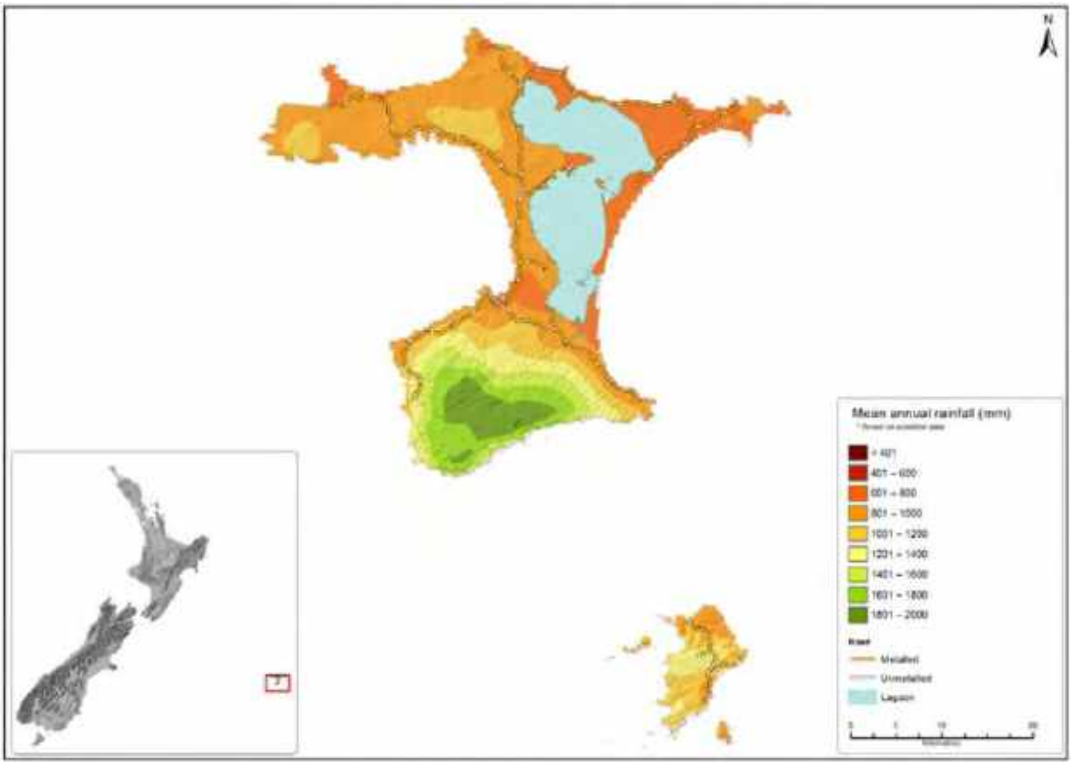


Figure 7: Rainfall distribution across the Chatham Islands (NIWA, 2016)

Figure 8 presents the seasonal data trends at the five active Environment Canterbury rainfall stations across the island, together with the NIWA station at the Chatham Islands airport. In addition, data for three other stations is shown, including the other disused stations at the airport and the Po Radio site, which has an extensive record from 1878 to 1958. Note that not all sites have the same range of data.

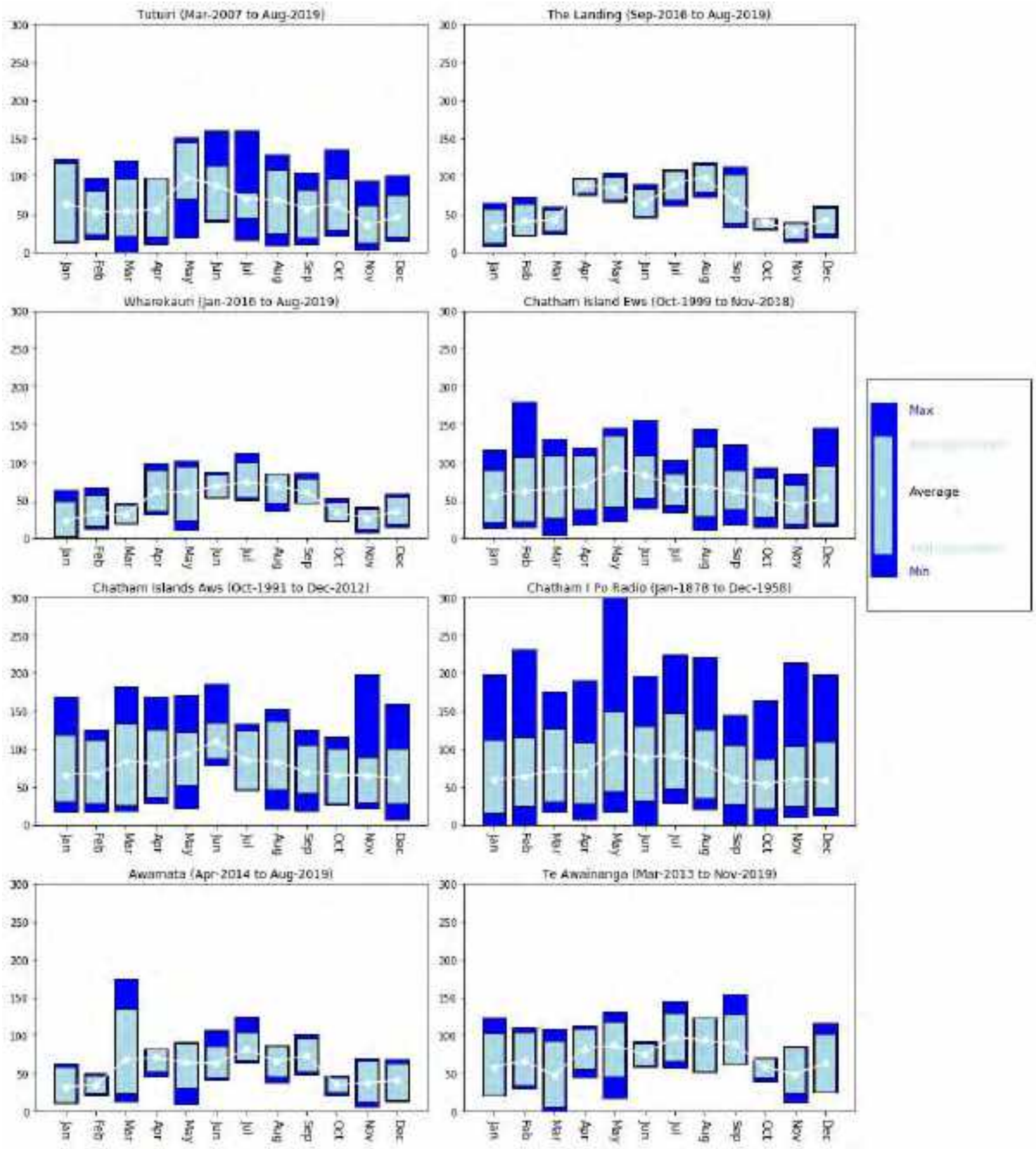


Figure 8: Rainfall seasonal distribution

These data indicate that typically, rainfall is higher in late autumn or winter, and lower in late spring and early summer. These patterns represent a typical seasonal distribution of rainfall. It is useful to note that the longer-term record from the Po Radio station indicates that monthly rainfall does vary significantly on the island, with the maximum observed in one month of more than 300 mm in May. However, typical monthly rainfalls for winter are in the order of 100 mm, while summer rainfall is typically in the order of 50 mm per month or less.

The data are not ideal for estimating long term rainfall trends as there is no single site with a consistent long-term record. The longest record that can be constructed from the available data is from the stations at Waitangi, where a reasonable record can be derived from three stations and extends from the late 1920s until 2012. It is unfortunate that this record does not extend into the current dry years.

A method of assessing whether long term changes in rainfall have occurred is to plot the cumulative deviation of annual rainfall from the long-term mean (CDFM). On the CDFM plot (Figure 9) the trend of the line provides some indication of the long term rainfall trends:

- When the slope of the line is upwards, the annual rainfall was greater than the long-term average;
- Where the line shows a stable trend over a period of time, the annual rainfall for that period is similar to the long-term average; and
- Where the trend of the line is downwards for a period of time, the annual rainfall was less than the long-term average during that period.

Note that the absolute values on the CDFM plot are not important. Also, only years with a full set of rainfall data are included (i.e. 364 days or more days). Gaps in Figure 9 indicate years where there are gaps in the rainfall record for that year.

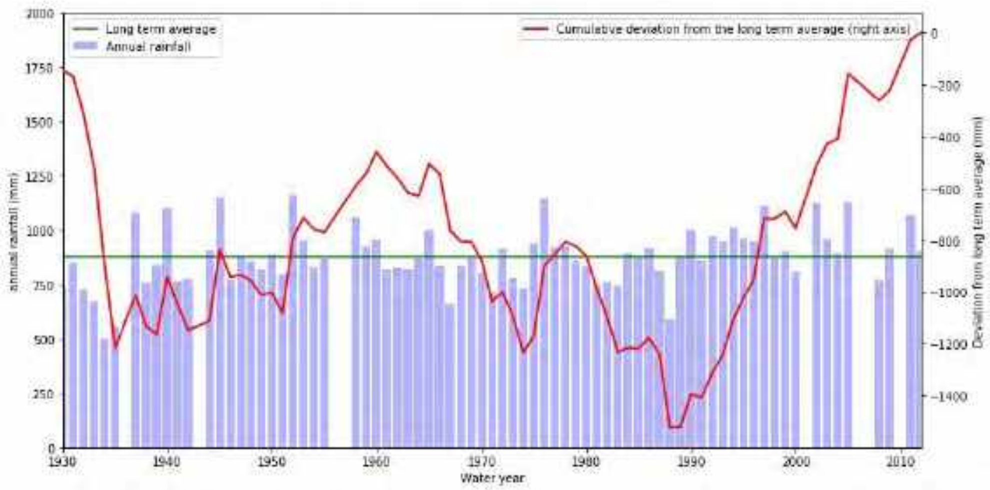


Figure 9: Cumulative deviation from the long-term average rainfall at Waitangi

The data indicate that between 1935 and around 1960, the average annual rainfall was overall greater than the long-term average, although this is partly due to several very wet years. Between 1960 and 1990, annual rainfall was overall less than the long-term average and since 1990, annual rainfall was greater than the long-term average until the end of the available data in 2012. It is not possible to determine the long-term trend since 2012 at the longer-term Waitangi site because there is no sufficiently long-term record available from one individual site. Re-installing a rainfall gauge at Waitangi would be helpful to extend this dataset and monitor long term changes in the future.

Based on annual rainfall totals, rainfall within the past few years appears broadly similar to the long-term average. However, the recent data from the Chatham Islands airport weather stations suggests that summer rainfall (particularly 2018 and 2019) may have been lower than average (Figure 10). These sites are located adjacent to one another, although the records are not precisely consistent.

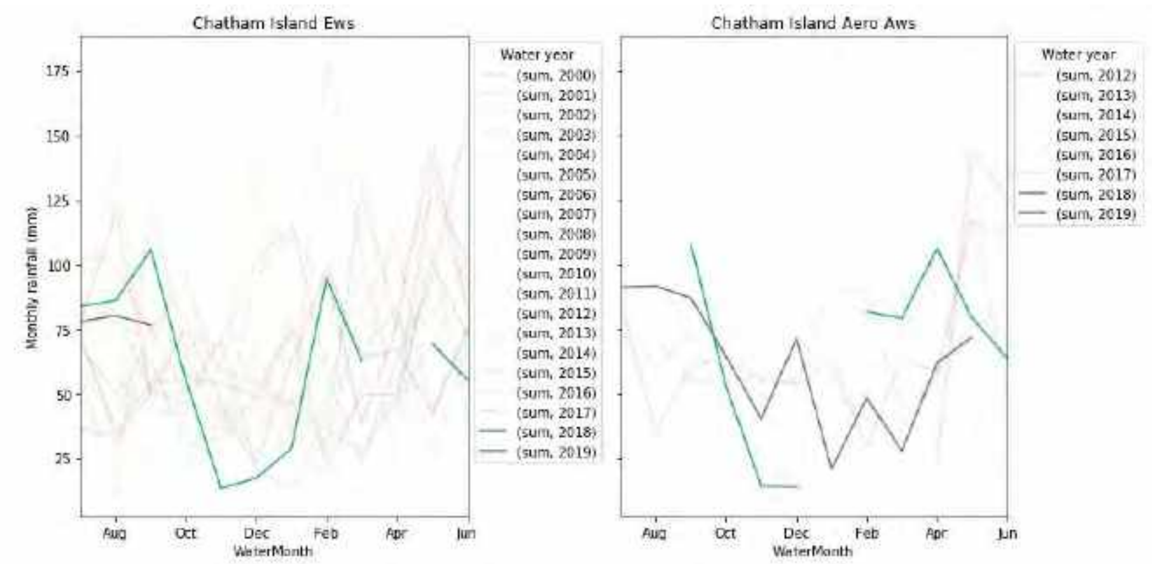


Figure 10: Monthly rainfall at the Chatham Island airport weather stations

Figure 10 shows the monthly total rainfall for months with more than 90% complete data. The data show hydrological years, for example the 2000 water year runs from July 1999 to June 2000. Figure 10 indicates that summer rainfall (particularly November and December 2017) in the 2017/2018 hydrological year was lower than normal at both the Chatham Island Ews station and the Chatham Island Aero Aws station. January 2018 was also lower than normal. Rainfall at the Chatham Islands Aero Aws station was also relatively low in the summer of the 2018/2019 hydrological year (i.e. in January 2019) compared to previous years. This recent pattern may be important with respect to future climate change patterns and particularly for residents who rely on rainfall tanks or sources with limited storage for potable water supplies.

3.2 Potential Evapotranspiration

There is limited long term evapotranspiration data available from sites around Chatham Island. The sites with evapotranspiration data available are shown below (Figure 11) and are located at Waitangi and the Chatham Island airport:

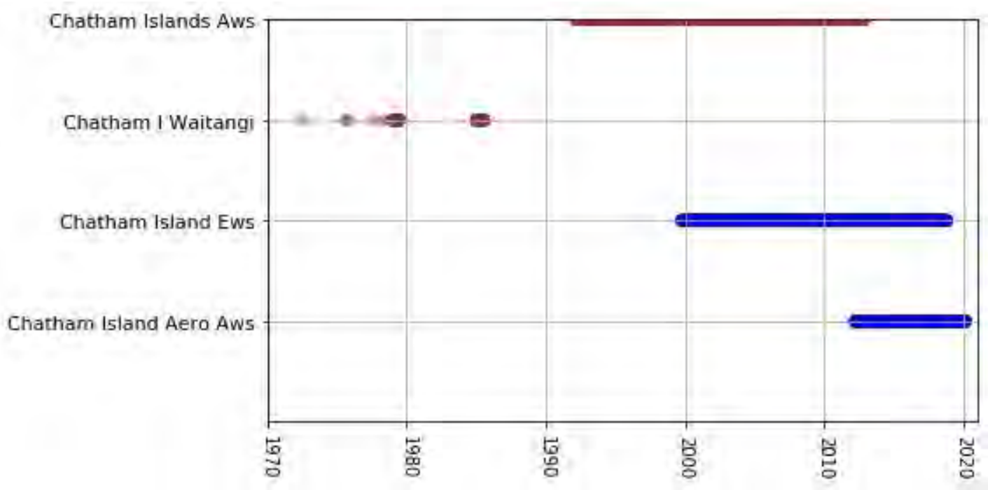


Figure 11: Potential evapotranspiration data availability

Figure 12 shows the annual evapotranspiration and rainfall totals at each of the sites above except for Chatham Island Waitangi, because that site has very little data available.

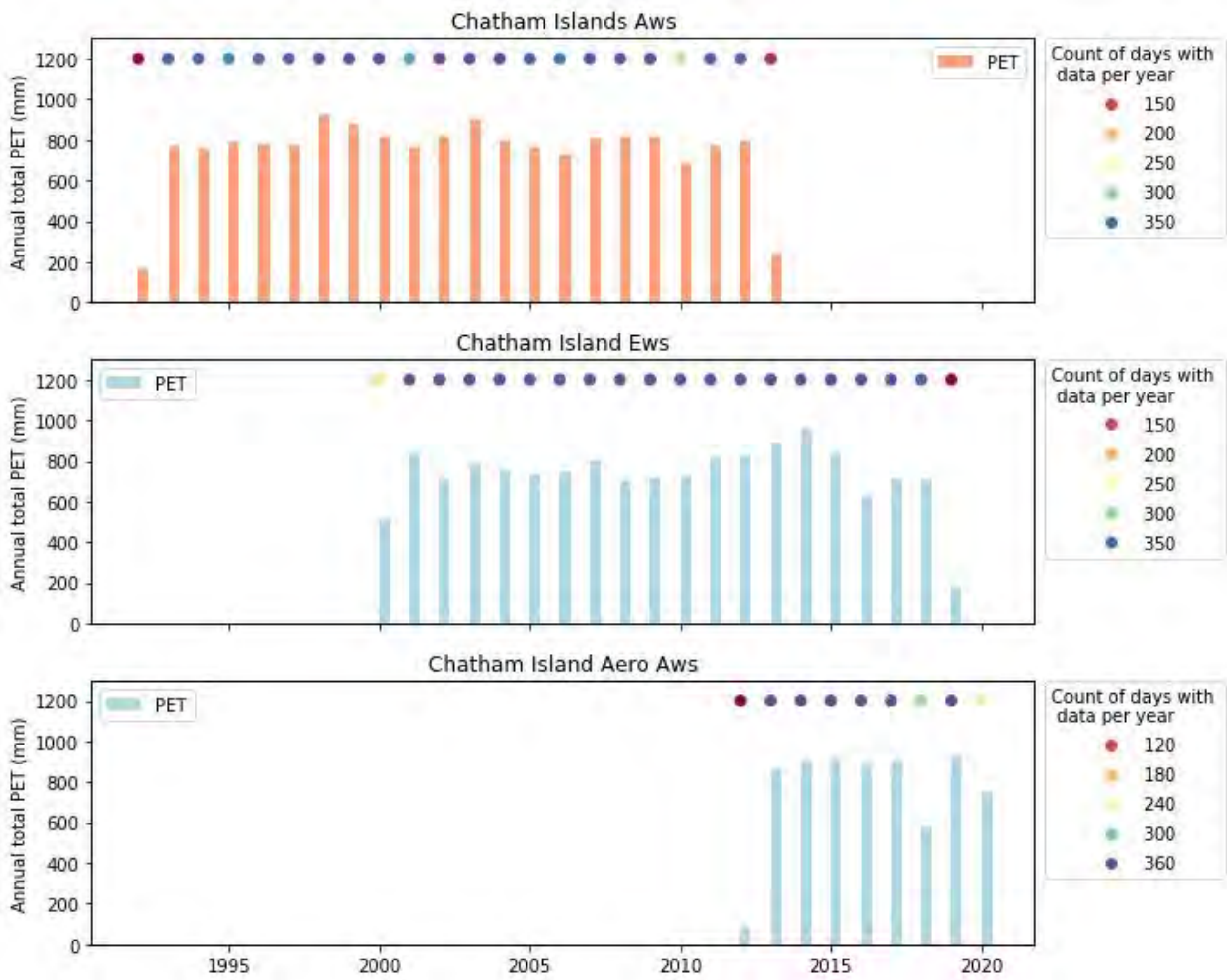


Figure 12: Annual total potential evapotranspiration data

Table 2 provides a statistical summary of the evapotranspiration data for the three sites.

Table 2: Evapotranspiration statistical summary for years with complete datasets (based on hydrological years)

Statistic (mm/year)	Chatham Island Aero Aws	Chatham Island Ews	Chatham Islands Aws
Years of available data	2012-2020	2000-2019	1992-2013
Years of complete data	6	18	16
Mean (mean annual rainfall in brackets)	899 (803)	772 (799)	812 (944)
Min	863	625	752
Lower Quartile	889	716	773
Median	903	747	804
Upper Quartile	913	827	818
Max	927	955	931

These data indicate that annual potential evapotranspiration is typically less than rainfall, although at Chatham Aero Aws, mean potential evapotranspiration has exceeded rainfall. It is also notable that the Chatham Island Ews and Chatham Island Aero Aws sites are located almost adjacent to one another and in some cases the annual totals are consistent, but in other cases they are not and the difference may imply other causes including measurement errors.

The PET data does not include quality codes, so the quality of the data is not known. However, as Figure 12 shows, the datasets are not always complete; both the Chathams Islands Aero Aws and Chatham Islands AWS site have missing data in some years. Understanding the reasons for these gaps and ensuring that the sites are regularly maintained would be prudent, particularly with respect to understanding long term rainfall and climatic patterns of the island and assisting in responding to assessment of climate change effects.

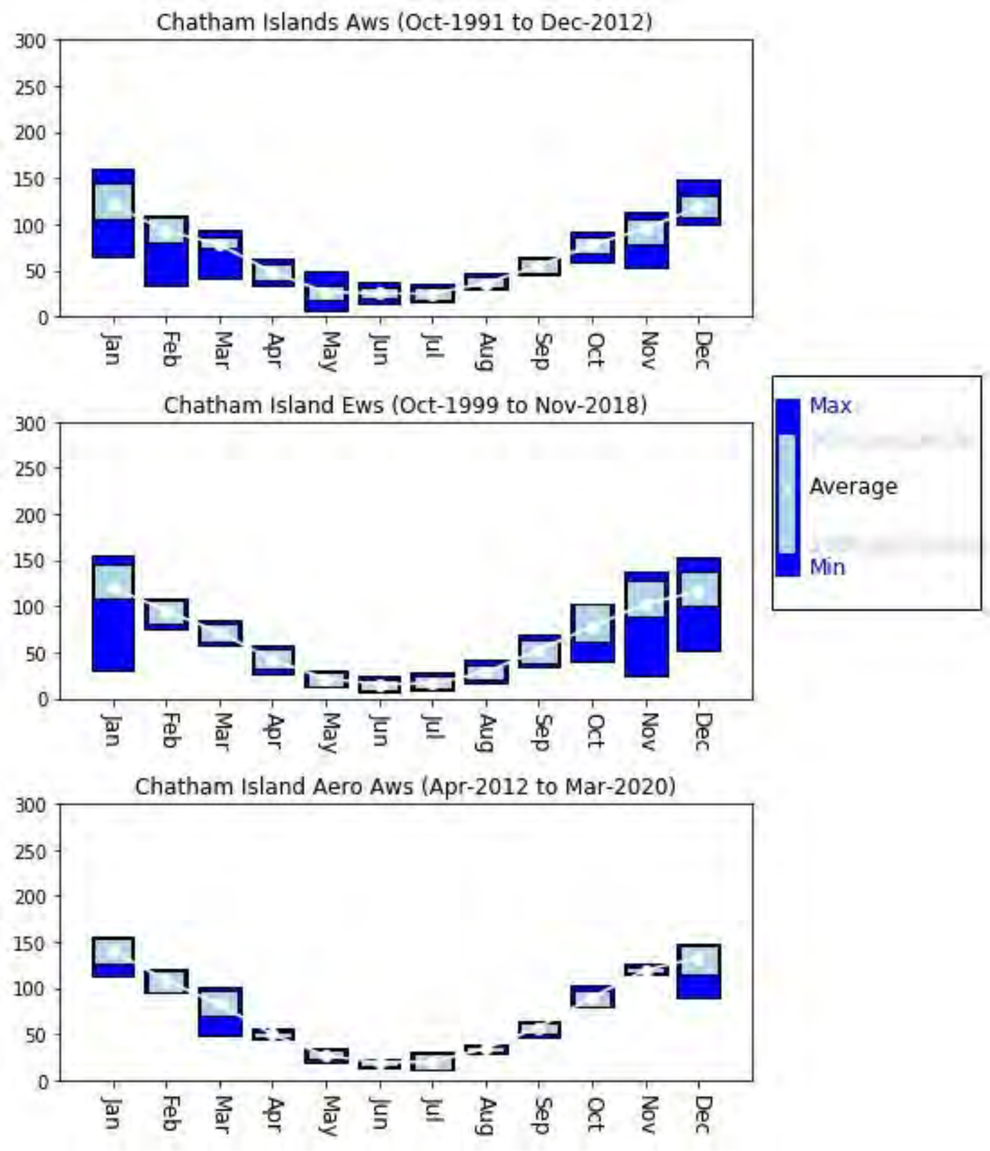


Figure 13: Seasonal variations of potential evapotranspiration

Figure 13 shows the average seasonal potential evapotranspiration data from the three main sites with available records. Unsurprisingly, the data shows a strong seasonal pattern, with greater potential evapotranspiration in summer compared to winter. The range of potential evapotranspiration is limited in winter, with consistent values of less than 50 mm/month. However, in summer there is more variation, with high values particularly in December and January, and with extreme low values in shoulder periods (December and March) that can approach winter values for the longer term records at Chatham Island Aws and Chatham Island Ews.

Given the limited spatial extent of potential evapotranspiration data, the spatial variation is not clearly defined. There does not appear to be a significant difference in potential evapotranspiration values between data at the Chatham Island airport site and the Waitangi sites, suggesting that potential evapotranspiration may be relatively uniform across those parts of the island. There is insufficient data to determine recent trends in PET, given gaps in the datasets.

4.0 Hydrology

4.1 Flow Recorder Sites

There are four current flow recorders on Chatham Island, monitoring flow in the Te Awainanga River, Tuku a Tamatea River, Tutuiri Creek and Awamata Stream. In additional there are two historical flow recorders. These are located in the Nairn River and in the Te Awainanga River upstream of the current long-term recorder site. The location of the current and historical recorder sites are shown in Figure 14. Table 3 illustrates the percentage of available flow data for each hydrological year (1 July to 30 June) at each of the recorder sites.

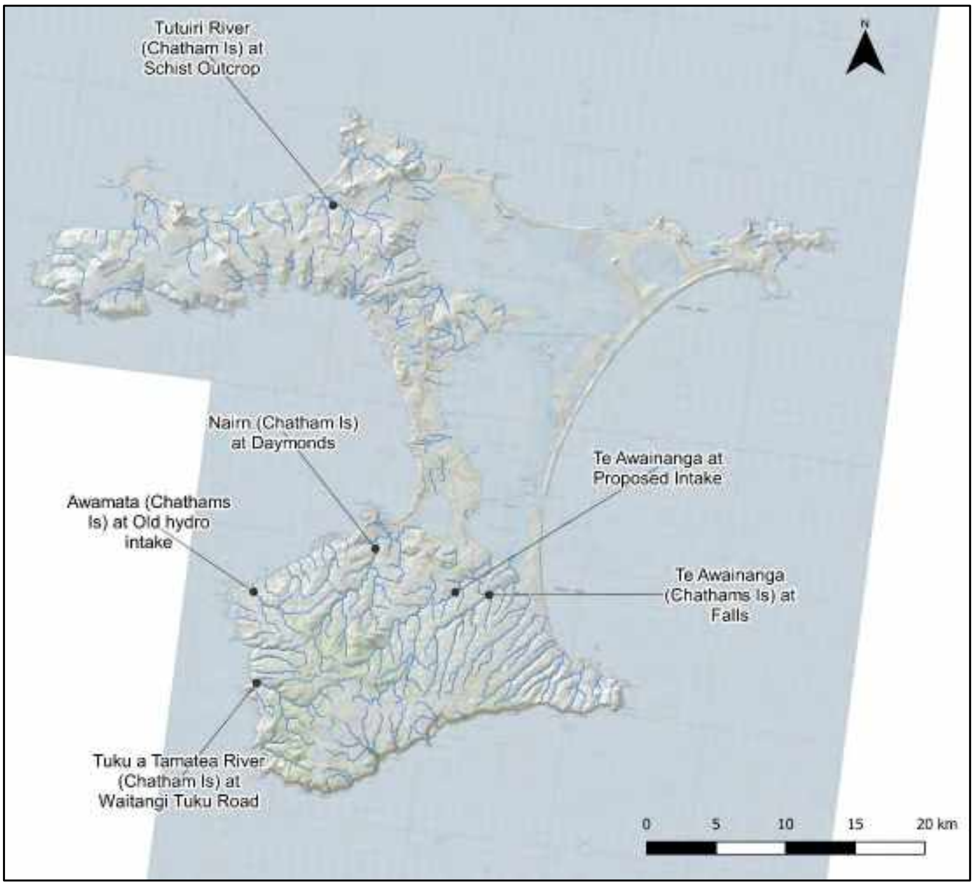


Figure 14: Main rivers and flow recorders

Table 3: Percent of record that is complete

Hydrological Year	Te Awainanga at Falls	Te Awainanga at Proposed Intake	Nairn at Daymonds	Tuku a Tamatea River at Waitangi Tuku Road	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop
1986-87	93%	0%	0%	0%	93%	93%
1987-88	100%	0%	0%	0%	100%	100%
1988-89	100%	0%	0%	0%	100%	100%
1989-90	100%	0%	0%	0%	100%	100%
1990-91	100%	0%	0%	0%	100%	100%
1991-92	100%	0%	0%	0%	100%	100%
1992-93	79%	0%	0%	0%	100%	100%
1993-94	100%	0%	0%	0%	100%	57%
1994-95	100%	0%	0%	0%	100%	0%
1995-96	100%	70%	0%	0%	100%	0%
1996-97	100%	100%	0%	0%	100%	0%
1997-98	100%	100%	0%	0%	100%	0%
1998-99	100%	100%	0%	0%	100%	0%
1999-00	100%	30%	0%	0%	100%	0%
2000-01	100%	0%	0%	0%	100%	0%
2001-02	100%	0%	0%	0%	100%	0%
2002-03	100%	0%	0%	0%	100%	0%
2003-04	100%	0%	0%	0%	100%	0%
2004-05	100%	0%	0%	0%	100%	0%
2005-06	100%	0%	0%	0%	100%	0%
2006-07	100%	0%	0%	0%	100%	79%
2007-08	100%	0%	0%	0%	100%	100%
2008-09	100%	0%	0%	69%	100%	100%
2009-10	100%	0%	0%	94%	100%	100%
2010-11	100%	0%	0%	71%	83%	77%
2011-12	100%	0%	77%	80%	100%	100%
2012-13	100%	0%	86%	100%	100%	85%
2013-14	78%	0%	96%	75%	100%	91%
2014-15	67%	0%	97%	100%	100%	78%
2015-16	98%	0%	99%	85%	99%	100%
2016-17	100%	0%	100%	100%	100%	100%
2017-18	100%	0%	100%	100%	99%	95%
2018-19	100%	0%	0%	100%	100%	100%
2019-20	41%	0%	0%	42%	41%	41%

All the current recorders are now operated by Environment Canterbury. Key information for the recorder sites and flow statistics are summarised in Table 4, median monthly flows are provided in Table 5 and flow duration curves in Figure 15 and Figure 16. It is noted that the significantly differing record lengths for these sites means that comparisons are for indicative purposes only. For the 7 day mean annual low flow (7D MALF) only the hydrological years with sufficient data in the low flow periods were included in the calculation of the 7D MALF. It is recognised that 7D MALF (and other statistics) are ideally based on long term flow data to ensure that average, wet and dry years/periods are included in the record and to ensure that the statistics are representative of the long term flow regime. As such the flow statistics and flow duration curves for the short-term recorder sites should be used bearing these limitations in mind.

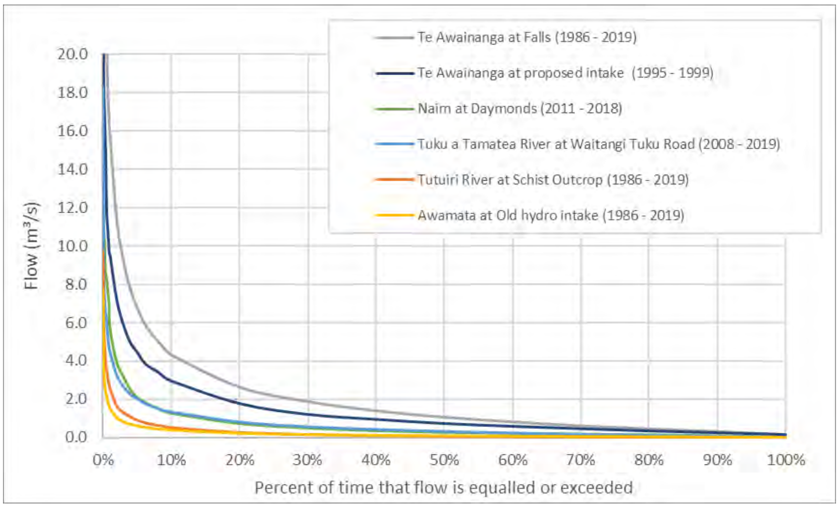


Figure 15: Flow duration curve for all recorder sites (0-20 m^3/s)

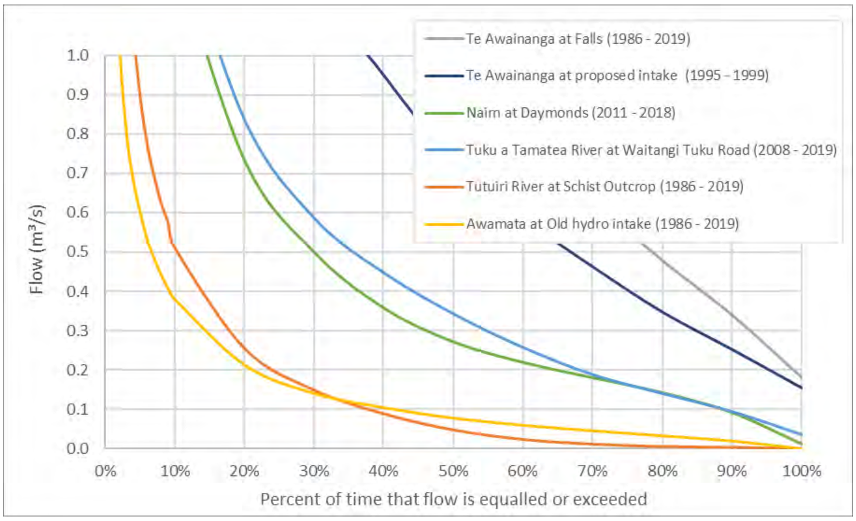


Figure 16: Flow duration curve for all recorder sites (0 - 1 m^3/s)

Table 4: Key information and flow statistics for Chatham Island flow recorder sites

Key recorder information and flow statistic	Te Awainanga at Falls	Te Awainanga at Proposed Intake	Nairn at Daymonds	Tuku a Tamatea River at Waitangi Tuku Road	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop
Site number	3446051	3450001	3452533	3379428	3446071	3436871
Catchment area (km2)	71.9	41.5	37.0	21.5	9.4	21.5
Available record period	1986 - 2019	1995 - 1999	2011 - 2018	2008 - 2019	1986 - 2019	1986 - 1994; 2006 - 2019
Minimum (L/s)	180	155	12	34	0	0
7D MALF[1] (L/s)	276	218	67	67	19	2
Lower Quartile (L/s)	552	408	162	160	39	9
Median (L/s)	1,087	734	272	342	78	48
Mean (L/s)	2,040	1,340	608	615	171	212
Upper Quartile (L/s)	2,214	1,432	598	694	170	194
Specific discharge at mean flow (L/s/km^2)	28.4	32.3	16.4	28.6	18.1	9.9
Mean Annual Runoff (mm/year)	896	1,019	518	903	572	311

1. *7 Day Mean Annual Low Flow*

Table 5: Median monthly flow for Chatham Island flow recorders (L/s)

Month	Te Awainanga at Falls	Te Awainanga at Proposed Intake	Nairn at Daymonds	Tuku a Tamatea River at Waitangi Tuku Road	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop
January	434	280	199	148	29	5
February	485	336	245	123	35	6
March	741	538	285	208	48	12
April	1,027	774	344	307	70	31
May	1,518	751	581	496	116	120
June	2,360	1,120	530	696	180	281
July	1,853	1,337	472	580	150	218
August	1,858	1,015	446	680	149	238
September	1,310	940	297	468	103	115
October	1,069	692	216	356	75	51
November	650	473	157	187	48	14
December	541	333	144	169	36	7

Table 3 indicates that for most recorder sites the data is very patchy with significant gaps in the data especially for the period from 2010 onwards. In addition some of the continuous flow recorder data (especially Tuku a Tamatea River at Waitangi Tuku Road) is rated poor or fair under the quality coding of the national Environmental Monitoring Standards (NEMS).

Te Awainanga at Falls and Awamata at Old Hydro are the only two recorders with reasonably complete long-term records. Each recorder site is separately discussed in section 4.1.1 to 4.1.5 below. Based on the available amount of data and completeness of the flow records it was decided that inter-annual variability and trend analyses would only be undertaken for these two recorder sites. For each recorder site hydrographs for the 2016-2017 hydrological year are produced. This is the only hydrological year with a complete record for most of the recorder sites (refer to Table 3).

4.1.1 Te Awainanga River

The Te Awainanga River is the largest watercourse on Chatham Island and drains a significant proportion of the southern hills. There is one current flow recorder, Te Awainanga at Falls, located approximately 4.5 km upstream of the river mouth with a record length of approximately 33 years. The catchment area at the recorder site is approximately 72 km^2. In addition to the current long-term flow recorder there is one historical flow recorder in the catchment; Te Awainanga at Proposed Intake, which is situated 10 km from the mouth and drains an area of approximately 41.5 km^2. The specific discharge at mean flow and mean annual runoff of the Te Awainanga River is relatively high compared to other watercourses on Chatham Island (refer to Table 4) reflective of the relatively high rainfall expected to occur in the southern hills.

The mean flow is 2,040 and 1,340 L/s for The Falls and Proposed Intake respectively. The median flow is 1,087 and 734 L/s for The Falls and Proposed intake respectively and median monthly flows vary between 434 and 2,360 L/s for the Falls and between 280 and 1,337 L/s for the proposed intake. Flows are generally high in winter and low in summer (Table 5). The flow duration curves for the sites (Figure 15 and Figure 16) indicate that flows are greater than most other rivers on Chatham Island and that flows are relatively well maintained during dry periods likely due to the relatively large catchment areas, higher expected rainfall in the upper reaches and the water retention capacity of the overlying peat and organic soils. Figure 17 shows the gauging location upstream of the Te Awainanga at Falls recorder site. Example hydrographs for Te Awainanga at Falls and Te Awainanga at Proposed Intake are included in Figure 18 and Figure 19 to illustrate a summer with some small floods/freshes (2016/17) and a dry summer (1998/99) with a minimal amount of freshes between mid-November and early May.

Figure 17: Te Awainanga at Falls

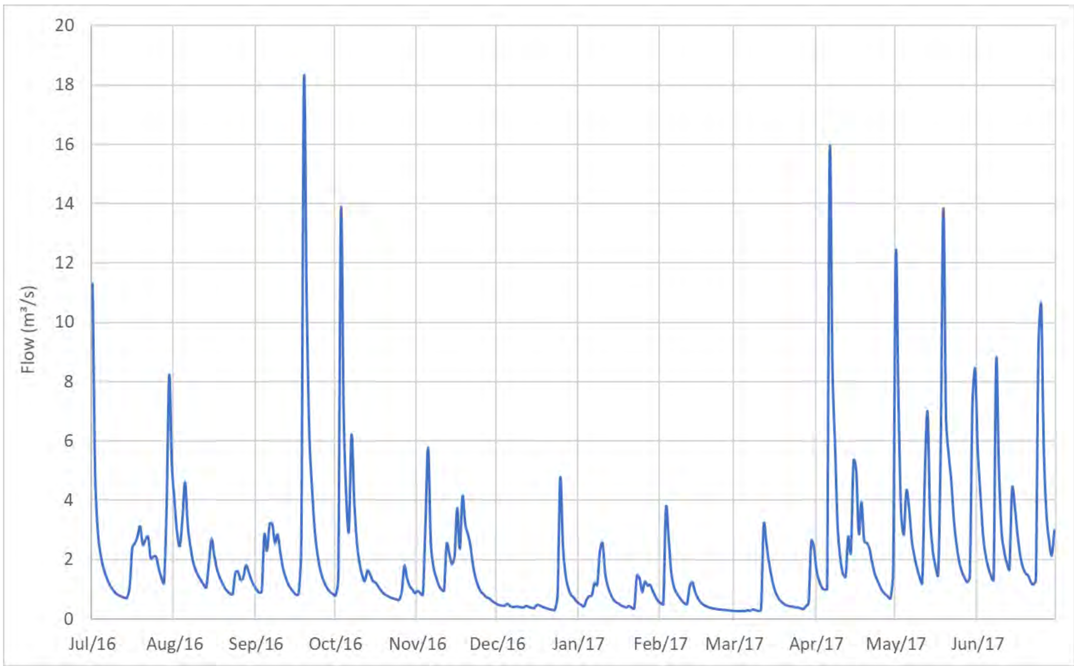


Figure 18: Example hydrograph for Te Awainanga at Falls for 2016-2017 hydrological year

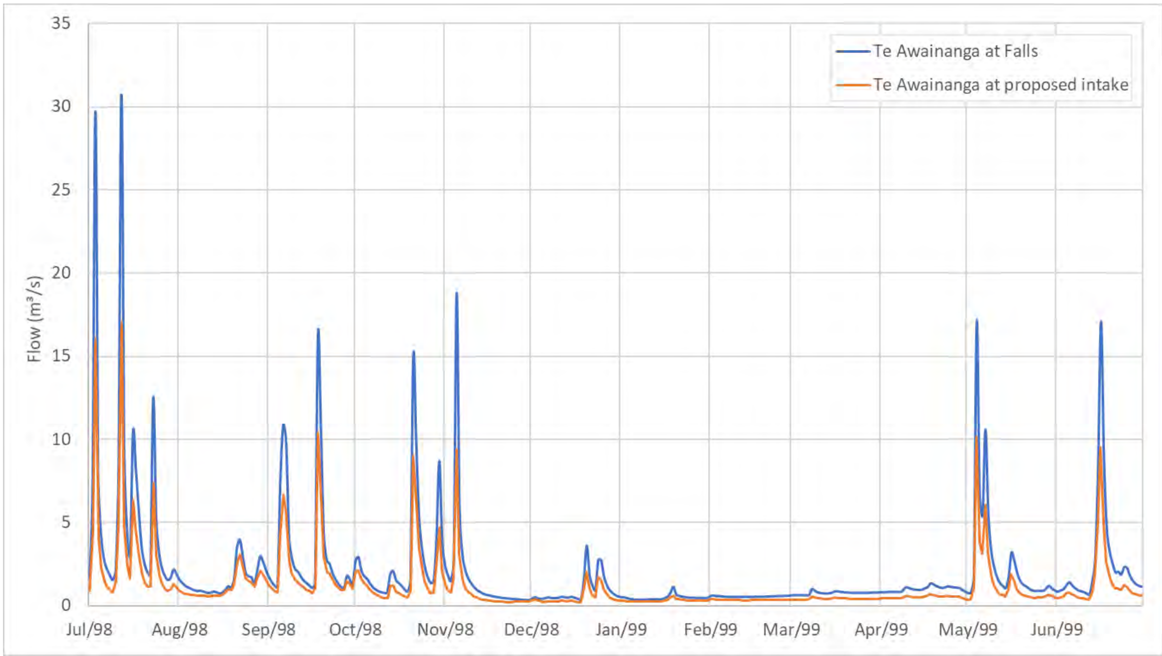


Figure 19: Example hydrograph for Te Awainanga at Proposed Intake and Te Awainanga at Falls for 1998 - 1999 hydrological year

Figure 20 illustrates the inter-annual variation in mean annual flow and the 4-year moving average flow for Te Awainanga at Falls flow recorder. Hydrological years with incomplete data (less than 98% complete, refer to Table 3) were excluded from the analyses. The mean annual flow varies greatly from year to year with the first complete hydrological year (1987-1988) on record having the lowest flow (1.13 m^3/s) and 1996-1997 having the highest flow (2.93 m^3/s). The 4-year moving average shows no obvious increasing or decreasing trend in mean annual flow.

In order to determine whether the last 10 years of data (the new data available since the last state of the environment report) significantly differ from the previous years a t-test was undertaken. A t-test measures if there is a statistically significant difference between two groups of data.

The mean annual flows were calculated and grouped into two periods 1985-2009 and 2010-2019. A two-sided t-test, assuming unequal variance, was conducted on both recorders. The t-test returned a $p>0.05$ and therefore it was concluded that there was no statistically significant difference for the mean annual flow between the new data (2010 to 2019) and the old data (1986 to 2009).

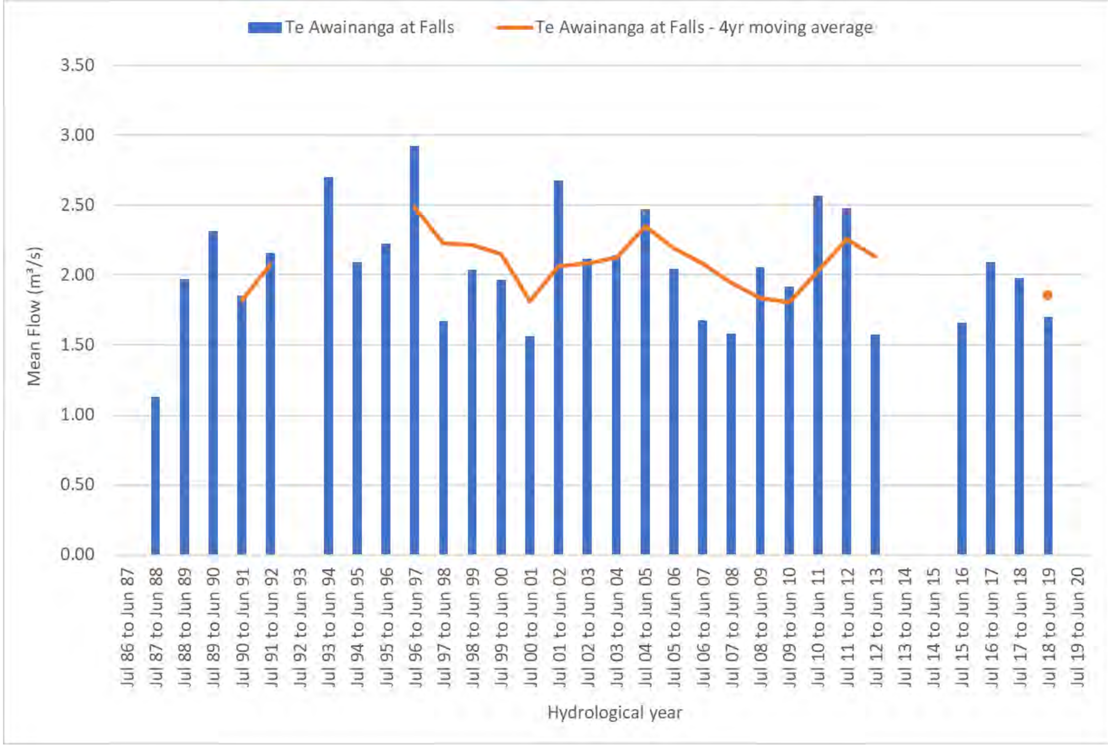


Figure 20: Inter-annual variation in mean flow and 4 year moving average for Te Awainanga at Falls Flow Recorder

4.1.2 Nairn River at Jack Daymonds

The Nairn River has the second largest catchment area on Chatham Island draining both the north-western part of the southern hills, and the lowland areas including Lake Huro. The River flows through parts of the main township of Chatham Island; Waitangi before draining into the southern end of Petre Bay.

Environment Canterbury operated a flow recorder on the upper reaches of Nairn River from September 2011 through to 1 July 2018, a record length of approximately seven years. The flow recorder site, Nairn at Jack Daymonds was located approximately 3 km from the mouth and drains an area of approximately 37 km^2. It is noted that the recorder site does not include the flow contribution from the large area draining to the lower reaches of the Nairn River catchment. This area predominantly consists of a low-lying basin (including drainage from Lake Huro via Mangape Creek). This lower catchment contribution is likely to have a very different hydrological regime compared to the elevated reaches of the Nairn River upstream of the recorder site. It is therefore appropriate to refer to this recorder site in future as the “upper catchment of the Nairn River” or “upper Nairn River” to acknowledge these two significant catchment areas.

The specific discharge at mean flow and mean annual runoff of the upper Nairn River is similar to Awamata Stream (see section 4.1 above) but lower than the other large rivers draining the southern hills. This is reflective of the lower elevation and lower rainfall in a relatively large portion of the upper Nairn River catchment (also refer to Figure 7). However, the specific discharge at mean flow and mean annual runoff is significantly greater than the Tutuiri River in the northern part of the Island (refer to Table 4).

The mean flow is 608 L/s, median flow is 272 L/ and median monthly flows vary between 144 and 581 L/s. Flows are generally high in winter and low in summer (Table 5). The flow duration curve for the site (Figure 15 and Figure 16) indicates that the flow regime of the Nairn River and Tuku a Tamatea River are very similar. Figure 21 shows the upper Nairn River site and a hydrograph for the 2016-2017 hydrological year is included in Figure 22.

Figure 21: Nairn at Jack Daymonds

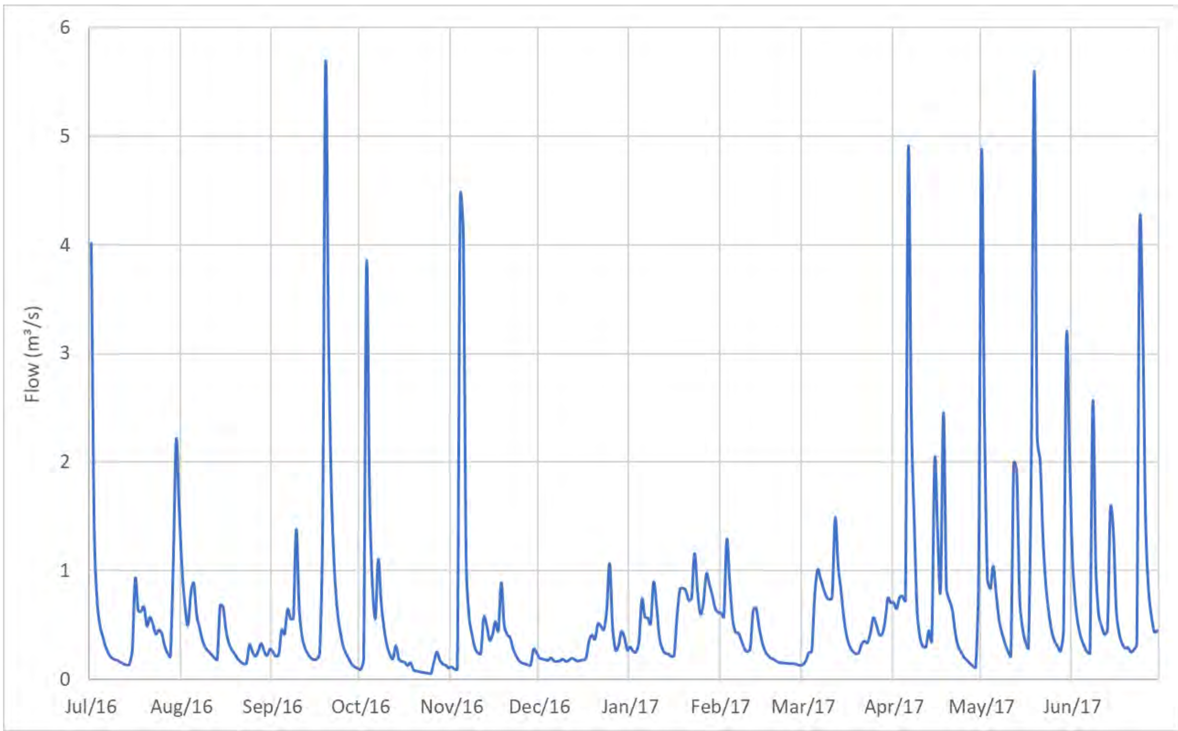


Figure 22: Example hydrograph for Nairn River at Jack Daymonds for 2016-2017 hydrological year

As commented above the upper Nairn River at Jack Daymonds flow recorder site was closed in 2018 and only a relatively short (seven year) record is available. Therefore, a regression analyses was undertaken with the three current recorder sites in the southern part of the island (Te Awainanga River at Falls, Tuku a Tamatea River at Waitangi Tuku Road and Awamata at Old Hydro Intake). The reason for undertaking the regression with all current recorder sites is that the upper reaches of the Nairn River catchment border all these catchments.

For the regression analyses there was insufficient data to use only gauging data and therefore mean daily flow values were also considered. All three sites correlated well with Nairn with r^2 values no lower than 0.85. Tuku a Tamatea provided the best correlation with an r value of 0.98 when considering all flows and 0.9 when considering only flows less than the median (on Tuku, the primary site). The regressions for Nairn versus Tuku are presented in Figure 23.

Based on the regressions, PDP recommend that there is no need to re-instate the upper Nairn River flow recorder as there is such a strong relationship with Tuku a Tamatea River. It is however recommended that more concurrent gaugings should be undertaken to maintain this relationship.

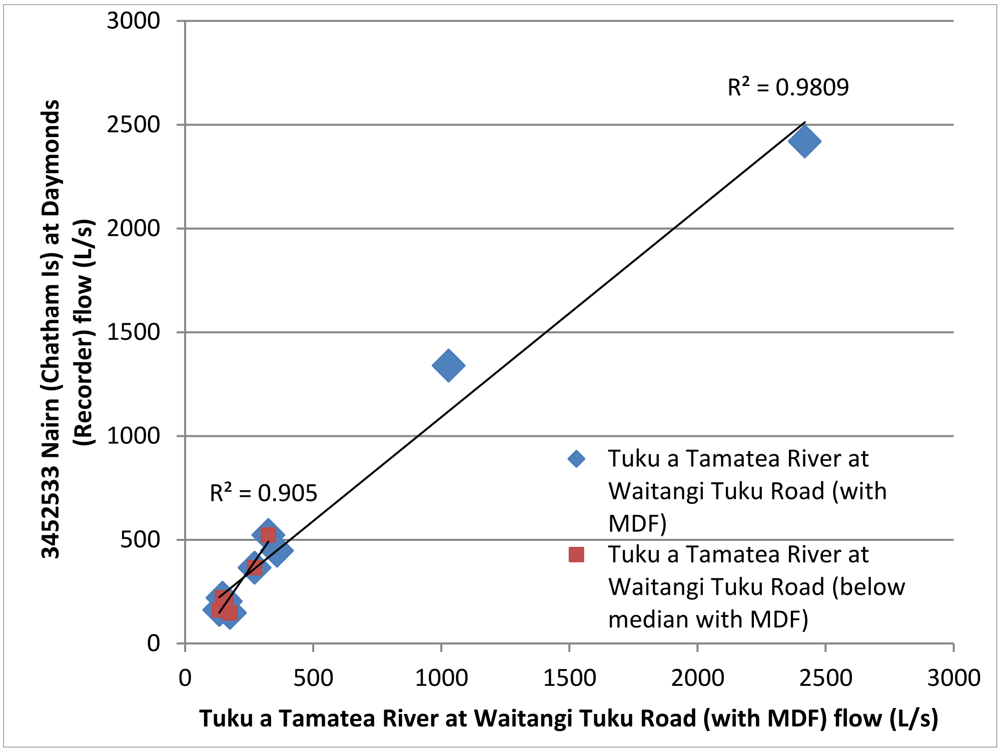


Figure 23: Regression between Nairn at Daymonds and Tuku a Tamatea River

4.1.3 Tuku a Tamatea River at Waitangi Tuku Road

The Tuku a Tamatea River is located in the south-west of the southern hills area, is relatively steep and drains an area of approximately 22 km^2. Environment Canterbury established a flow recorder in July 2008 and data for the site is available through to November 2019. The flow recorder, Tuku a Tamatea at Waitangi Tuku Road, is located approximately 400 m upstream of the mouth at the coast. The specific discharge at mean flow and mean annual runoff are relatively high and similar to the Te Awainanga River (Table 4).

The mean and median flow are 615 L/s and 342 L/s respectively and the median monthly flows vary between 123 and 696 L/s (refer to Table 4 and Table 5). Figure 24 shows the Tuku a Tamatea River at Waitangi Tuku Road and a hydrograph for the 2016-2017 hydrological year is included in Figure 24. The example hydrograph and flow duration curve for the site (Figure 15 and Figure 16) indicate that the flow regimes for the Tuku a Tamatea and upper Nairn River are very similar.

Figure 24: Tuku a Tamatea River at Waitangi Tuku Road

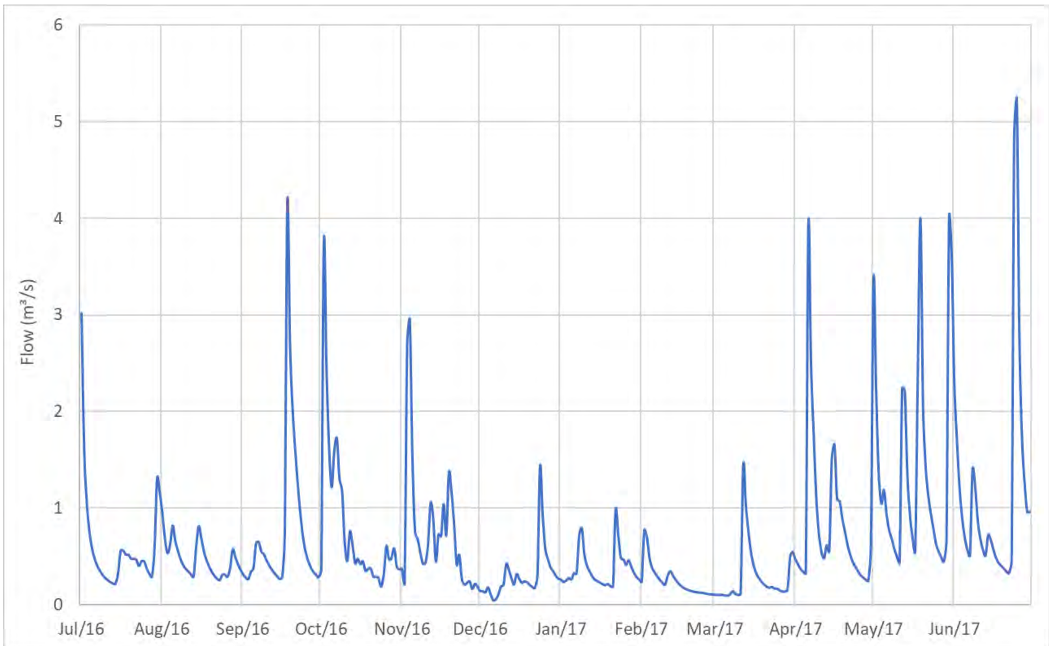


Figure 25: Example hydrograph for Tuku a Tamatea River at Waitangi Tuku Road for 2016-2017 hydrological year

4.1.4 Awamata at Old Hydro Intake

Awamata Stream drains a portion of the western area of the southern hills and some of its headwaters border the Nairn River catchment. The flow recorder is located approximately 200 m upstream of the mouth and has a 33 year record length (1986-2019). The catchment area is relatively small (at 9.4 km^2) compared to the other recorder sites in the southern hills area and, due to the lower rainfall in the majority of the catchment, the specific discharge and mean annual runoff are lower than the Te Awainanga and Tuku a Tamatea River but similar to the upper Nairn River (Table 4).

The mean and median flow are 171 and 78 L/s respectively and median monthly flows vary between 29 and 180 L/s (Table 4 and Table 5). The flow duration curve for the sites (Figure 15 and Figure 16) indicate that flows are less than 200 L/s for approximately 80% of the time. The river can dry up during periods of extreme drought which has occurred once for a period of approximately 3 weeks in April/May 1988. Figure 26 shows the recorder site and an example hydrograph is included in Figure 27.

Figure 26: Awamata at Old Hydro Intake

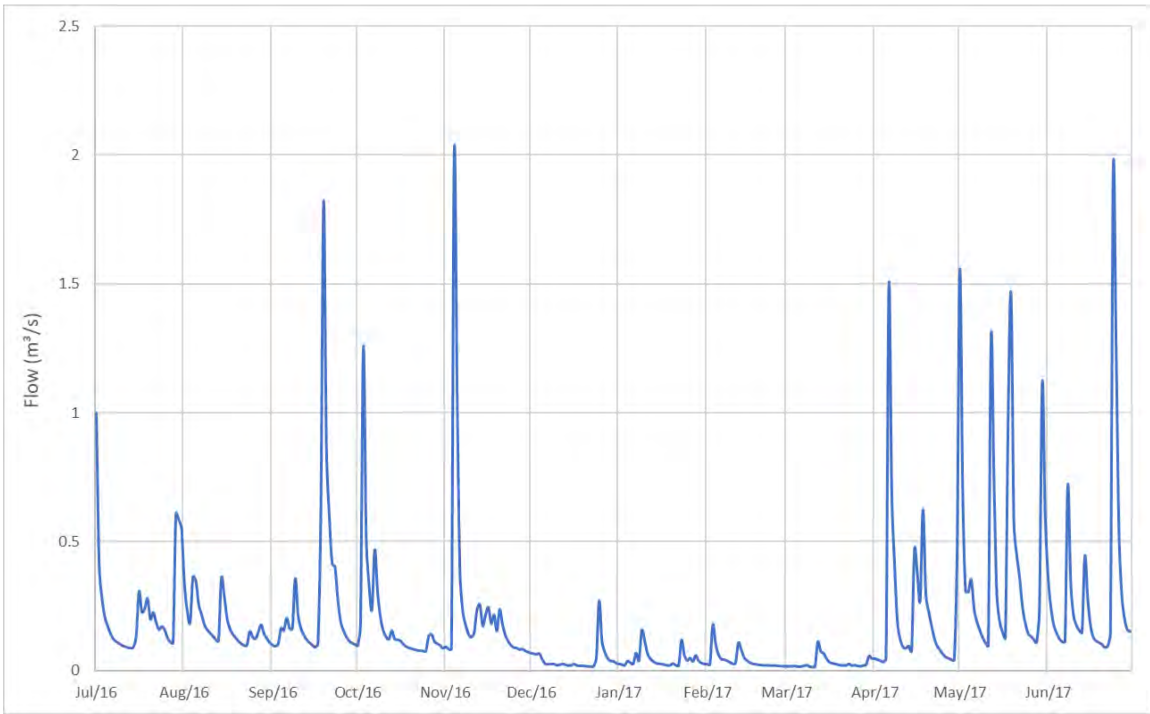


Figure 27: Example hydrograph for Awamata at Old Hydro Intake for 2016-2017 hydrological year

Figure 28 illustrates the inter-annual variation in mean annual flow and the 4-year moving average flow for the Awamata at Old Hydro Intake flow recorder. Hydrological years with incomplete data (less than less 98% complete, refer to Table 3) were excluded from the analyses. The mean annual flow varies greatly from year to year with the first complete hydrological year (1987-1988) on record having the lowest flow (0.07 m^3/s) and 1993-1994, 1996-1997 and 2001-2002 having the highest flow (0.23 m^3/s). The 4-year moving average shows no obvious increasing or decreasing trend in mean annual flow.

In order to determine whether the last 10 years of data (the new data available since the last state of the environment report) significantly differ from the previous years a t-test was undertaken. A t-test measures if there is a statistically significant difference between two groups of data.

The mean annual flows were calculated and grouped into two periods 1985-2009 and 2010-2019. A two sided t-test, assuming unequal variance, was conducted on both recorders. The t-test returned a $p>0.05$ and therefore it was concluded that there was no statistically significant difference for the mean annual flow between the new data (2010 to 2019) and the old data (1986 to 2009).

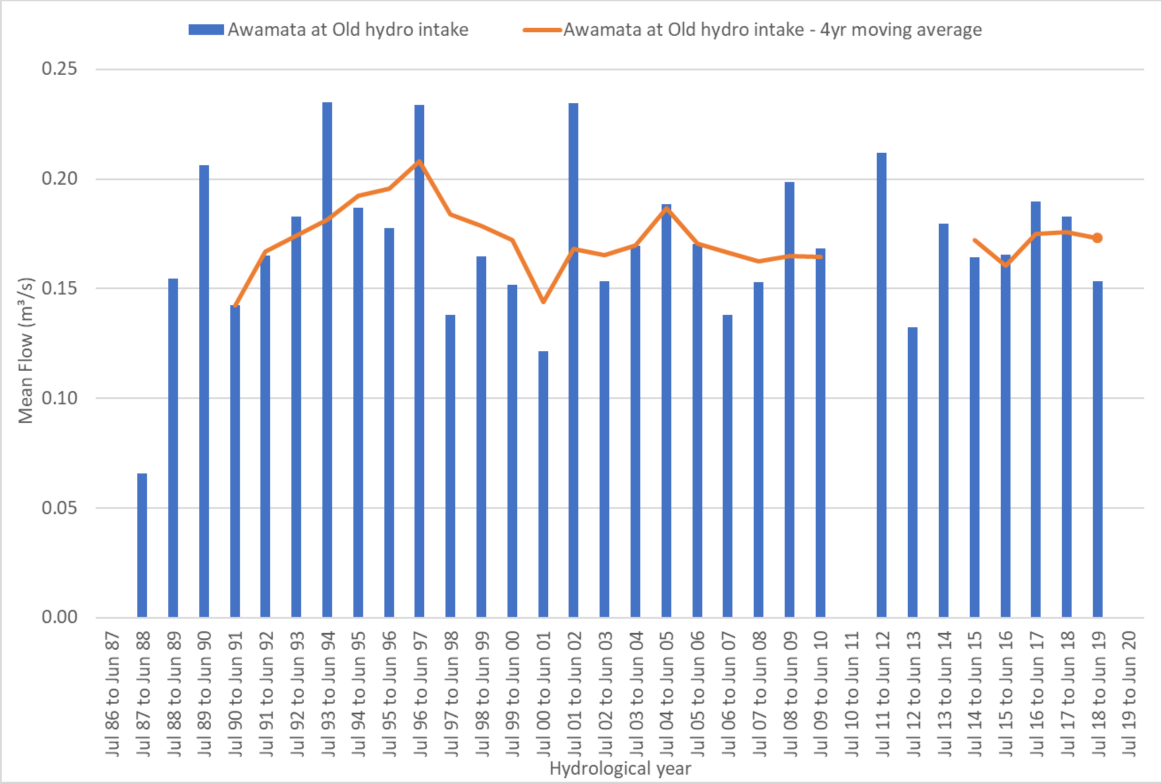


Figure 28: Inter-annual variation in mean flow for Awamata at Old Hydro Intake

4.1.5 Tutuiri Creek at Schist Outcrop

The Tutuiri River is the largest river in the north of Chatham Island. It is the only river with a flow recorder on the northern part of the Island. The flow recorder, Tutuiri at Schist Outcrop, is located approximately 1.7 km upstream of the mouth and drains an area of approximately 21.5 km^2. The flow recorder was established by NIWA in 1986 and subsequently closed in 1994. The recorder was reinstated by Environment Canterbury in September 2006 and a flow record for the site is available until November 2019. Due to the relatively lower rainfall in the northern part of the island the specific discharge at mean flow and mean annual runoff of the Tutuiri River is much lower than the rivers draining the southern hills (refer to Table 4). For example, the mean annual runoff of the river at 311 mm/year is only about 60% of the runoff from the upper Nairn River and only around 35% of the runoff from the Te Awainanga River (at Falls).

The mean and median flow are 212 L/s and 48 L/s respectively and the median monthly flows vary between 5 and 281 L/s. Similar to the other rivers on Chatham Island, flows are generally high in winter and low in summer (Table 5). Flows are less than 50 L/s for approximately 50% of the time (Figure 15 and Figure 16). The river can dry up in extremely dry years as has happened for approximately 3 weeks in December 1988/January 1989. Figure 29 shows the

Tutuiri River and Figure 30 shows a hydrograph for the 2016-2017 hydrological year. There are fewer distinct floods showing on the hydrograph for this river, indicating either the lower rainfall and/or higher water storage within this catchment.

Figure 29: Tutuiri River at Schist Outcrop

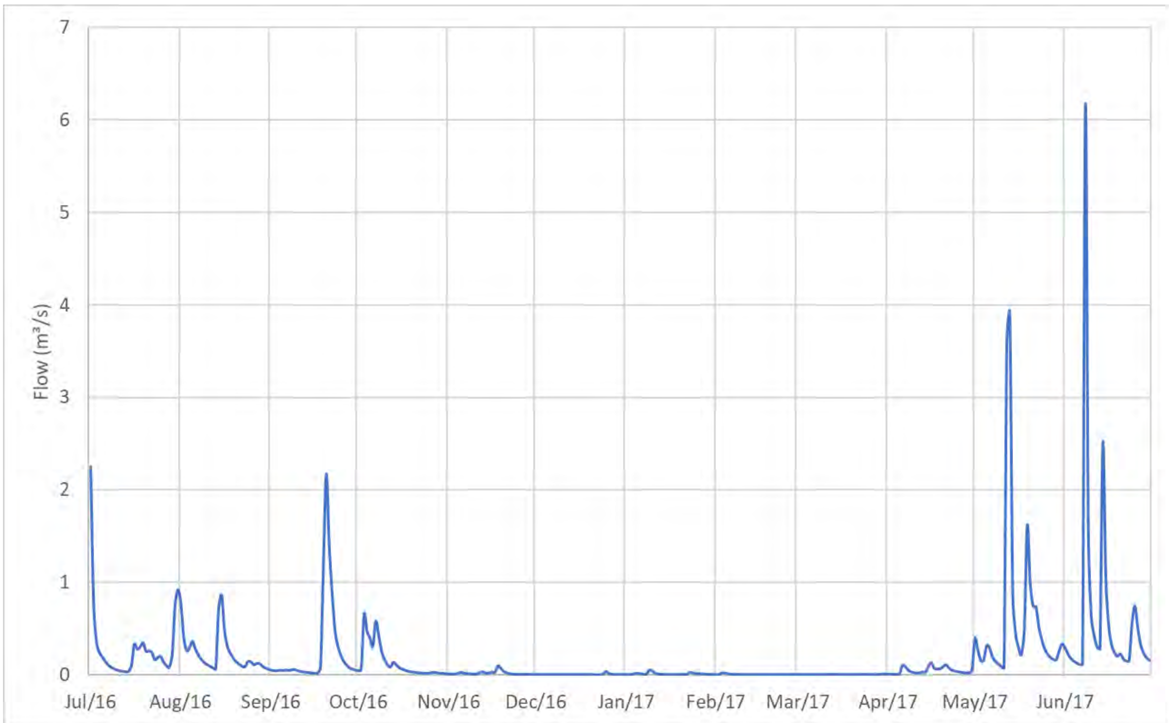


Figure 30: Example hydrograph for Tutuiri at Schist Outcrop for 2016-2017 hydrological year

4.2 Watercourses with Spot Gauging Information

In addition to the flow recorder sites, spot gaugings have been undertaken at a further 27 sites at various frequencies between April 2005 and December 2014. No spot gauging information is available after December 2014, and it is unclear why this activity was discontinued. Table 6 and Figure 31 show the details and locations of these sites. Appendix A, Table 1 shows the concurrent gaugings for each site.

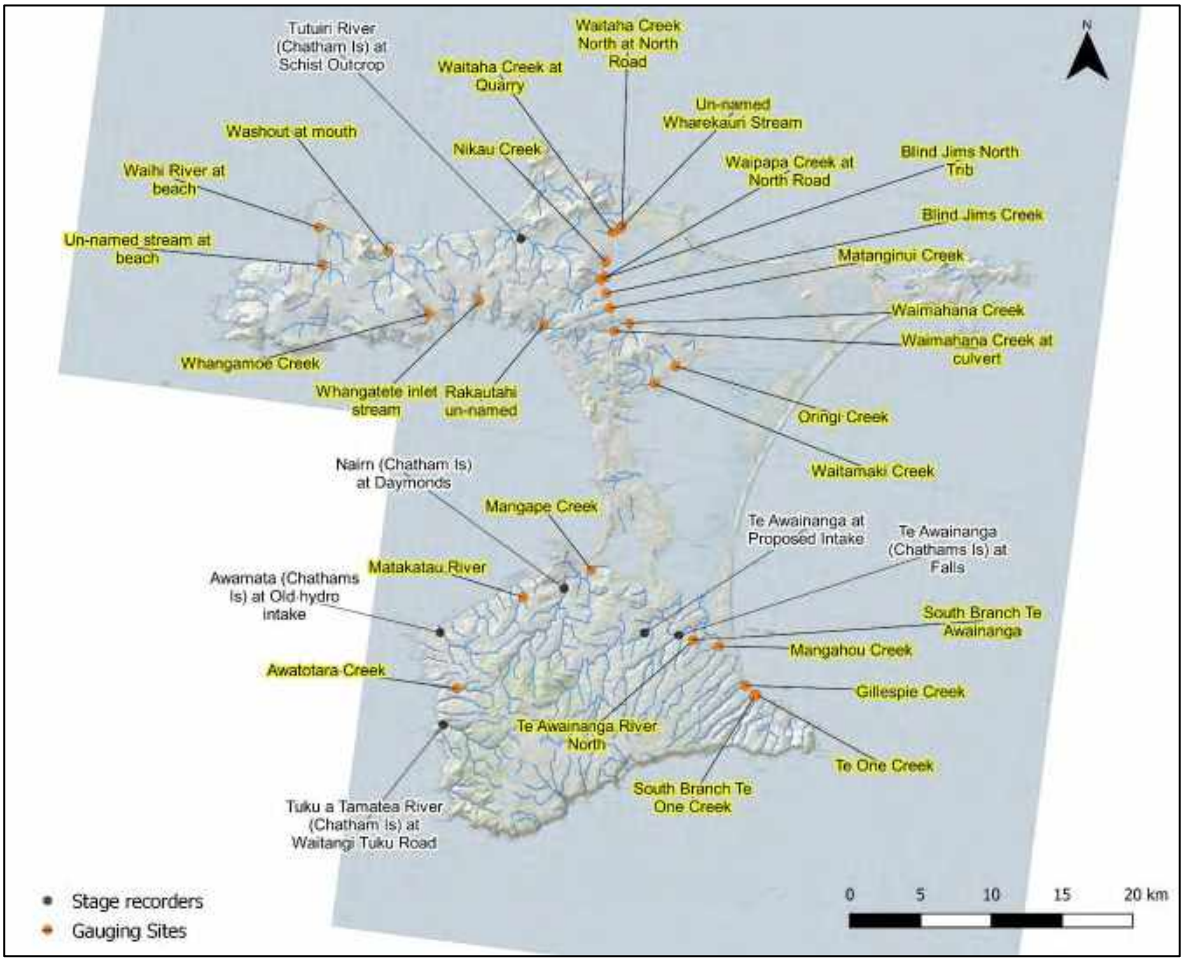


Figure 31: Location of primary stage recorder sites and gauging locations (labelled in yellow)

Table 6: Gauging locations on Chatham Island			
Site Number	River	Site Name	Number of gaugings
Northern Watercourses			
3248763	Waihi River	Beach	14
3254737	Unnamed Stream	Beach	13
3298753	Washout	Mouth (Waitangi West Road)	12
3509698	Oringi Creek	Air Base Road	13
3332713	Whangamoe Creek	Inlet	4
3366726	Whangatete Inlet Stream	Waitangi West Road Bridge	16
3413715	Rakautahi	Port Hutt Road	16

Table 6: Gauging locations on Chatham Island			
Site Number	**River**	**Site Name**	**Number of gaugings**
3449752	Waipapa Creek	North Road	19
3451765	Nikau Creek	North Road	4
3452754	Blind Jims (North) Trib	North Road	6
3453786	Waitaha Creek	Quarry	9
3454743	Blind Jims Creek	North Road	16
3458733	Matanginui Creek	North Road	13
3458789	Wharekauri Stream	North Road	0
3459791	Waitaha Creek	North Road	5
3463717	Waimahana Creek	Culvert	6
3473724	Waimahana Creek	Chudleigh Reserve	3
3496686	Waitamaki Creek	Air Base Bridge Road	16
3436871	Tutuiri River (Recorder)	Schist Outcrop	73
Southern Watercourses			
3545509	South Branch Te Awainanga	Waitangi/Owenga Road	1
3546509	Te Awainanga River North	Owenga Road	8
3385454	Awatotara Creek	Waitangi Tuku Road Bridge	18
3423524	Matakatau River	Waitangi Tuku Road Bridge	14
3468549	Mangape Creek	Bridge	9
3564507	Mangahou Creek	Waitangi Wharf Owenga Road Bridge	18
3586482	Gillespie Creek	Waitangi Wharf Owenga Road Bridge	18
3593475	South Branch Te One Creek	Alfreds	9
3594477	Te One Creek	Waitangi/Owenga Road	6
3452533	Nairn (Recorder)	Daymonds	11
3379428	Tuku a Tamatea River (Recorder)	Waitangi Tuku Road Bridge	42
3446051	Te Awainanga (Recorder)	Falls	140
3446071	Awamata (Recorder)	Old hydro intake	153

A regression analysis for the gaugings for each of the 27 sites against the three long term sites (Te Awainanga at Falls, Awamata at Old Hydro Intake and Tutuiri at Schist Outcrop) has been completed. Where possible, the regression analysis was performed with gauged data only, but if the number of concurrent gaugings was less than six (using only gauging data), then the primary recorder data was supplemented with mean daily flow data. Mean daily flow values for the primary sites are shown in black text in Appendix A, Table 1. In some instances, there was insufficient data to complete a regression analysis.

If sufficient gauging data was available, 7D MALF (7 day Mean Annual Low Flow) estimates were calculated using flows below the median only in line with the recommendations from Henderson et. al. (2003).

Table 2, Appendix A shows the results of the regression analysis. The preferred regression equation is highlighted:

- A regression equation highlighted green represents the equation that provides the estimates for all flow statistics (mean, median and 7D MALF);
- A regression equation highlighted blue represents the equation that provides the estimate for the mean and median flow but not for the 7DMALF; and
- A regression equation highlighted yellow represents the equation that provides the estimate for the 7DMALF statistic.

The following guidelines were applied to select the regression equation to be used to estimate flow statistics:

- No regression was undertaken if the number of data points (concurrent flows) was less than six. It is noted that ideally more data points are used, however for the purpose of state of the environment reporting, this was considered to be adequate;
- The r^2 value had to exceed 0.6 for the regression to be considered suitable for the purposes of this assessment. It is noted that ideally r^2 values better than 0.6 are used, however for the purpose of state of the environment reporting this was considered to be adequate;
- If the r^2 value for the regression equation using all flows was less than 0.6, then the regression for flows below the median was also discounted;
- If sufficient data was available preference was given to concurrent gauging data rather than gauging data supplemented by mean daily flow data. If the r^2 values were reasonably close (i.e. within 0.1) then preference was given to the regression established with concurrent gaugings only;
- Preference to use flows for the recorder in the northern part of the Island (Tutuiri at Schist) for the northern spot gauging sites and preference for the use of recorders in the southern hills for the spot gauging sites in the south. This preference was also set at an r^2 difference of 0.1;

- Both selected regressions (all flows and flows below the median) had to come from the same primary recorder; and
- For all sites, regressions were undertaken with the three long term primary recorder sites (Te Awainanga at Falls, Awamata at Old Hydro Intake and Tutuiri at Schist Outcrop). One of the spot gauging sites (Awatotara) was also compared with another (relatively short term) recorder site (Tuku a Tamatea River at Waitangi Tuku Road). The reason for doing this was that the Awatotara catchment is located very close to the Tuku a Tamatea River and gaugings for this site are generally undertaken on the same day as the gaugings for the Tuku a Tamatea flow recorder site.

The regression plots can be found in Appendix A, Figures A-1a to A-17a. The spot gauging sites are grouped into two areas: Northern watercourses and Southern watercourses.

Northern Watercourses

18 sites have spot gaugings available in the northern watercourses. These include: Waihi River, Unnamed Stream, Washout, Oringi Creek, Whangamoe, Whangatete Inlet Stream, Rakautahi, Waipapa Creek, Nikau Creek, Blind Jims (North) trib, Waitaha Creek (at quarry), Blind Jims Creek, Matanginui Creek, Wharekauri Stream, Waitaha Creek (at North Road) , Waimahana Creek (at Culvert), Waimahana Creek (at Chudleigh Reserve) and Waitamaki Creek.

Most of the sites correlate best with Tutuiri River at Schist (the northern primary site). Only one site (Rakautahi) correlated well for flows below the median. The Te Awainanga at Falls flow recorder provides the best regression for the Waihi River, this was also concluded by ECan (2010). Blind Jims (North) Trib correlated best with Awamata at Old Hydro Intake. Four sites (Unnamed Stream, Oringi Creek, Blind Jims Creek and Waitamaki) did not return a sufficiently high r^2 value (>0.6) to be considered suitable for regression with any of the recorders. There is insufficient data to undertake regression analysis for Whangamoe Creek, Nikau Creek, Wharekauri Stream, Waitaha Creek and Waimahana Creek (at Chudleigh Reserve).

Waitamaki Creek at Air Base Road Bridge had a stage recorder between 2010 and 2015. This recorder would have been very useful to estimate flows for Waitamaki Creek but potentially also for some of the other streams in the area that do not correlate well with any of the other flow recorder sites. However, following discussions with Environment Canterbury and data quality checks on the data it was determined that the continuous flow record for this site was unreliable. Furthermore, three recorded zero gaugings were discounted as ECan indicated that the comment files for these gaugings stated that a gauging was unable to be performed on those days due to various weather conditions rather than an absence of flow (the three recorded zero values should be removed from the ECan spot gauging database). For the remaining nine gaugings, a good correlation could not be achieved with any of the primary sites. Due to the short term recorder site in Waitamaki Creek not having any reliable data this is still an area where gathering further hydrological data would be useful.

Figure 32 shows the gauged flows for Waitamaki Creek and four nearby tributaries of Te Whanga Lagoon. The four tributaries presented are the only sites that have more than three concurrent gaugings with Waitamaki Creek. It is noted that two of those sites (Matanginui and Waipapa) correlate well with Tutuiri. Oringi Creek and Waipapa Creek correlate well with Waitamaki Creek. For the other two sites, despite the lack of data, the sites appear to have potential to correlate well with Waitamaki Creek, and PDP recommend reinstating the recorder (at a suitable location). It is recommended that further gaugings be undertaken for the northern tributaries of Te Whanga Lagoon. This should include the sites with insufficient data and the sites that do not provide a good regression with Tutuiri (Oringi Creek, Blind Jims Creek, Nikau Creek, Wharekauri Stream, Waitaha Creek and Waimahana Creek (at Chudleigh Reserve)).

It is also recommended that further gaugings are obtained for Unnamed Stream and Whangamoe Creek which are located in the north western part of the Island but do not flow into Te Whanga lagoon. These are the only two other sites in the north western part of the island where regression equations could not be provided due to insufficient data or a poor correlation with Tutuiri.

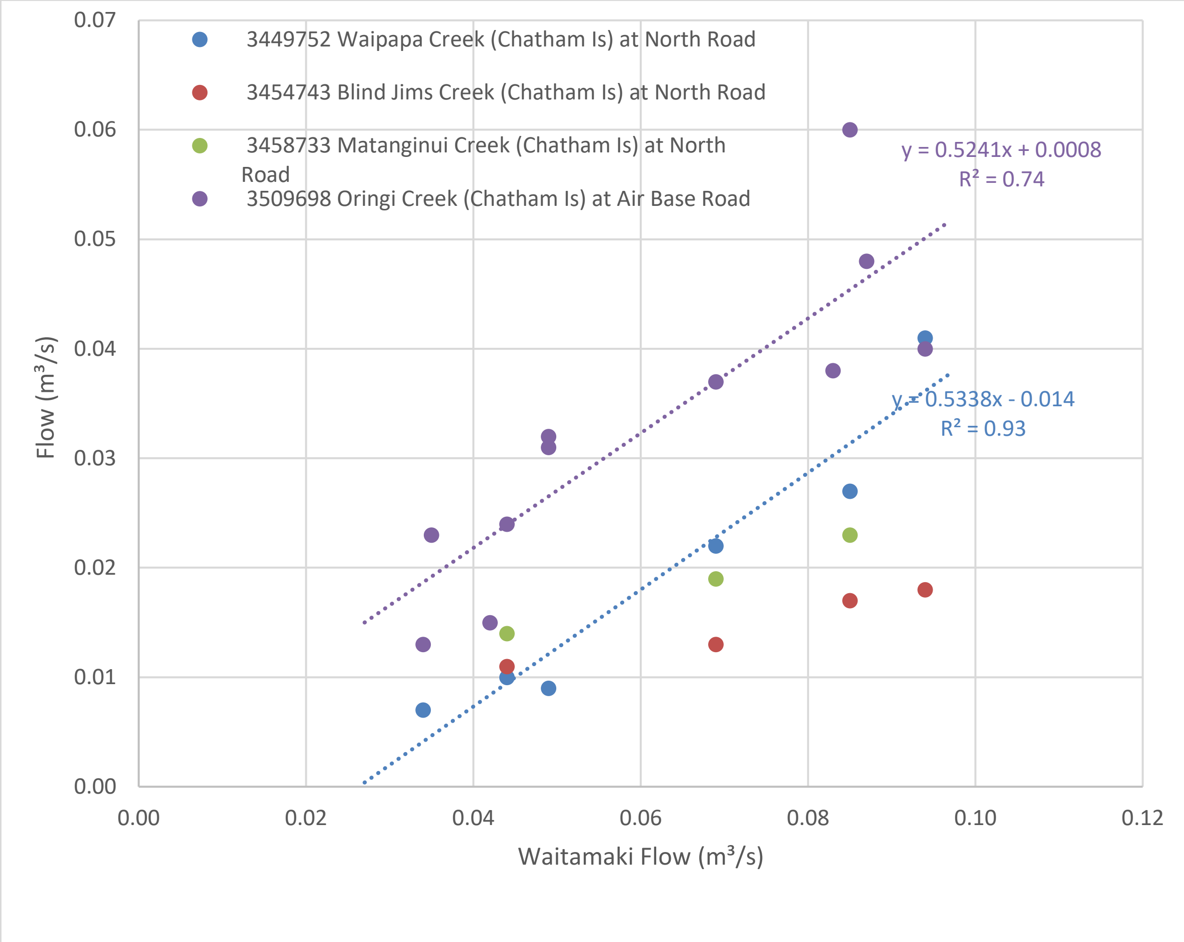


Figure 32: Regression of Waitamaki Creek against nearby tributaries of Te Whanga Lagoon

Southern Watercourses

The 9 watercourses gauged in this location include: Awatotara Creek, Matakatau River, Mangape Creek, Te Awainanga River North, South Branch Te Awainanga River, Mangahou Creek, Gillespie Creek, Te One Creek and South Branch Te One Creek. Awatotara Creek correlates well with the Tuku a Tamatea River ($r^2 = 0.95$) whilst the Matakatau River correlates best with the Awamata Stream. Mangape Creek (that drains Lake Huro) not surprisingly, does not return a good correlation with any of the primary sites. Te Awainanga River North, Mangahou Creek, Gillespie Creek, Te One Creek and South Branch Te One Creek all correlated very well with Te Awainanga at Falls. There are insufficient gaugings for South Branch Te Awainanga.

The selected regression equations from Table 2, Appendix A were used to estimate flow statistics (median, mean and 7D MALF), specific discharge at mean and median flow and mean annual runoff. These statistics are presented in Table 7.

Figure 33 shows the specific discharge at mean flow for all gauged catchments where a regression relationship could be identified. This figure shows that the southern catchments, tend to produce higher specific discharges at mean flow. The same general pattern can be seen for the specific discharge at median flow (refer to Table 7).This is likely to be a function of both rainfall and geology. Rainfall is likely to be higher in the southern catchments and the underlying strata in the southern parts of the island predominantly consists of shallower organic soils overlying (low permeability) basalt.

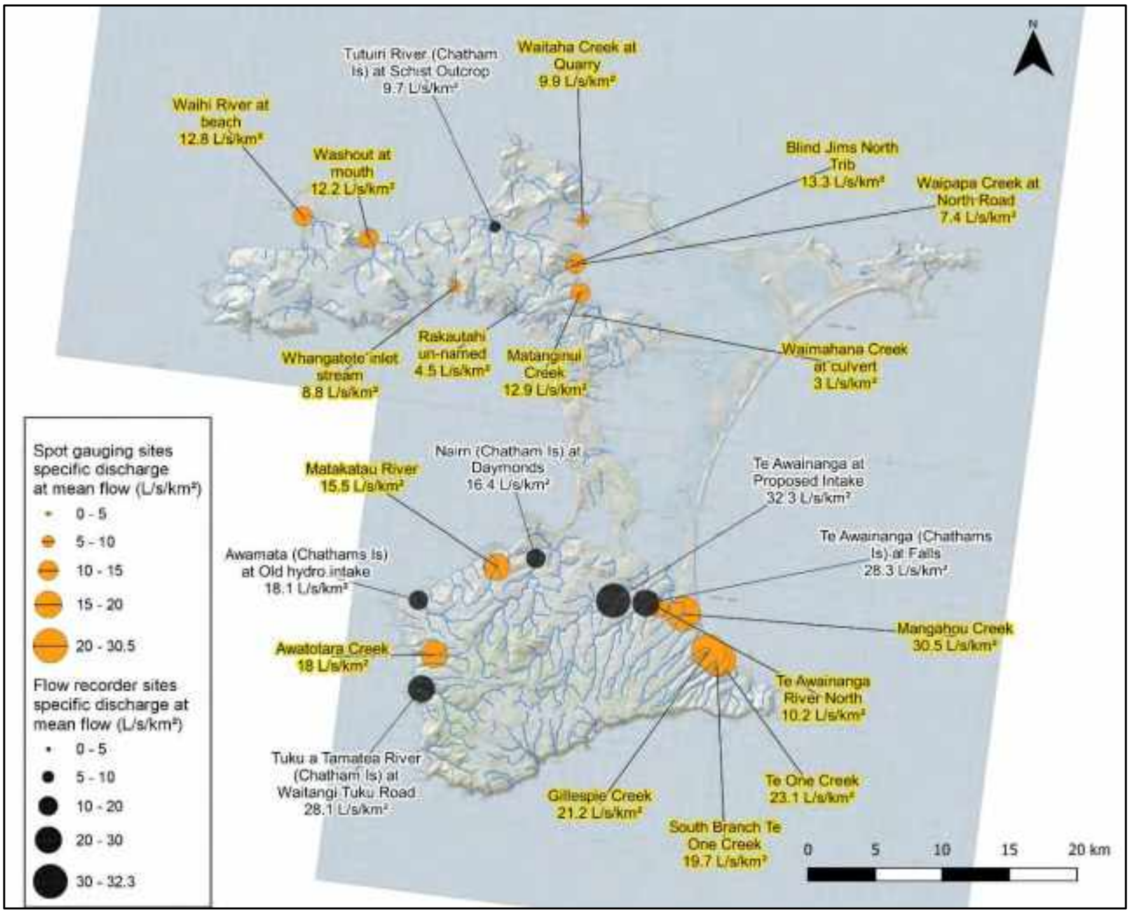


Figure 33: Specific discharge at mean flow for flow recorder and spot gauging sites

Table 7: Flow statistics for gauging sites estimated based on regression analyses

Gauging site number and location	Catchment Area (km^2)	All flows (calculate the median and mean)						Flows less than the median (calculate the 7DMALF)					Specific Discharge at mean flow ($L/s/km^2$)	Specific Discharge at median flow ($L/s/km^2$)	Mean annual runoff (mm/yr)	Comments
		Primary Recorder	# of concurrent gaugings	r^2	Regression equation	Median	Mean	Primary Recorder	# of concurrent gaugings	r^2	Regression equation	7DMALF				
Northern Watercourses																
3248763 Waihi River at Beach	6.69	Te Awainanga	13	0.68	y = 0.0545x - 18.83	40	92	Insufficient data - using all flows	13	0.71	y = 0.0545x - 18.83	0	13.7	6.0	433	
3254737 Unnamed Stream at Beach	5.06	Tutuiri River	12	0.43	No correlations											r^2 values all <0.6
3298753 Washout at Mouth (Waitangi West Road)	17.41	Tutuiri River	10	0.85	y = 0.8447x + 40.93	80	217	Insufficient data - using all flows	10	0.85	y = 0.8447x + 40.93	43	12.5	4.6	393	
3509698 Oringi Creek at Air Base Road	2.64	Tutuiri River	11	0.03	No correlations											r^2 values all <0.6
3366726 Whangatete Inlet Stream at Waitangi West Road Bridge	2.81	Tutuiri River	12	0.86	y = 0.1038x + 4.11	9	26	r^2 value < 0.6 - using all flows	12	0.86	y = 0.1038x + 4.11	4	9.2	3.2	289	
3413715 Rakautahi (un-named) at Port Hutt Road	6.88	Tutuiri River	12	0.97	y = 0.1401x - 0.84	6	28	Tutuiri River	7	0.91	y = 0.0975x + 0.57	1	4.1	0.8	130	
3449752 Waipapa Creek at North Road	5.84	Tutuiri River	15	0.92	y = 0.2173x + 8.65	19	54	r^2 value < 0.6 - using all flows	15	0.92	y = 0.2173x + 8.65	9	9.2	3.2	291	
3452754 Blind Jims (North) Trib at North Rd	0.883	Awamata	6	0.82	y = 0.0964x - 4.71	3	12	Insufficient data - using all flows	6	0.82	y = 0.0964x - 4.71	0	13.3	3.2	420	
3453786 Waitaha Creek at Quarry	2.53	Tutuiri River	8	0.78	y = 0.1133x + 1.35	7	25	Insufficient data - using all flows	8	0.78	y = 0.1133x + 1.35	2	9.9	2.6	311	
3454743 Blind Jims Creek at North Road	1.44	Tutuiri River	14	0.49	No correlations											r^2 values all <0.6
3458733 Matanginui Creek at North Road	1.96	Tutuiri River	11	0.86	y = 0.0638x + 14.51	17	28	Insufficient data - using all flows	11	0.86	y = 0.0638x + 14.51	15	14.2	8.9	447	
3463717 Waimahana Creek at Culvert	8.48	Tutuiri River	6	0.89	y = 0.0656x + 12.04	15	26	Insufficient data - using all flows	6	0.89	y = 0.0656x + 12.04	12	3.0	1.8	96	
3496686 Waitamaki Creek at Air Base Road Bridge	8.3	Tutuiri River	11	0.19	No correlations											r^2 values all <0.6
Southern Watercourses																
3385454 Awatotara Creek at Waitangi Tuku Road Bridge	5	Tuku a Tamatea	15	0.95	y = 0.1614x - 7.41	47	90	Tuku a Tamatea	6	0.85	y = 0.0991x + 2.14	9	18.0	9.4	567	Tuku a Tamatea has been used in place of Tutuiri River at Schist. Used concurrent gauging data only
3423524 Matakatau River (Chathams) at Waitangi Tuku Rd Bridge	4.8	Awamata	10	0.76	y = 0.4073x + 4.76	37	74	Insufficient data - using all flows	10	0.76	y = 0.4073x + 4.76	12	15.5	7.6	488	Used concurrent gauging data only
3546509 Te Awainanga River North at Owenga Road	1.23	Te Awainanga	7	0.99	y = 0.0069x - 1.50	6	13	Insufficient data - using all flows	7	0.99	y = 0.0069x - 1.50	0	10.2	4.9	321	
3468549 Mangape Creek at Bridge	0.84	Awamata	9	0.11	No correlations											r^2 values all <0.6
3564507 Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	9.98	Te Awainanga	10	0.95	y = 0.1454x + 8.81	166	304	Te Awainanga	6	0.78	y = 0.127x + 11.88	47	30.5	16.6	962	Used concurrent gauging data only
3586482 Gillespie Creek at Waitangi Wharf Owenga Road	5.94	Te Awainanga	10	0.88	y = 0.0578x + 8.72	71	126	r^2 value < 0.6 - using all flows	10	0.88	y = 0.0578x + 8.72	25	21.2	12.0	670	Used concurrent gauging data only
3593475 South Branch Te One Creek at Alfreds	4.25	Te Awainanga	9	0.87	y = 0.0573x - 32.62	29	84	Insufficient data - using all flows	9	0.87	y = 0.0573x - 32.62	0	19.7	6.9	622	
3594477 Te One Creek at Waitangi/Owenga Rd	8.13	Te Awainanga	6	0.98	y = 0.0891x + 7.02	103	188	Insufficient data - using all flows	6	0.98	y = 0.0891x + 7.02	32	23.1	12.7	730	

Notes: Insufficient data (less than six concurrent gaugings) for analysis at sites: 3332713 Whangamoe Creek (Chatham Is) at Inlet, 3451765 Nikau Creek (Chatham Is) at North Road, 3458789 Unnamed Wharekauri Stm (Chatham Is) at North Rd, 3459791 Waitaha Creek North (Chatham Is) at North Road, 3473724 Waimahana Creek (Chatham Is) at Chudleigh Reserve, 3545509 South Branch Te Awainanga (Chatham Is) at Waitangi/Owenga Rd.

5.0 Groundwater

No records of the groundwater bores on the island are currently available, and therefore it is not possible to determine where potable groundwater is typically available based on the location of bores. However, some estimates can be derived from the geological mapping across the island.

At a large scale, the outcropping geology of the island can be split into three main strata types, including:

- volcanic strata found across the southern part of Chatham Island;
- limestone strata found across the central part of the island; and
- Aeolian sands across the mid-western and northern part of the island
- peat and silt deposits, which are found across much of the northern half of Chatham Island, as well as overlying the southern tablelands.

These deposits can all hold groundwater, however, groundwater in basaltic and limestone strata is typically found in fractures and a productive yielding bore relies on intersecting a series of water bearing fractures. Bores in these types of deposits are frequently of an exploratory nature with variable chances of success. Groundwater can also occur in the extensive sand deposits adjacent to the dune lakes, and depending upon sand grain size, these may be permeable and reasonable water yielding, but are likely to be closely connected to the dune lakes. Groundwater can also occur in peat and silt deposits but the low permeability of these strata means that bores are typically very low yielding unless they either also intercept sand or volcanic ash layers within the peat, or are constructed as bores with associated surrounding permeable gravel pack structures.

Given the geology of the island, highly productive groundwater bores are generally not expected, and high producing bore such as for irrigation or high volume industrial use are not likely to be required. Water requirements are more likely to be for small scale domestic supplies, for which low yielding bores may be suitable. However, there is a significant information gap in this respect and more information should be collated from existing bores and assessment of other potential bore development.

Information should be gained from drilling companies who have worked on the island drilling the existing bores to help fill this gap. The presence of existing bores in the vicinity of Waitangi and Te One indicates some groundwater is available and a survey of those sites should be undertaken to establish the locations and depth. A database of any new bores should also be established and plan requirements for drillers to provide logs of any new bores should be developed. Groundwater quality information should also be collected and recorded where possible so that suitable sources can be identified.

6.0 Review of Abstractive Pressure, Consents and Permitted Activities

There is generally very limited consented water use on the Chatham Islands and information provided by consultants for Chatham Islands Council that there are likely to be no more than two relatively large groundwater takes. One of these is for the disused meatworks (Chatham Enterprise Trust), and a second is related to concrete batching plant use for the recent wharf construction, and now targeted to boost the Waitangi potable supply.

Other water takes include groundwater take supplies for potable water to Waitangi township and the Waitangi hospital, and a surface water take from Lake Rangitai which provides potable water to the township of Kaingaroa. Bores have been drilled to provide potable supply for Owenga but we understand the water quality found was unsuitable. The fish factories at Te One, Port Hutt and Kaingaroa may also use localised groundwater sources.

Information provided by consultants for Chatham Islands Council indicate that the groundwater take for Waitangi typically uses up to 100 m^3/day at times, although on average the use is less than 60 m^3/day. The local population of Waitangi is approximately 200 people, which implies that each person uses around 300 L/day (if all supplied water is used for domestic purposes), which is consistent with water use elsewhere in New Zealand. However, tourist and visitor numbers will seasonally increase these numbers. Information is also available for the Kaingaroa Plant, which indicates a typical daily flow of around 20 m^3/day.

The total resident population of the Chatham Islands is around 700 people and those residents living outside Waitangi, Te One, Owenga, and Kaingaroa may use in the order of an additional 150 m^3/day. Many residents outside Waitangi and Kaingaroa are likely to predominantly use rainwater collection tanks, which would reduce pressure on other limited water sources. It is unclear how many of them may use springs or private bores, but this is currently likely to be small. The total potable (and total) water use on the island is likely to be less than 250 m^3/day on average (an average of 2.9 L/s) but it is difficult to assess the additional water use by the fish factories and other small industrial sites. At a broad scale, this scale of abstractive pressure is small in a New Zealand context, but the potential sources of potable water are also likely to be small. This is likely to become a significant resource management issue if water use requirements grow, or water yields from say rainfall collection or localised sources diminish from reduction in regular rainfall.

Those residents who rely on rainwater tanks may experience seasonal water shortages during times of low rainfall (for example during the summer of 2017/2018). Consideration and investigation of alternative sources of water would be prudent, which is considered at a high level in Sections 5, 7 and 11. As part of this work, it would be helpful to collect groundwater level information from key supplies (i.e. the Waitangi supply).

7.0 Water Balance for Monitored Catchments

An estimated water balance has been completed for each of the main monitored catchments on Chatham Island. These water balances are based on the estimated differences between rainfall across the catchments and the estimated mean annual runoff, calculated from the flow analysis in Section 4.0. The difference between the rainfall and estimated mean annual runoff represents a combination of recharge to groundwater (and/or longer-term storage within shallow peaty soils/strata) and evaporation/evapotranspiration. The estimated water balances therefore provide some information on whether groundwater storage resources could occur in each of the catchments listed.

However, it is important to highlight that there are considerable uncertainties in these estimates. They are all based simplistically on annual averages, rather than a consideration of daily changes in rainfall, actual evapotranspiration, run-off and soil moisture, which would require considerably more information and modelling. It is also important to highlight that Chatham Island does not contain large scale alluvial aquifers as occur on mainland New Zealand; much of the island is covered by peat basins overlying volcanic strata. Groundwater resources are therefore not likely to be widespread.

7.1 Te Awainanga

The mean annual flow at the Falls flow recorder site is 2,040 L/s which implies a mean annual runoff of around 896 mm/year. The rainfall gauge at Te Awainanga has an average annual rainfall of around 881 mm/year (based on eight years of data), however, this gauge is located on the lower slopes of the Southern Hills area. No rainfall gauges are located at higher elevations within the Southern Hills but estimates from NIWA (Pearce, 2016) indicates that rainfall across the Southern Hills area could be up to 2,000 mm/year (refer to Figure 7). It is considered likely that rainfall across the catchment to Te Awainanga could be closer to 2,000 mm/year than the 881 mm/year recorded at the gauge, although actual rainfall data would be required to establish this.

Potential evapotranspiration data for the closest site (Chatham Islands Aws) averages around 812 mm/year. Actual evapotranspiration data cannot be calculated because accurate soils data across the island is limited, however that estimate is likely to be generally consistent with the estimate of rainfall (~1,500 to 2,000 mm/year) and mean annual runoff (895 mm/year), and allowing for a small amount of soil and shallow groundwater storage/recharge. Note that generally, groundwater recharge is not likely to be significant as a result of the catchment geology, which is dominated by lower permeability peaty soils overlying volcanic strata.

7.2 Tuku a Tamatea River

Similar comments apply to the Tuku a Tamatea River as the Te Awainanga, in that it also has a catchment located within the Southern Hills, where rainfall is expected to be notably higher than observed at the rainfall gauges around the coast. The estimated mean annual runoff from the Tuku a Tamatea catchment, based on flows at Waitangi Tuku Road is around 903 mm/year. The closest rain gauge is located at Awamata, where the average annual rainfall is around 680 mm/year, implying that rainfall feeding the Tuku a Tamatea River must be much greater than the rainfall observed at Awamata.

In a similar manner to the Te Awainanga catchment, the estimated rainfall (likely around 1,500 mm/year to 2,000 mm/year) less potential evapotranspiration (812 mm/year) is close to the mean annual runoff for the catchment, which suggests that appreciable groundwater recharge and discharge may be limited. Reportedly springs and seeps from the fractured volcanic rock are harvested and reticulated as stock water supplies in this area, although there is no detailed information regarding these supplies.

7.3 Upper Nairn River

The upper Nairn River is also fed from the Southern Hills, however the mean annual runoff for the assessed part of the catchment is estimated at around 518 mm/year. Based on the rain gauge in the catchment, the average annual rainfall is around 840 mm/year, although higher rainfall is likely across the upper parts of the catchment. If higher rainfall across the entire catchment or in the higher parts of the catchment does occur (for example in the range 1,000 to 1,500 mm/year), it is possible that a small amount of groundwater recharge could occur in this area, allowing for potential evapotranspiration of up to 812 mm/year, although further work would be required to evaluate this. It is also important to note that the flow gauge on the Nairn is located some distance upstream from Waitangi and enters a low lying basin (including drainage from Lake Huro via Mangape Creek) before reaching the sea. The water balance therefore only refers to the upper part of the Nairn River catchment.

Some groundwater recharge could be consistent with the reported groundwater use at Waitangi, where more than one bore are used for community supply, suggesting that some form of consistent groundwater recharge is likely to occur. However, the source of that recharge is not clear as the gauge is located upstream from Waitangi and could reflect localised infiltration of fractured rock rather than any association with the Nairn River. Further investigation of the existing bore structures, groundwater behaviour, and water quality analysis could provide further information in this regard. While this may indicate a small potential groundwater resource, any groundwater use in this area, if penetrating to below sea level, would need to carefully consider the potential effect from saline intrusion.

7.4 Awamata

The Awamata catchment is the westernmost catchment draining the Southern Hills, although its catchment is smaller than the others. Average annual runoff from the catchment is estimated at around 572 mm/year, compared to the mean annual rainfall at Awamata (the closest rainfall station) of around 680 mm/year. Whilst the average rainfall across the catchment is likely to be more than 680 mm/year, it may not be as high as other catchments such as Te Awainanga and Tuku a Tamatea. Based on NIWA data (Pearce, 2016) the average annual rainfall may be closer to 1,000 mm/year to 1,500 mm/year. Allowing for potential evapotranspiration of around 812 mm/year, it is unlikely that significant groundwater recharge occurs in the area, although as noted for the above assessments, there is considerable uncertainty based on the limited information.

7.5 Tutuiri

The Tutuiri catchment is located at the northern end of the island and intercepts the basement schist geology with characteristics different to the other gauged catchments towards the south of the island. The predominant geology consists of schist, overlain with quaternary silt and peat deposits, whereas the south of the island consists of peat deposits overlying volcanic strata. The mean annual runoff estimated from flow gauging is around 311 mm/year, compared to mean rainfall of around 741 mm/year (as gauged at Tutuiri at the schist outcrop). Average annual potential evapotranspiration at the Chatham Island airport monitoring stations is around 772 mm/year (based on the record from the Chatham Islands Ews station).

The difference between the mean annual rainfall and average annual potential evapotranspiration is less than the mean annual runoff. This may imply that actual evapotranspiration is much less than the potential rate and/or that rainfall across the total catchment is greater than estimated at the gauge. If actual evapotranspiration is much less than potential evapotranspiration, some groundwater recharge could occur at times of the year in the catchment alongside the river together with some slow release of water from the peat deposits that occur within the wider catchment. The schist strata can be weathered to form some alluvial gravels (noted on the geological map) which could occur alongside the river, which could also provide some water storage. Ritson (2010) indicated that in some winter months there was less rainfall than flow in the catchment, which could be due to groundwater or other natural storage discharge. As noted for the above assessments, the magnitude of any recharge is uncertain at present and some further investigation would be prudent.

8.0 Climate Change

8.1 Available Information

Global warming and the climate change it brings are caused by the build-up of greenhouse gases in the Earth's atmosphere. As recognised in the report *'Climate Change Projections for New Zealand, Atmospheric projections based on simulations undertaken for the IPCC 5th Assessment 2nd edition' (Ministry for the Environment, 2018)* climate change effects over the next decades are predictable with some level of certainty and will vary from place to place throughout New Zealand. A description of what is likely to happen in New Zealand and on a more regional scale has been described in that report. The projected overall changes for New Zealand draw heavily on climate model simulations from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. Overall, these projected changes are similar to those from the previous assessment (Ministry for the Environment, 2008) which were based on the IPCC Fourth Assessment.

The Ministry for the Environment (MfE, 2018) report considers four scenarios for New Zealand. These pathways are known as Representative Concentration Pathways (RCPs). The four pathways are:

- A low emissions scenario (RCP2.6), where global carbon dioxide emissions stop after 2080, after which some is actually removed from the atmosphere;
- A high emissions, business as usual scenario (RCP8.5);
- Two intermediate scenarios (RCP4.5 and RCP6.0) which represent futures where global emissions stabilise at different levels.

The MfE (2018) report provides a detailed description of the climate change projections for New Zealand. In summary the key changes New Zealand is likely to experience, relevant for the Chatham Islands assessment are:

- Higher temperatures, with an increase of about 0.7 °C (low emissions scenario) and 1.0 °C (high emissions scenario) by 2040. By 2090 temperatures are projected to increase by between 0.7 °C (low emissions scenario) and 3.0 °C (high emissions scenario) and by 2110 temperatures are projected to increase by between 0.7 between (low emissions scenario) and 3.7 °C (high emissions scenario);

- A change in rainfall patterns – the overall pattern for changes in annual rainfall is a reduction in the north and east of the North Island and increases almost everywhere else, including the Chatham Islands;
- Increase in the number of hot days, and decrease in the number of frost days and snow days;
- Increased frequency and intensity of droughts over time, particularly under a high emissions scenario.

The MfE (2018) report discussed above provides climate change atmospheric projections but does not cover sea level rise. Another report from the Ministry for the Environment (2017) labelled '*A summary of coastal hazards and climate change guidance for local government'* provides sea-level rise predictions for New Zealand based on a range of scenarios. As detailed in this report, New Zealand tide records show an average rise in relative mean sea level of 1.7 mm per annum over the 20th century. Globally, the rate of rise has increased, and further rise is expected in the future.

The scenarios in the MfE (2017) report are similar but slightly different than those used for the atmospheric projections. They only include one intermediate scenario (RCP4.5) and one additional more extreme (RCP8.5) scenario is included. The four scenarios and the approximate estimated New Zealand wide regional sea-level rise projections for 2120 (relative to 1986-2005) are:

- A low emission, effective mitigation scenario (RCP2.6). This scenario is projected to results in a sea level rise of around 0.55 m by 2120.
- An intermediate–low emission scenario (RCP4.5). This scenario is projected to results in a sea level rise of around 0.68 m by 2120.
- A high emission, no mitigation scenario (RCP8.5). This scenario is projected to results in a sea level rise of around 1.05 m by 2120.
- A higher, more extreme H+ scenario, based on the RCP8.5 (83rd percentile) projections from Kopp et al (2014). This scenario is projected to results in a sea level rise of around 1.35 m by 2120.

Figure 34 illustrates the New Zealand wide sea-level rise projections for the scenarios discussed above.

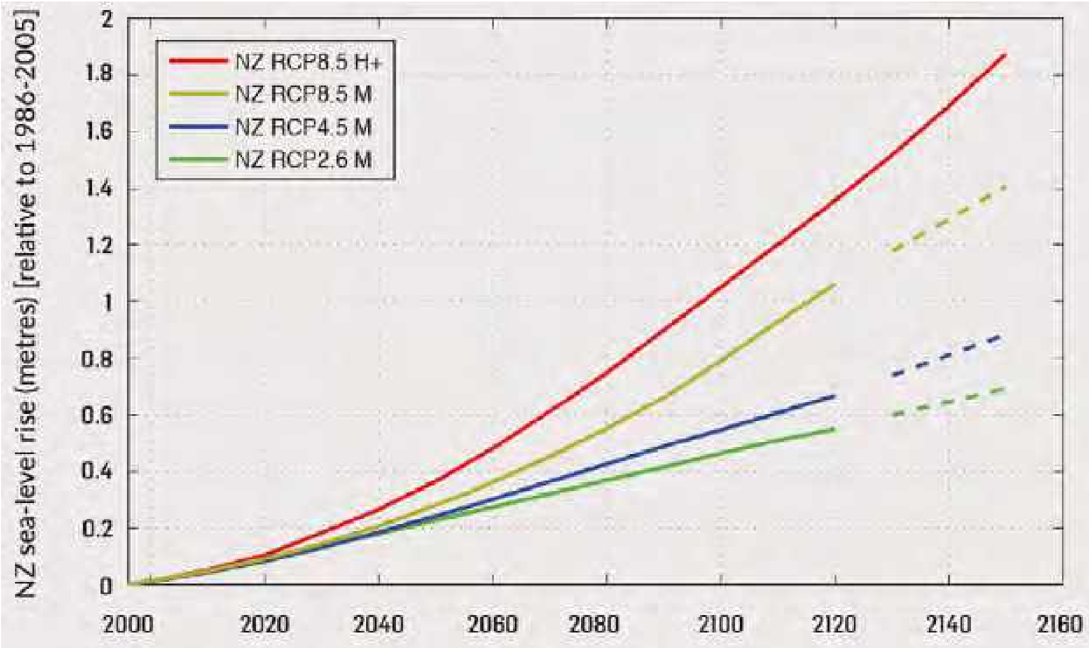


Figure 34: New Zealand sea-level rise projection scenarios (MfE, 2017)

8.2 Overview of Project Climate Change Impacts for Chatham Island

The MfE (2018) report provides specific atmospheric climate change projections for the Chatham Islands. In general, the projected changes for the Chatham Islands are similar to mainland New Zealand with increased temperatures, an increase in the number of hot days, and decrease in the number of frost days and snow days and an increase in annual rainfall.

Temperatures are likely to be 0.7°C to 1.0°C warmer by 2040 and 0.7°C to 2.8°C warmer by 2090. By 2090 the Chatham Islands are expected to experience fewer frosts and more days per year where maximum temperatures exceed 25°C.

Annual rainfall is expected to increase on the Chatham Islands. Annual rainfall is projected to increase by 2 to 3 percent in 2040 and by 4 to 6 percent in 2090. The main increase in rainfall is expected in winter and spring with increases of 4 to 6 percent in winter and 2 to 4 percent in spring for 2040. For 2090 rainfall is projected to increase 5 to 11 percent in winter and 6 to 8 percent in spring. Projected average changes in rainfall in summer and autumn are generally small.

These projected changes in temperature and rainfall are expected to have limited effect on the general annual water balance and potable water supplies on the Chatham islands. A general increase in rainfall may benefit recharge to the underlying shallow strata and peat basins and increase water levels in lakes and rivers but this may be offset in part by the increase in temperature resulting in an increase in evapotranspiration.

Although there is a projected annual increase in rainfall under climate change it is noted that it can be expected that there will be an increased frequency and intensity of extreme events, such as both floods and droughts over time, particularly under a high emissions scenario which may affect recharge to the underlying strata and/or shallow soils and peat at times.

It is noted that the volume of recharge to the underlying strata and/or shallow soils and peat on Chatham Island is considered likely to be generally small based on the differences between rainfall, potential evapotranspiration and river flows (also refer to section 7.0) so the impact of this change may be important. In addition, increased frequency and intensity of droughts is likely to affect Chatham Island residents who rely on rainwater collection tanks or localised water sources for their water supply.

The sea level rise predictions for New Zealand detailed in the MfE (2017) report are representative for the Chatham Islands. Sea-level at the Chatham Islands is projected to rise by between 0.55 m (low emissions scenario) and 1.35 m (high emissions scenario, RCP8.5 H^+) by 2120.

Although the groundwater resource in the Chatham Islands is expected to be limited based on the geological information, it is reported that groundwater bores are in use across Chatham Island, therefore a rise in sea level does have the potential to impact the resource by increasing the likelihood of saline intrusion into the water bearing strata if are likely to be connected to the coast, although more information is required to investigate this. In particular, the community supply bore at Waitangi may be at increased risk given its elevated, but coastal location. However, the rise in sea level may be offset in part by increased rainfall and increased groundwater recharge/discharge, although the relationship between these effects is not well understood for the Chatham Islands. Regardless, it would be prudent to undertake some assessment of the potential for any risk of saline intrusion at the community supply bore in Waitangi. Further information would be required to evaluate this risk.

Sea level rise scenarios may also affect (increase) the connections of coastal lakes and lagoons to the sea. In particular the opening and closing regime of Te Whanga Lagoon may be adversely affected, and opening points to the north may become a potential risk and affect roading and access to Kaingaroa.

9.0 Surface Water Quality

A central government funded contract between Environment Canterbury and the Chatham Islands Council has allowed Environment Canterbury staff to carry out surface water quality monitoring since April 2005. This monitoring resulted in a State of the Environment report in 2007 (Meredith & Croucher, 2007) which detailed the aims of the surface water quality monitoring programme, as follows:

- Characterise the range of watercourse 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; and,
- Establish a long-term monitoring programme to allow identification of trends in the water quality of freshwater resources on Chatham Island.

These were expected to provide information useful for:

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

Following on from Meredith & Croucher (2007), a series of annual water quality reports were produced, largely updating the assessment of the “state” of water resources. These did not attempt to establish long term trend assessments (ECan 2010, 2014, 2015, 2016; PDP, 2018a, 2018b).

This report details the results of water quality monitoring data from 2005 to 2019, and places these results within the wider temporal context of the available long-term monitoring data by assessing temporal trends and providing comparisons to national guideline values.

9.1 Methods

9.1.1 Sample Sites

Following an initial survey conducted in April 2005 by Meredith & Croucher (2007), 24 accessible watercourse sites, five lake sites, and four Te Whanga Lagoon sites were determined to be representative of the range of waterbodies on Chatham Island and appropriate for water quality and/or ecological sampling. Most watercourse sites were located at road crossings and culverts, while lake and Te Whanga Lagoon sites were located nearby to access points from the road and/or adjacent to stream sites.

Seven additional lake sites, one additional stream site, and one additional Te Whanga Lagoon site were added to the programme between September 2005 and June 2006. The water quality and ecology of all these sites were reported on in Meredith & Croucher (2007). All lake sites (with the exception of Lake Huro) are located on the northern half of the Island. One further stream site and one Te Whanga Lagoon site were added in October 2006 but were not reported on in Meredith & Croucher (2007).

Due to the large volume of sites being sampled initially, monitoring site numbers were reduced after the reporting by Meredith & Croucher (2007) to include 14 watercourses, five lakes, and three Te Whanga Lagoon sites (Figure 35). The refined sites were a subset of those reported on in Meredith & Croucher (2007) but included one new river (Nairn River) and one new Te Whanga Lagoon site (Southern Basin (West)).

Data analyses for the refined monitoring site programme are reported on within this section. Photographs illustrating the lake, watercourse, and Te Whanga Lagoon representative sites are included in Appendix B.

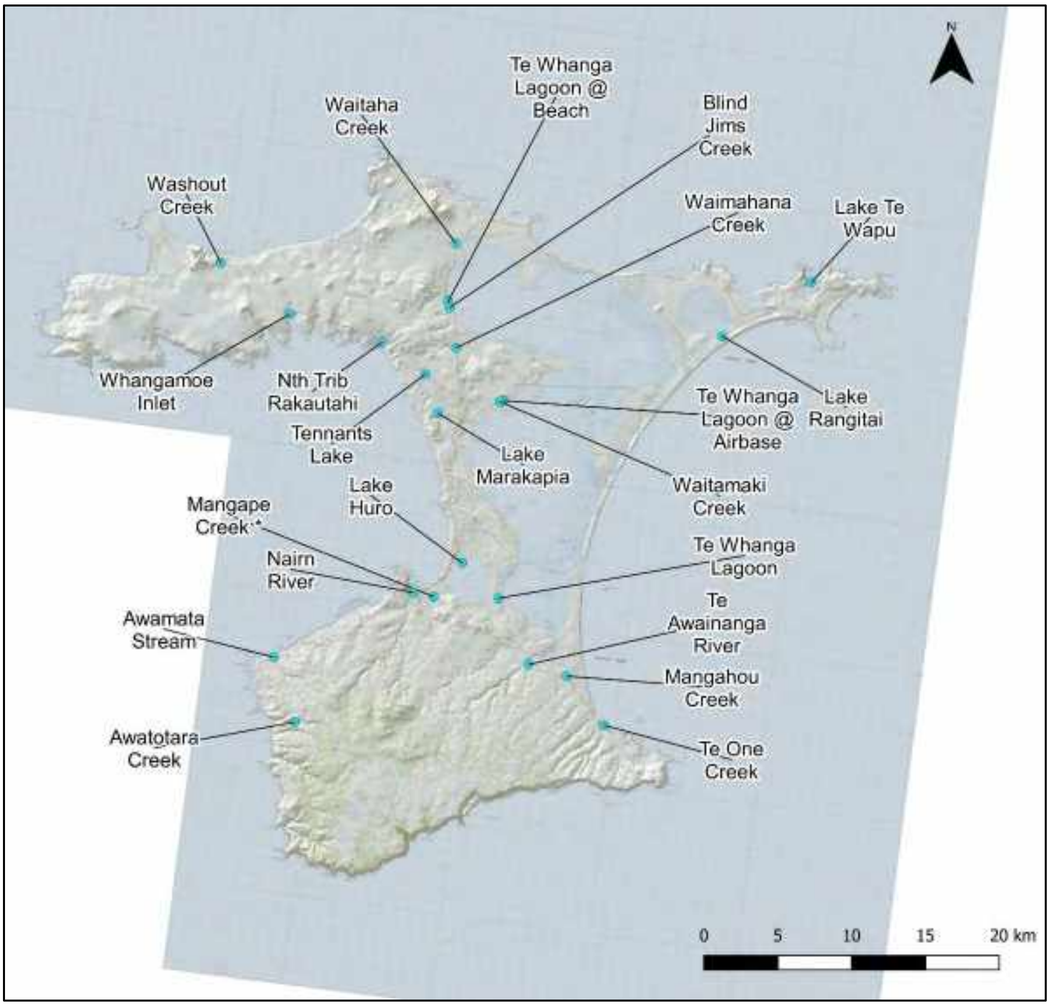


Figure 35: Chatham Island long term surface water quality monitoring sites

9.1.2 Sample Collection

Water quality monitoring was conducted approximately once every three months (quarterly) at each site between April 2005 and June 2019. Quarterly sampling was conducted initially by Environment Canterbury staff, and later by multi-purpose staff based on the island. Logistical limitations of both mainland based staff and resident multi-purpose staff availability prevented sampling more frequently than quarterly. Other alternatives will need to be explored if more frequent sampling (monthly) is considered necessary in the future. Quarterly sampling is considered the absolute minimum effective interval for categorising the likely variability and any seasonal changes in water quality. The low “power” of quarterly sampling may mean that trends may not be readily discernible until long data collection periods (i.e. 20 years) have been completed.

Samples were collected following the methods described in Meredith & Croucher (2007). The following methodology directly reflects that followed by Meredith & Croucher (2007).

Lake samples and Te Whanga Lagoon samples were collected at knee depth after wading from the shoreline, and watercourse samples were collected by bankside methods collecting samples from the middle of the channel. Sample collection methodology was standardised and consistent with the document "Procedures Manual: Chatham Island Surface Water Quality 2013" (ECan, 2013).

At each site, field observations and measurements (using field meters) were recorded for physicochemical characteristics. Water samples were collected in laboratory supplied bottles for a range of nutrient and chemical analyses. A separate sample for chlorophyll-*a* analysis was collected at lake and Te Whanga Lagoon sites. The full range of physicochemical characteristics tested is listed in Appendix C. Variation from parameters routinely tested in mainland New Zealand included additionally testing for dissolved organic carbon (DOC), to reflect the dominant role of dissolved peat substances in Chatham Island surface waters.

At the end of each collection day water samples were frozen, unless they were to be returned to mainland New Zealand on the flight the next day in which case they were stored in the dark at 4°C. Chlorophyll-*a* samples were stored unfrozen and in the dark. All chilled and frozen samples were transported directly to the laboratory at the end of each field trip. For the first few years samples were analysed at the Environment Canterbury in-house laboratory and then after this was closed, they were analysed at Hill Laboratories.

Biological sampling was conducted at 19 stream sites in April 2005. At each site a 500 µm mesh triangular mouth sweep net was used to sample transects across representative habitats (runs, riffles, pools, and margins). These frequently 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 inert material. To condense samples for storage and transport they were washed, and large quantities of plant, wood, gravel, silt and sand material were removed. 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.

9.1.3 Sample Analysis

Environment Canterbury's water quality laboratory conducted analyses on surface water quality samples for the first years of the program. When the Environment Canterbury laboratory was closed samples were analysed at Hill Laboratories. The details of the parameters analysed, laboratory analytical methods and respective detection limits is given in Appendix C.

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 (Meredith *et al*., 2003; Winterbourn & Gregson, 1989; Stark *et al.*, 2001).

9.1.4 Data Analysis

Data were analysed using a combination of Microsoft Excel and R software. Microsoft Excel was used for the initial digital input of data and basic table edits, while R was used to generate summary statistics and graphs, and to conduct multivariate and trend analysis.

Censored data (data that was recorded below laboratory detection limits) were altered prior to analysis (except trend analysis), following the method prescribed by Environment Canterbury water quality scientists. Detection limits were variable, with inconsistencies associated with changes in the analysing laboratory and laboratory methods used over time. Thus, where less than 40% of the data for a single parameter analysed per site included censored data, the absolute reading was defined as half of the reported detection limit. Where greater than 40% of data for a single parameter and site was censored, the absolute reading was defined as half on the highest detection limit reported. Where greater than 70% of data was censored, all observations for that parameter at that site were omitted from further analysis. Further justification for these alterations is presented in Ballantine (2012).

Censored data was converted to a value equal to half of the detection limit for multivariate analysis methods (i.e. cluster analysis and NMDS ordination). This treatment was applied to aid comparison between the results presented herein with those produced by Meredith & Croucher (2007).

The trophic level Index (TLI) for the past five years of data (2014-2019) was calculated for each lake following a modified version of the standard methodology for New Zealand (Burns *et al*., 2000). TLI is typically calculated following a core set of parameters (chlorophyll-*a*, total nitrogen (TN), total phosphorus (TP), and Secchi disc clarity). However, the shoreline sampling methodology did not allow for Secchi disc sampling and TLI was instead calculated from the average of the remaining three parameters. The TLI methodology also requires calculation from a year of monthly sampling.

Calculation from quarterly sampling is therefore a departure from accepted national methods.

Multivariate analysis methods were used to identify groupings amongst sites based on annual means for water quality parameters. Groupings were presented using non-metric multidimensional scaling (NMDS) and cluster diagrams. For lakes, differentiation was based on differences in pH, conductivity, water clarity, dissolved organic carbon (DOC), chlorophyll-*a*, dissolved oxygen (DO), total nitrogen (TN), total phosphorus (TP), and dissolved inorganic nitrogen (DIN). For stream/river sites, grouping/clustering of sites were determined based on differences in pH, water clarity, conductivity, DOC, DO, TN, TP, DIN, ammoniacal nitrogen, nitrate-nitrite nitrogen, and Dissolved Reactive Phosphorus (DRP). These parameters were selected as they closely resemble those selected by Meredith & Croucher (2007), allowing for meaningful comparisons between reports, while retaining a large dataset. Multivariate analysis could not be conducted on the Nairn River site due to insufficient data.

Parameters were plotted and transformations were applied to those for which outliers were observed and able to be corrected. Log (ln) transformations were applied to conductivity, DOC, chlorophyll-*a*, and TP to reduce the impact of observed right-skewed outliers, while a cube-root transformation was applied to pH to reduce the impact of left-skewed outliers within the lake site data. For watercourse sites, log transformations were applied to conductivity, TN, TP, DIN, ammoniacal nitrogen, nitrate-nitrite nitrogen, and DRP values, while square-root and cube transformations were applied to DOC and DO values, respectively. Values were then normalised (scaled). A similarity matrix was produced based on Euclidean distance measurements. From this, two-dimensional NMDS plots and cluster diagrams were generated.

Interpretation of NMDS ordination plots is determined by the relative distance between points representing observations/sites on the plot. The ‘stress’ value generated following NMDS ordination indicates how accurate the plotted points are, compared to the true distribution of the data (the ‘goodness of fit’). A stress value around or above 0.2 indicates a ‘poor’ fit, below 0.1 indicates a ‘fair’ fit, below 0.05 indicates a ‘good’ fit, while a stress value of 0 would imply a ‘perfect’ fit (Kruskal, 1964).

Trend analysis was conducted using the LWP-Trends library functions (2020 update), produced for use in R by Land Water People Ltd (LWP) (Snelder & Fraser, 2018). These functions build on the Mann-Kendall and Seasonal Kendall tests used in the widely employed TimeTrends software (Jowett, 2009), which are used to establish temporal trends in water chemistry. Scatterplots of long term data were also scrutinised to ensure there were no complex patterns that may not be readily explained by simple trend analysis. Site and variable combinations were restricted to those for which there were measurements for at least 90% of the years and 90% of the seasons within the respective time period (Larned *et* *al*., 2016). In order to maximise the number of site and water quality parameters analysed following these criteria, data from the most recent monitoring year (2019) was excluded from analysis as it did not include the full monitoring year. Temporal trends were established for each site and parameter combination for five, ten, and fourteen-year assessment periods up to the end of 2018.

Observed trends were categorised as being 'significant' or 'probable' based on the following criteria, as described in State of the Environment – Surface Water Quality in Otago 2006-2017 (Otago Regional Council, 2017):

- Should the Kendall statistic P-value be <0.05; the probability that the sen slope is less than or greater than zero be 0.95-1; and the percent annual change in sen slope be >1%; label "Significant".
- Should the Kendall statistic P-value be 0.05-0.10; the probability that the sen slope is less than or greater than zero be 0.9-0.95; and the percent annual change in sen slope be >1%; label "Probable".
- Where the P-value is >0.10 and the probability is >0.5 but less than 0.9, and the trend is obviously not stable over time; and the analysis is limited by power, label "Indeterminate". In this case, a trend is likely present; however, the limited dataset does not allow this to be determined with confidence. A trend may be determined over a longer time period.
- Where the P-value is ~1; the probability ~0.5; and the sen slope ~ 0; label "Stable". This indicates that there is no trend in the data apart from seasonal variation, and that the overall trend is flat or 'stable' over time.
- Where there is not enough data to complete trend analysis; for example, when a large proportion of the values were censored (data has <5 non-censored values and/or <3 unique non-censored values), or when there is no, or very little variation in the data (<3 unique non-censored values, or a long run of identical values); label "Detection limit".

Trend categories and associated symbols are presented in Table 8.

Table 8: Trend analysis categories and associated symbols

Symbol	Description
↑↑	Significantly Increasing
↓↓	Significantly Decreasing
↑	Probably Increasing
↓	Probably Decreasing
↔	Stable

Table 8: Trend analysis categories and associated symbols

Symbol	Description
?	Indeterminant
DL	Detection limit

9.2 Results - Lakes

Median annual results from water quality monitoring across all sites and monitoring years are presented in Appendix D. Long term data is presented in this section, summary analysis of additional data collected are provided in Appendix E.

A total of five lake sites were monitored between April 2005 and June 2019 (Table 9). Lakes were sampled approximately quarterly throughout this period; however, the full suite of physicochemical parameters was not collected consistently per sampling occasion.

Physical characteristics and general observations made for each lake are presented in Table 9. Results from trophic level index (TLI) analysis are presented in Table 10 and Table 11.

Table 9: General description of physical characteristics of monitored lakes and surrounding land-use

Reference ID	Lake	Max depth (m)	Area (ha)	Sediment type	Surrounding land use
LH	Lake Huro	0.3	598	Sand, peat margin	Pastoral farming
LM	Lake Marakapia	2.5	36	Sand, organic mud margin	Pastoral farming
LR	Lake Rangitai	1.3	867	Sand, peat margin	Pastoral farming
TW	Lake Te Wapu	0.5	34	Sand	Rubbish dump, native forest/scrub,

Table 9: General description of physical characteristics of monitored lakes and surrounding land-use

Reference ID	Lake	Max depth (m)	Area (ha)	Sediment type	Surrounding land use
					pastoral farming
LT	Tennants Lake	4	50	Sand	Pastoral farming

Notes:
Description of lake physical properties are based on Meredith & Croucher (2007) and Champion and Clayton (2000) and may be subject to change.

9.2.1 General Lake Water Quality – Long term

Between 2005 and 2019, there was a high degree of variation reflected in the water quality parameters assessed amongst monitored Chatham Island lakes (Figures 37). Median conductivity ranged between 56.9 (Tennants Lake) and 568.85 ms/m (Lake Te Wapu). Most of these lakes are minimally influenced by seawater, as indicated by low conductivity readings, although higher conductivity readings at Lake Te Wapu are indicative of the intermittent connection between this site and the sea (i.e. seawater is approximately equal to 5,150 ms/m).

All monitored lakes were slightly alkaline, with median pH ranging between 8.3 and 8.55 (Figures 37 Figure 36). Water clarity tube readings ranged between 18 and 100+ cm. The highest water clarity was recorded at the dune lakes (Tennants Lake, Lake Rangitai, and Lake Marakapia), while lowest water clarity was at the peat lakes (Lakes Te Wapu and Huro) which averaged 38 and 18 cm, respectively. The lower median water clarity at Lakes Te Wapu and Huro coincided with markedly higher chlorophyll *a* concentrations at these sites (5.95 and 17.85 µg/L, respectively), indicative of either suspended organic particles (peat), planktonic algal blooms, or both. The dune lakes (Tennants Lake, Lake Rangitai, and Lake Marakapia) had consistently low median chlorophyll *a* concentrations (0.75, 0.80 and 0.95 µg/L, respectively).

Median DOC concentrations ranged between 11.8 (Tennants Lake) and 38 mg/L (Lake Te Wapu) (Figure 37). Previous SOE reporting indicated that many of the Chatham Island lakes were highly peat stained, and Lake Te Wapu in particular has peat-stained water and significant stock access to the only inflowing streams (Meredith & Croucher, 2007). Elevated DOC concentrations at this site are therefore not surprising.

Median DO concentrations were high, ranging between 9.7 and 10.6 mg/L, while median temperatures ranged between 13.7 and 14.9°C (Figure 37). Median DO saturation was expectedly high with little variation amongst the Chatham Island Lake sites sampled, ranging between 97 and 101%.

Comparisons to national guideline levels are provided in the short-term trends section (section 9.2.5).

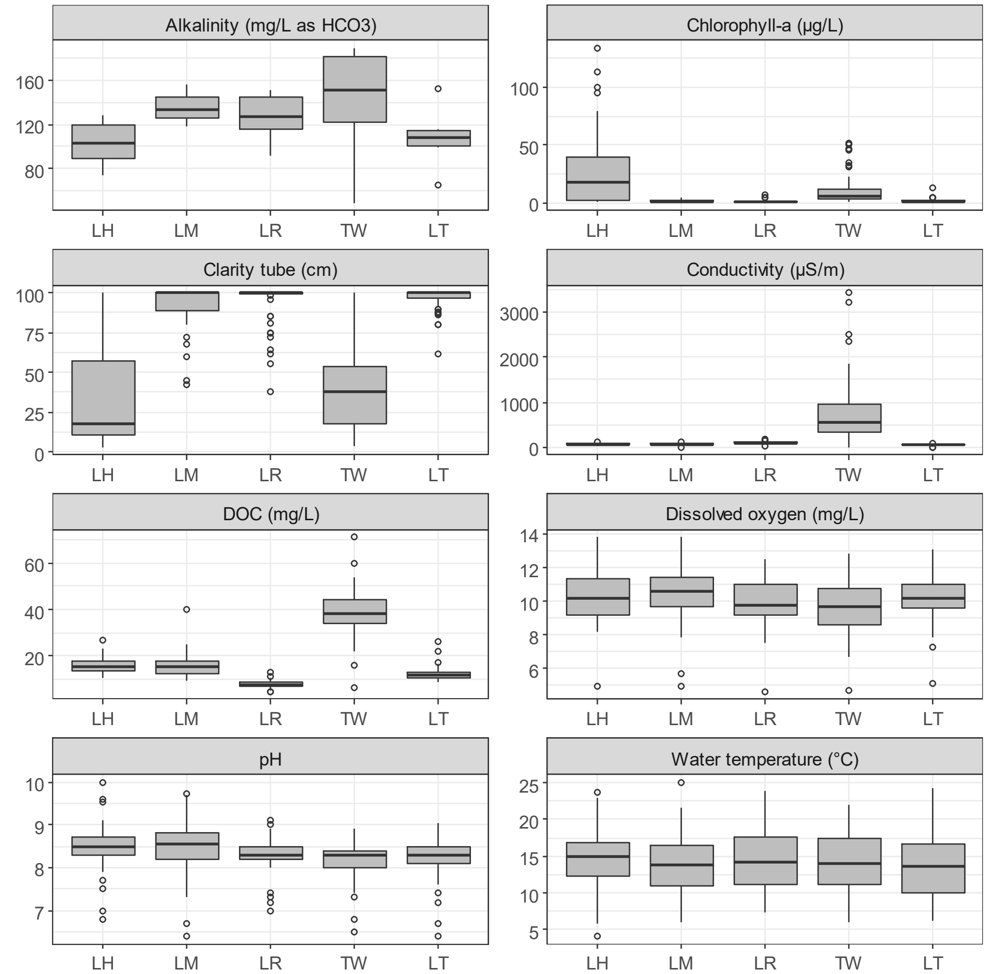


Figure 36: Summary of physicochemical water quality data collected from five Chatham Island lake sites between 2005 and 2019

9.2.2 Lake Nutrient Concentration – Long-term

Summary nutrient concentration for each lake site between 2005 and 2019 is presented in Figure 37. Total organic nitrogen (TON) was calculated as DIN subtracted from TN. DRP is not included in this figure as data was limited for all sites (censored data) but Lake Huro, which shows that the DRP component of total phosphorus at this site is small (9%), DRP data can been seen in the summary tables and figures presented in Appendices D and F.

Peat Lakes Huro and Te Wapu show the lowest median clarity of all monitored lakes, associated with elevated chlorophyll-*a* and DOC concentrations, respectively. While the Dune Lakes are represented by much higher water clarity, as well as low conductivity and DOC levels. Further, more detailed descriptions of these parameters by site is provided in the short-term nutrient section.

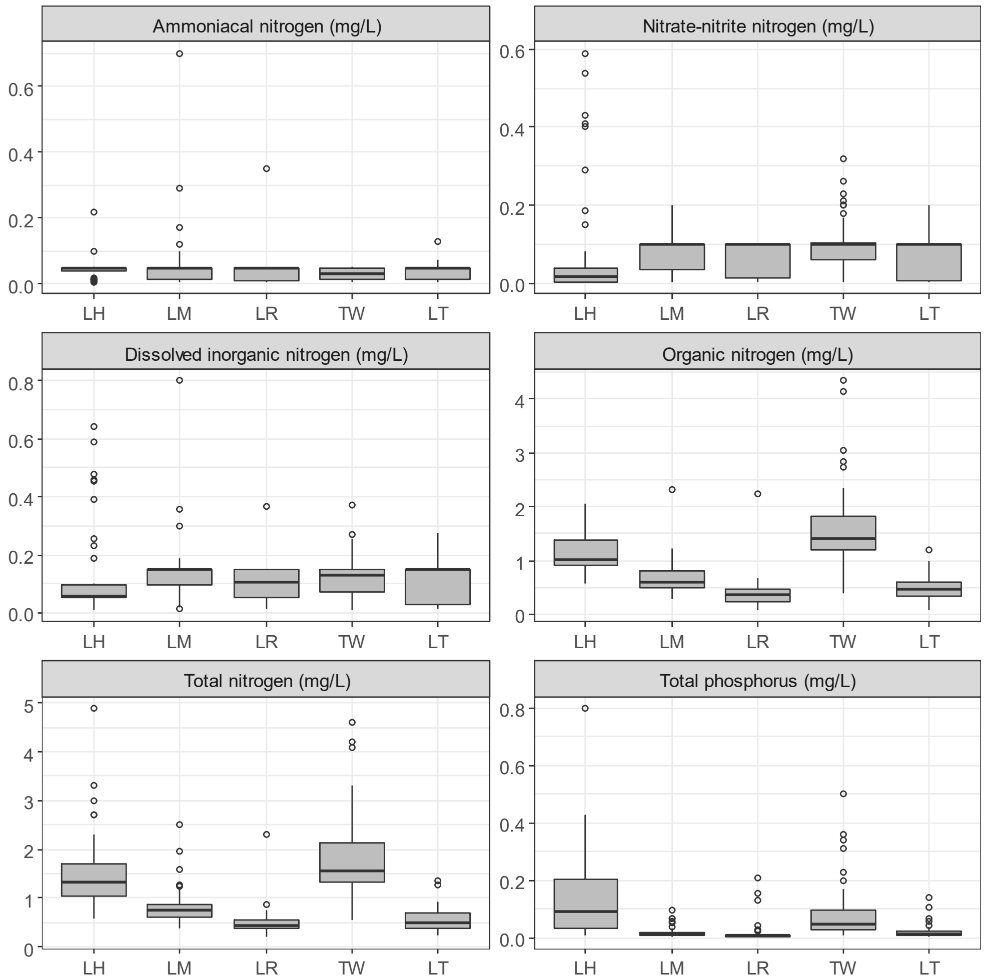


Figure 37: Summary of water quality (nutrient) data collected from five Chatham Island lake sites between 2005 and 2019

9.2.3 Lake Trophic Status and Nutrient Limitation

Trophic Level Index

Lake phytoplankton are dependent on dissolved inorganic nutrients for growth and reproduction, while macrophyte communities can utilise both nutrients in the sediments, and dissolved inorganic nutrients. As the abundance of these nutrients increase within the lake ecosystem, so can the rate of phytoplankton and macrophyte growth. Nutrient enriched lakes can support large populations of aquatic macrophytes, which can lead to negative ecosystem-scale consequences due to diurnal hypoxia and pH swings (i.e. following plant respiration and decomposition), or of planktonic algae, which can cause decreased visual clarity and possibly oxygen depletion upon decomposition. In Chatham Island lakes, planktonic algae are the primary management issue. Other factors are direct toxicity effects of nutrient enrichment (i.e. fish kills following ammonia or nitrate toxicity). Dissolved nitrogen and phosphorus concentrations, and the ratios in which they are present, are predominantly the limiting nutrients in lake ecosystems, unless there are dominant heterotrophic communities present. Heterotrophic communities can utilise organic carbon, and reduced compounds such as iron, manganese, sulphur and carbon as energy sources.

Lake Te Wapu had the highest five year mean concentrations across the three lake trophic status parameters (chlorophyll-*a*, TN and TP; Table 10), with TN in the hypertrophic range, TP in the supertrophic range and chlorophyll-*a* in the eutrophic range. Lake Te Wapu also scored high in comparison to the other lakes, with TN in the supertrophic range and chlorophyll-*a* and TP in the eutrophic range.

Five year mean TN for Tennants Lake and Lake Marakapia were in the supertrophic range, with Lake Rangitai in the eutrophic range for TN. Mean TP for these three sites were all within the mesotrophic range. Chlorophyll-*a* was within the oligotrophic ranking for Lake Marakapia and Tennants Lake, with Lake Rangitai within the microtrophic range.

The discontinuity across trophic status parameters is likely indicative of nutrient limitation (particularly phosphorus) or low nutrient availability if the nutrients are unavailable and are bound in peat material.

Table 10: Mean 5-year (2014- 2019) lake trophic level grades sorted by mean chlorophyll-*a* (Chl-*a*), total nitrogen (TN), and total phosphorus (TP)

Lake	Chl- *a* (mg/m^3)	TN (g/m^3)	TP (g/m^3)
Lake Te Wapu	8.25	1.79	0.065
Lake Huro	5.05	1.22	0.039
Lake Marakapia	1.44	1.05	0.015
Tennants Lake	1.32	0.73	0.018
Lake Rangitai	0.72	0.50	0.013

Table 10: Mean 5-year (2014- 2019) lake trophic level grades sorted by mean chlorophyll-*a* (Chl-*a*), total nitrogen (TN), and total phosphorus (TP)

Notes:
Brown = hypertrophic; grey = supertrophic; red = eutrophic; yellow = mesotrophic; green = oligotrophic; blue = microtrophic

The lake trophic level indices and index (TLI) provides a description of overall trophic status based on logarithmic regression-based indices of nitrogen and phosphorus concentrations, phytoplankton density (chlorophyll-*a*), and Secchi depth. Indices are calculated for each parameter and averaged to formulate an overall TLI value (Burns *et al*., 2000). As water quality data is collected at these sites quarterly, not monthly, an average five year TLI was calculated. Annual TLI states for each site are calculated in PDP 2018 and show interannual variation at most sites.

Individual calculated indices for each parameter and overall lake TLI values are presented in Table 11. Note that Secchi depth was not measured during the monitoring of these lakes and was therefore not included in the TLI calculation. As Secchi depth can be influenced by parameters unrelated to nutrient enrichment (such as low visual clarity unrelated to phytoplankton growth), TLI calculation based on three parameters only is not uncommon in New Zealand and should provide a reasonable comparison of lake trophic status amongst the Chatham Island lakes.

Table 11: 5-year trophic level indices and overall trophic level index (TLI)

Lake	TLc[1]	TLn[2]	TLp[3]	Overall TLI
Lake Te Wapu	4.55	6.18	5.52	5.41
Lake Huro	4.01	5.68	4.85	4.84
Lake Marakapia	2.62	5.48	3.65	3.92
Tennants Lake	2.52	5.00	3.91	3.81
Lake Rangitai	1.85	4.52	3.46	3.28

Notes:
1. *Trophic level – chlorophyll-a*
2. *Trophic level – nitrogen*
3. *Trophic level - phosphorus*

Brown = hypertrophic (6.0-7.0); grey = supertrophic (5.0-6.0); red = eutrophic (4.0-5.0); yellow = mesotrophic (3.0-4.0); green = oligotrophic (2.0-3.0); blue = microtrophic (1.0-2.0)

Lake TLI values in Table 11indicate that the Peat Lakes Te Wapu and Huro represent a higher average trophic status (supertrophic and eutrophic, respectively), when compared to the Dune Lakes Marakapia, Rangitai, and Tennants Lake (mesotrophic).

A previous report indicated a high occurrence of algal blooms in Lakes Huro and Te Wapu, where Lake Huro was described as having 'persistent year-round algal blooms' (Meredith & Croucher, 2007). The current five year average TLI for Lake Huro of eutrophic (green and murky, with high amounts of nutrients and algae) represents an improvement from previous TLIs of hypertrophic (saturated in nutrients, excessive algae growth) and annual TLIs show a general improving trend over time (PDP, 2018). The five-year average TLI state for Lake Te Wapu of supertrophic (very high nutrient enrichment) is similar to that previously measured (Meredith & Croucher, 2017; PDP, 2018). Annual TLIs show interannual variation for this site ranging from eutrophic to hypertrophic associated with variable conditions in the lake.

Lake Marakapia shows an improvement from eutrophic in the 2007 report (Meredith & Croucher, 2007) to mesotrophic, with minimal interannual variation indicating a stable system with moderate levels of nutrients and algae. Overall, Lake Rangitai and Tennants Lake have both remained in the mesotrophic state, with some interannual variation in Lake Rangitai, indicting an oligotrophic state (clear with low levels of nutrients and algae) for some years (PDP, 2018).

Lakes were also assessed to determine their respective degree of potential nutrient limitation. Both nitrogen and phosphorus nutrients are fundamental requirements for plant growth, therefore the ratio of these nutrients can indicate if one is limiting for plant growth. This can be analysed for either total nutrients (TN:TP) - that reflect the total nutrient pools within the lake (which can be reflective of the nutrients contained with phytoplankton biomass), or as soluble nutrients (DIN:DRP) - that reflect the quantity and therefore ratio of soluble nutrients available for stimulating additional plant growth. When concentrations of one growth limiting nutrient (i.e. nitrogen) are high, the ratio of nutrients in the environment can differ from the uptake ratio of the plant, and plant growth is limited by the availability of the less abundant nutrients. As soluble phosphorus records are limited for the lake sites, DIN:TP ratios have been analysed to provide a more meaningful interpretation of nutrient limitation in the lakes. DIN:TP ratios have been shown to be a better indicator than TN:TP ratio for nitrogen and phosphorus limitation of phytoplankton (Bergström, 2010).

Table 12 presents both the total and soluble nutrient ratios for the monitored Chatham Island lakes for the five-year period of 2014-2019.

Table 12: 5-year (2014-2019) median lake TN:TP and DIN:TP ratios ranked and grouped by nutrient limitation category

Lake	TN (mg/L)	TP (mg/L)	TN:TP
Lake Te Wapu	1.55	0.03	47.69
Lake Huro	1.03	0.02	44.04
Lake Marakapia	0.86	0.01	61.79
Tennants Lake	0.69	0.01	57.50
Lake Rangitai	0.39	0.01	71.82
Lake	**DIN (mg/L)**	**TP (mg/L)**	**DIN:TP[1]**
Lake Te Wapu	0.14	0.03	4.14
Lake Huro	0.06	0.02	2.55
Lake Marakapia	0.15[1]	0.01	10.71
Tennants Lake	0.15[1]	0.01	12.50
Lake Rangitai	0.15[1]	0.01	27.27

Notes:
TN:TP ratio - P limited >20; N/P co-limited 10-20; N limited <10
DIN:TP ratio - P limited >3.4; N/P co-limited 1.5 – 3.4; N limited <1.5

1. *Values represent censored data and potentially under-represent DIN limitation*
2. *TN:TP limitation thresholds are sourced from Croucher &Meredith (2007) for direct comparison. DIN:TP thresholds are sourced from Bergström, 2010*

TN:TP ratios indicate phosphorus limitation occurs at each of the five sites; however, TN concentrations were much higher than corresponding DIN concentrations (Table 12), reflecting that TN concentrations are mostly made up of organic nitrogen (TON) stored within phytoplankton biomass or peat materials, instead of soluble nitrogen (DIN) available for plant uptake. For comparison, DIN only corresponded to 4.9% of the TN available at Lake Huro, 7.5% at Lake Te Wapu and 14-30–% at the remaining three lakes.

The DIN:TP ratios, which indicate the more bioavailable nutrients, are similar to the total ratio, with four of five lakes phosphorus limited. Lake Huro is co-limited by both nitrogen and phosphorus, or limited by other factors (e.g. light availability).

9.2.4 Grouping by Lake Type

Chatham Island lakes fall under groupings based on relative differences and similarities in water chemistry. A cluster diagram and NMDS plot, illustrating the relative differences and similarities amongst monitored lake sites, were produced based upon measurements of pH, conductivity, water clarity, DOC, chlorophyll-*a*, dissolved oxygen (DO), TN, TP, and DIN. These multivariate methods allow for relative intra-site water chemistry comparisons between sampling dates and inter-site comparisons between lakes. Cluster analysis indicated that there were four major groupings; these groupings are presented within the cluster diagram and NMDS plot (Figure 38; Figure 39).

Lakes Huro and Te Wapu generally formed two distinct groupings (cluster 1 and cluster 2, respectively), indicating that water quality at these sites had little cross-over with the other lake sites. In addition to them being peat lakes, the separate grouping of these two lakes was largely determined by distinctively high TN and TP concentrations, as well as low water clarity, high chlorophyll-*a* or DOC concentrations.

The remaining dune lake sites generally formed the third cluster, with the positioning of points indicating a high degree of crossover between sites related to high water clarity. Single points from Lake Huro (2019) and Lake Marakapia (2017) formed the fourth group. These points within the fourth group were highly distinct from the other points within their respective lake sites, indicating atypical water quality on these sampling occasions including high conductivity and DOC at Lake Huro in 2019 and increased nutrient and lower DO at Lake Marakapia in 2017, which may be related to recent droughts.

Overall, the lakes on Chatham Island cluster together dependant on the type of lake (dune or peat). This is not surprising due to the low number of lake sites analysed (five) and given their morphological and topographical similarities (all shallow, low altitude, and within similar landscape and climate conditions).

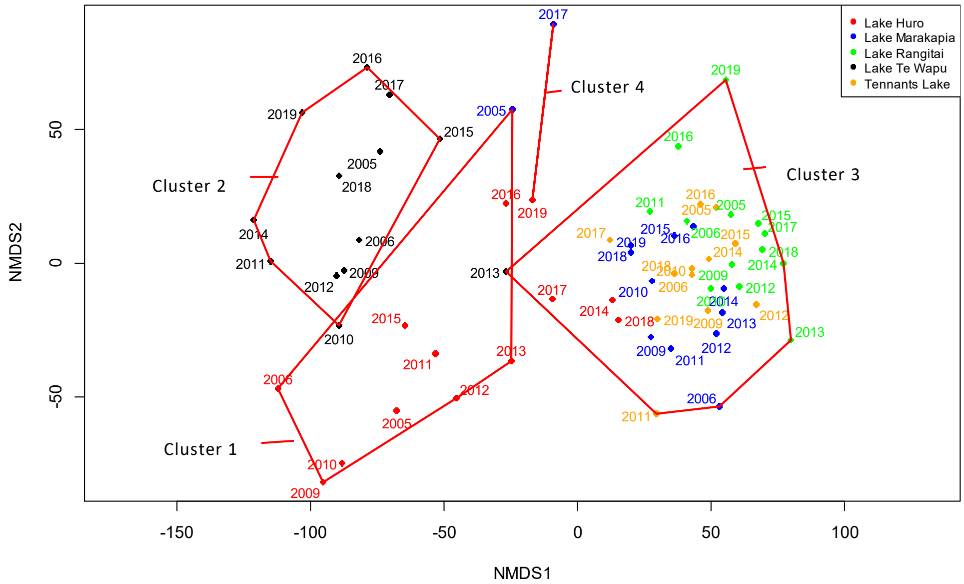


Figure 38: Non-metric multidimensional scaling plot (NMDS) representing relative similarities in water chemistry between and within Chatham Island lakes over time

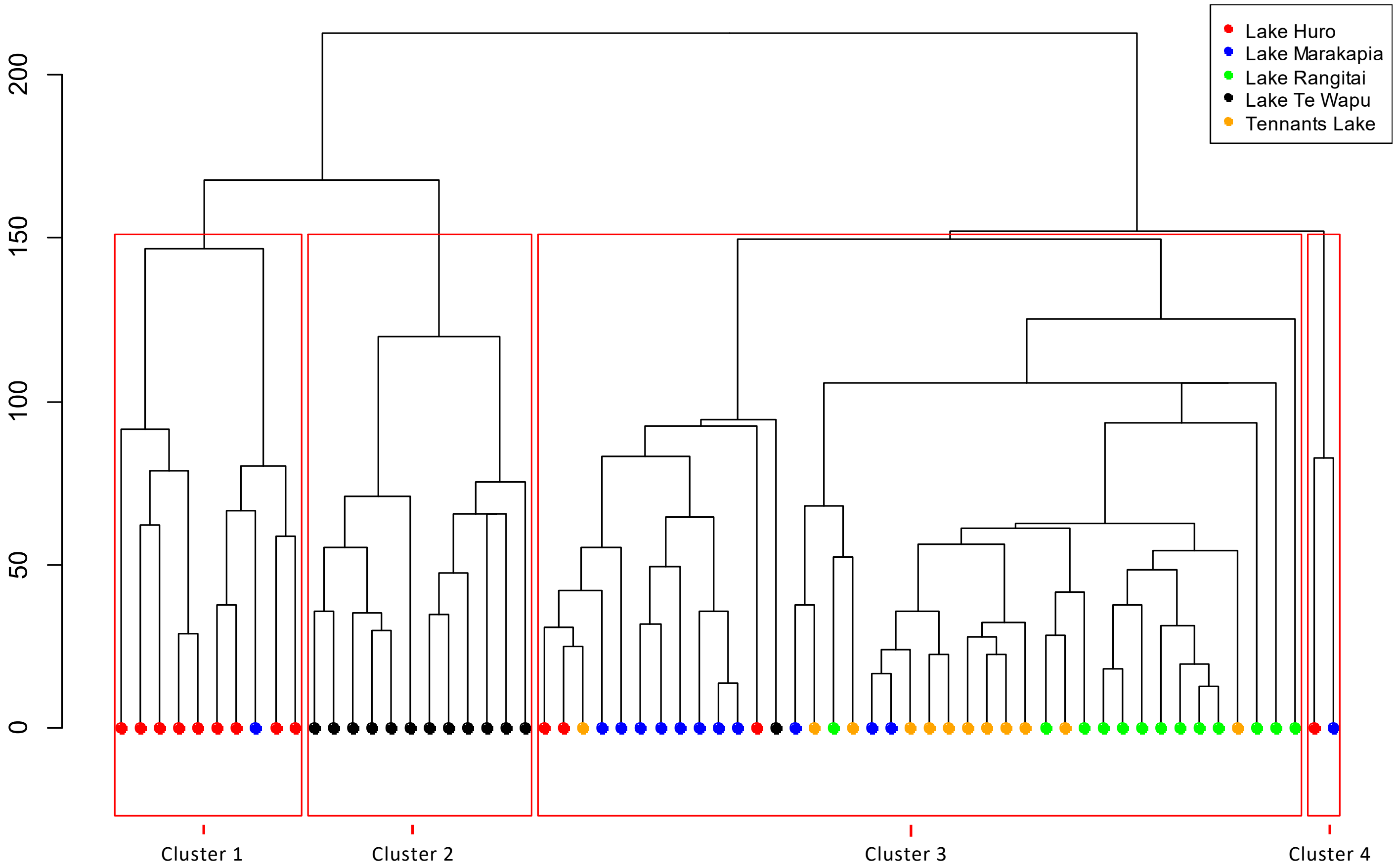


Figure 39: Cluster analysis dendrogram showing grouping of replicate samples at different similarity levels (Y axis) from all lake monitoring sites on Chatham Island based on water quality characteristics. Red boxes indicate defined clusters

9.2.5 General Lake Water Quality – Short-term Status and Trends

The five most recent full monitoring years (2014-2018) represent the current state of lake water quality on Chatham Island. Summarised data for a range of water quality parameters are presented in Figure 40 and comparisons between 'current state' water quality and New Zealand water quality policy attributes (i.e. NPS-FM (2017) and the proposed NPS-FM (2019)) are provided in the subsections below.

Where feasible, seasonal and non-seasonal Mann Kendall tests for correlation (trend analysis) were also conducted, establishing to what extent average physicochemical water quality parameters changed during the 2005-2018, 2009-2018, and 2014-2018 monitoring periods (Table 13).

Trend analysis

Temporal trend analysis was limited by a number of factors, primarily relating to the availability of quarterly data and the influence of censored values on analysis (see Section 9.1.4 for further detail). Observable directional trends across many site-variable combinations could therefore not be established statistically with confidence. Indeterminant trends, and trends that were not analysed due to data deficiency are not described in detail below; however, scatterplots presenting the temporal variability of reported water quality parameters across all survey sites are presented in Appendix F.

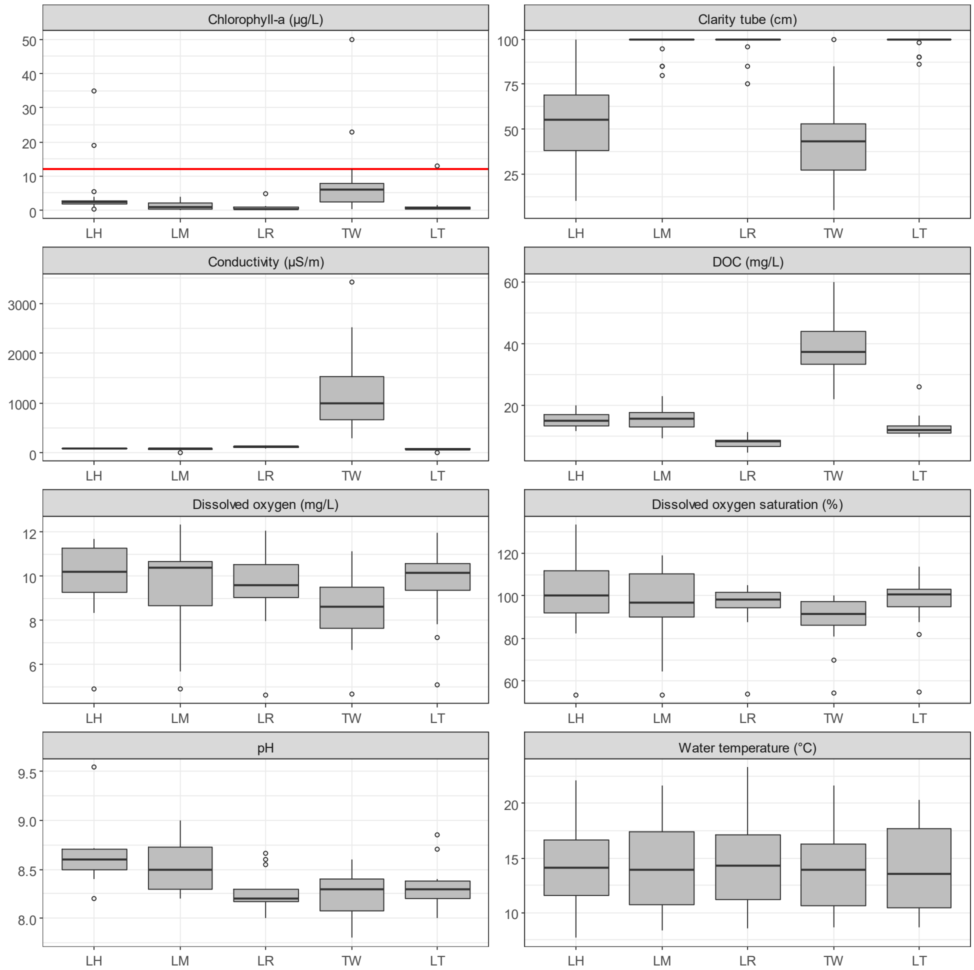


Figure 40: Summary of physicochemical water quality data at five monitored Chatham Island lake sites during the 2014-2018 monitoring period. Horizontal red line represents NPS-FM (2017) national 'bottom-line' value (annual median chlorophyll-*a*).

Summarised results following these analyses are presented in Table 13. Results from trend analysis were not presented if yielding fewer than one meaningful result (i.e. categorised as 'Significant' or 'Probable') for a respective site, variable, and year combination.

Table 13: Summary trend analysis on physicochemical parameters across lake sites (5 year, 10 year and 14 year trends)

	Temperature (°C)			DO (mg/L)			pH			Conductivity (µS/m)			Clarity tube (cm)			DOC (mg/L)			Chl-*a* (µg/L)		
Trend (years)	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year
Lake Huro	-	?	-	-	-	-	?	-	-	-	-	-	-	↑↑ 4.64	-	?	?	?	?	↓↓ 2.19	↓↓ 3.36
Lake Marakapia	↔	?	-	?	↓↓ 0.13	-	?	?	-	-	-	-	↓↓ 1.33	?	-	↑↑ 1.46	?	?	?	?	?
Lake Rangitai	?	-	-	?	-	-	?	-	-	-	-	-	-	-	-	?	-	-	DL	-	-
Lake Te Wapu	?	?	?	↔	↓↓ 0.28	-	?	↔	?	-	↑↑ 127	-	?	?	-	?	?	?	?	?	?
Tennants Lake	?	?	?	?	?	↔	?	↔	?	↑↑ 4.68	↑↑ 3.17	↑↑ 2.5	↓↓ 2.7	↔	-	?	-	-	?	?	?

Notes:

↑↑ = 'Significantly Increasing; ↓↓ = 'Significantly Decreasing''; ↑ = 'Probably Increasing'; ↓ = 'Probably Decreasing'; ↔ = 'Stable'; '?' = 'Indeterminant'; 'DL' indicates too few values were above minimum detection level to complete analysis; '-' indicates that too few data points were available to complete analysis.

***Green** colour coding = 'improving' water quality trend; **red** = 'degrading' water quality trend*

Lake Temperature

Median water temperatures were relatively consistent amongst the monitored Chatham Island lakes during the 2014-2018 period. Median temperature ranged between 13.6°C at Tennants Lake and 14.3°C at Lake Rangitai (Figure 40). In contrast, peak (95th percentile) temperatures were considerably higher and slightly more variable, ranging between 20.2°C at Lake Te Wapu and 21.5°C at Lake Marakapia.

Dissolved Oxygen (DO)

DO concentrations are influenced by a number of biotic and abiotic factors; for example, concentrations remain saturated in turbulent lake waters, but can fluctuate diurnally due to photosynthesis and respiration processes and can become depleted due to the biological breakdown of organic materials. Layering or stratification processes can also affect dissolved oxygen concentrations. For lakes located within peat basin catchments, peat waters can be highly organic and either contribute anoxic water or water with high biological oxygen demand (BOD) to the lakes. Additionally, where pastoral agriculture is the dominant land-use practice, organic pollution from agricultural sources (i.e. cattle excreta, and wash off of soil and attached nutrients) can depress oxygen concentrations.

Median surface DO concentrations were above 9 mg/L amongst all the long term monitored Chatham Island lakes, indicating that these sites are capable of supporting a diverse range of aquatic life in their surface waters. Median DO concentrations were high or close to saturation for Lake Marakapia (10.39 mg/L), Lake Huro (10.2 mg/L), Tennants Lake (10.15 mg/L), Lake Rangitai (9.6 mg/L), and were notably lower at Lake Te Wapu (8.6 mg/L) (Figure 36). In contrast, minimum DO concentrations over this period were much lower in all lakes, reaching 4.62 mg/L at Lake Rangitai, 4.66 mg/L at Lake Te Wapu, 4.91 mg/L at Lake Huro, 4.92 mg/L at Lake Marakapia, and 5.1 mg/L at Tennants Lake. At these minimum DO levels, it is likely that the resident aquatic communities amongst all monitored lakes will be highly stressed, and there is a risk of sensitive invertebrate and fish taxa being lost.

Trend analysis for the 2009-2018 period indicated that median annual DO concentrations have been declining by 0.28 and 0.13 mg/L per annum at lakes Te Wapu and Marakapia, respectively (Table 13). This analysis also indicated that DO concentrations have been stable at Tennants Lake and Lake Te Wapu over the previous 14 and five years, respectively.

pH

Median pH was variable amongst lake water quality monitoring sites during the 2014-2018 monitoring period (Figure 40). All lakes presented consistently alkaline pH values which was surprising in a peat dominated environment where peat environments are expected to be more acidic. This must be a unique feature of the specific peats of Chatham Island (Dracophyllum peats). Lakes Huro and Marakapia had slightly higher median values (pH 8.6 and 8.5, respectively) than Lakes Rangitai and Te Wapu and Tennants Lake (pH 8.2, 8.3, and 8.3, respectively), but these are all remarkably similar.

pH values were similarly variable at sites over time; Lake Huro was most variable, fluctuating between pH 9.5 and 8.2, followed by Tennants Lake (pH 8-8.85), Lakes Marakapia and Te Wapu equally (pH 8.2-9 and 7.8-8.6, respectively), and Lake Rangitai (pH 8-8.66). These fluctuating alkaline values may reflect the effects of diurnal variations in algal respiration/photosynthesis, particularly in lakes like Huro with consistent algal blooms.

Conductivity

Water conductivity is a measure of its capability to pass electrical current. This is directly related to the concentration of ions in the water, which can be strongly influenced by both natural and anthropogenic processes such as salinity, geology, and organic pollution, respectively.

Median conductivity was moderate amongst the monitored Chatham Island lakes during the 2014-2018 monitoring period, ranging between 70 and 119.8 µS/m (Tennants Lake and Lake Rangitai, respectively; Figure 40). However, median conductivity recorded from Lake Te Wapu was very high at 985.3 µS/m. Peak (95th percentile) conductivity values followed a similar pattern, typically with low values ranging between 84.5 and 154.5 µS/m (Tennants Lake and Lake Rangitai, respectively). The peak (95th percentile) conductivity measurement for Lake Te Wapu was 2700.2 µS/m, representing an 18-fold higher value compared to the next highest median level at Lake Rangitai. This equates to a value over 50% seawater concentration.

Trend analysis derived meaningful trends in conductivity for Lake Te Wapu and Tennants Lake (Table 13). Results for the 2009-2018 period indicate that conductivity levels at Lake Te Wapu increased during this period, with an average increase of 127 µS/m per annum, likely related to saltwater intrusion. Conductivity levels at Tennants Lake also produced an increasing trend across all analysed monitoring periods. Increases in trend slope for Tennants Lake across the reported monitoring periods indicate that in recent years, sources of ions in this lake environment have been increasing. It is unclear what the source of this increasing ion concentration could be, but it could be related to anything from agricultural contaminants through to increased wind driven sea salt spray.

Lake Colour and Clarity

Observed water colour at the Chatham Island lake sites between 2014-2018 varied between clear, coffee, red/brown, and green. Coffee and red/brown colouration is derived from interactions between lake water and peat materials, which are known to have a concentration of reduced and leachable organic carbon (Meredith & Croucher, 2007), while green colouration is likely indicative of high phytoplankton concentrations.

Lake Huro was most frequently reported as having clear water (75% of occasions), with occasional reports of coffee, red/brown, and green colouration (12.5, 6.25, and 6.25% of occasions, respectively). Lake Rangitai, Tennants Lake, and Lake Marakapia also most often had clear water 70, 66.7, and 63.2% of the time, respectively). Tennants Lake was otherwise dominated by observations of coffee and red/brown colouration (33.3% of occasions in total), while Lakes Rangitai and Marakapia had a more even occurrence of coffee, red/brown, and green colouration. The observed water colouration at Lake Te Wapu was either coffee or red/brown for 100% of the observations (27.8 and 72.2% of occasions, respectively). These observations provide a good record of seasonality and extent of algal blooms (green colour) and peat ingress (red/brown) in these lakes.

Median water clarity measurements (poor water clarity) were lowest for Lakes Te Wapu and Huro (44 and 55 cm, respectively)(Figure 40). Median water clarity measured for the remaining lakes was 100+ cm. Lakes Te Wapu and Huro also received the lowest minimum clarity readings (5 and 10 cm, respectively), representing distinctly lower values than the other lake sites with minimum clarity measurements ranging from 75-86 cm.

Results from temporal trend analysis indicate that water clarity improved significantly at Lake Huro between 2009 and 2018. This appears to be primarily associated with lesser or lack of persistence of the algal blooms. In contrast, water clarity at Lake Marakapia and Tennants Lake significantly declined between 2014 and 2018, associated with occasional algal blooms and ingress of sediment or peat materials from lake edge erosion.

Microbial water quality

Escherichia coli (E. coli) is a bacterial indicator of faecal contamination by warm blooded animals. This can be generated by both native or feral wildlife or agricultural livestock. For lake sites located within catchments dominated by pastoral agriculture, this parameter can be indicative of poorly managed livestock accessing the lake edges or inflowing streams. It can also be influenced by casualty stock dying if stranded on the lake edges.

During the 2014-2018 monitoring period, *E. coli* monitoring was conducted only for the Lake Rangitai site. It is therefore not possible to make inferences regarding faecal contamination for the remaining waterbodies.

The median and 95th percentile *E. coli* concentrations recorded for Lake Rangitai were 9.5 and 195 MPN/100mL (Table 14). Following the NPS-FM (2017), these concentrations characterise Lake Rangitai by the 'A' attribute state, indicating that the risk of Campylobacter infection following primary contact is approximately 1%.

95th percentile *E. coli* concentrations did not surpass 'national bottom-line' values from the proposed NPS-FM (2019) of 540 MPN/100 mL; however, the maximum *E. coli* concentration recorded from this site (579 MPN/100 mL) indicates that this site sporadically receives higher faecal inputs, during which time it is not suitable for primary contact.

As Lake Rangitai is the source of the potable water supply for Kaingaroa, and there is little or no primary contact recreation, the potable water standards are of relevant consideration. However, it should be noted that these concentrations are very high and of concern for a potable supply without a high standard of water treatment.

Table 14: Summary of *E. coli* levels for Chatham Island lake sites for contact recreation during the 2014-2018 period

	E. coli (MPN/100 ml)			NPS-FM (2017) Attribute State			NPS-FM (2019) Draft Attribute State[1]	
Site Name	Annual Median	95th percentile	Annual Maximum	Annual Median	95th percentile	Overall	Overall	Bottom Line
Lake Rangitai	9.5	194	579	A	A	**A**	**B**	Pass

Notes:

1. *Attribute states are derived from the draft NPS-FM (2019) numeric attribute states. Values may be subject to change.*

Dissolved Organic Carbon (DOC)

High DOC concentrations in waterbodies can be indicative of organic pollution from anthropogenic sources; however, as most Chatham Island catchments comprise extensive peat basins where organic matter is permanently wet and available to leach into surface water, DOC origins are likely to be due to natural sources. High DOC can limit the potential use of water for potable and industrial uses and reduces the aesthetic and ecological values of water.

DOC measurements were typically high, with median values of the five lakes ranging between 8.2 and 37.5 mg/L, with peak median concentrations coming from Lake Te Wapu (37.5 mg/L; Figure 41). Peak (95th percentile) values were similarly variable, with Lakes Huro, Marakapia, Rangitai, and Tennants Lake measuring 19.1, 23, 10, and 18.1 mg/L, respectively, and Lake Te Wapu measuring 54.3 mg/L.

Trend analysis indicates that DOC concentrations at Lake Marakapia increased by an average of 1.46 mg/L between 2014 and 2018, resulting in a significantly degrading trend (Table 13). This otherwise clear dune lake is therefore trending towards becoming slightly peat coloured.

Phytoplankton Concentrations

Aquatic chlorophyll-*a* concentrations in water bodies are indicative of phytoplankton growth. These values indicate the extent to which water bodies are impacted by excessive algal growth (blooms) that are often stimulated by inputs of dissolved nutrients. Excessive algal growth is likely to degrade aquatic habitat and have a negative effect on ecosystem health.

Median chlorophyll-*a* concentrations recorded during the 2014-2018 monitoring period were variable, ranging between 0.4 mg/m^3 at Lake Marakapia to 6 mg/m^3 at Lake Rangitai (Figure 40; Table 15). Five-year maximum values were similarly variable, ranging between 4 mg/m^3 for Lake Te Wapu and 50 mg/m^3 for Lake Rangitai. The high five-year maximum values recorded from lakes Te Wapu and Huro are also indicative of phytoplankton blooms probably resulting from high nutrient concentrations in conjunction with periods of bright warm weather. The high values for Lake Rangitai may also be associated with the high potable abstractions greatly reducing the lake wetted area and shallowing or concentrating lake nutrients. Lake Rangitai phytoplankton state would likely improve if the lake refilled and maintained a more natural level regime.

Amongst the Chatham Island lake sites, neither five-year median nor maximum chlorophyll-*a* concentrations surpassed national ‘bottom line’ thresholds, as stipulated in the NPS-FM (2017). However, overall values for Lakes Huro and Rangitai sit within Attribute State C, indicating that ecological communities are moderately impacted by algal and plant growth arising from elevated nutrient levels.

Trend analysis indicates that chlorophyll-*a* concentrations at Lake Huro decreased by on average 2.2 and 3.4 mg/m^3 during the 2009-2018 and 2005-2018 periods, respectively, resulting in a significantly improving trend (Table 13).

Table 15: Summary of Chlorophyll-*a* (Chl-*a*) levels for Chatham Island lake sites during the 2014-2018 period

	Chl-a Planktonic (mg/m^3)		NPS-FM (2017) Attribute State			
Site name	Five-year median	Five-year maximum	Annual median	Annual maximum	Overall	Bottom line
Lake Huro	2.4	35	B	C	**C**	**Pass**
Lake Te Wapu	0.9	4	A	A	**A**	**Pass**
Lake Marakapia	0.4	4.8	A	A	**A**	**Pass**
Lake Rangitai	6	50	C	C	**C**	**Pass**
Tennants Lake	0.7	13	A	B	**B**	**Pass**

9.2.6 Lake Nutrient Concentrations – Short-term Status and Trends

Lake nutrient concentrations over the most recent full five-year monitoring period (2014-2018) were summarised to establish the current state of lake nutrients amongst the five monitored lake sites on Chatham Island.

From these summarised values, it is possible to make inferences regarding how the current state and trends compare with water quality policy in New Zealand (i.e. NPS-FM (2017)), which are discussed in the following parameter subsections. Data was truncated, excluding monitoring conducted in 2019, for comparability with trend analysis which was not conducted on the 2019 dataset. Summarised data for nutrient parameters, key for describing water quality in New Zealand lakes, are presented in Figure 41.

Where feasible, seasonal and non-seasonal Mann Kendall tests for correlation (trend analysis) were conducted, establishing to what extent average nutrient concentrations changed during the 2005-2018, 2009-2018, and 2014-2018 monitoring periods.

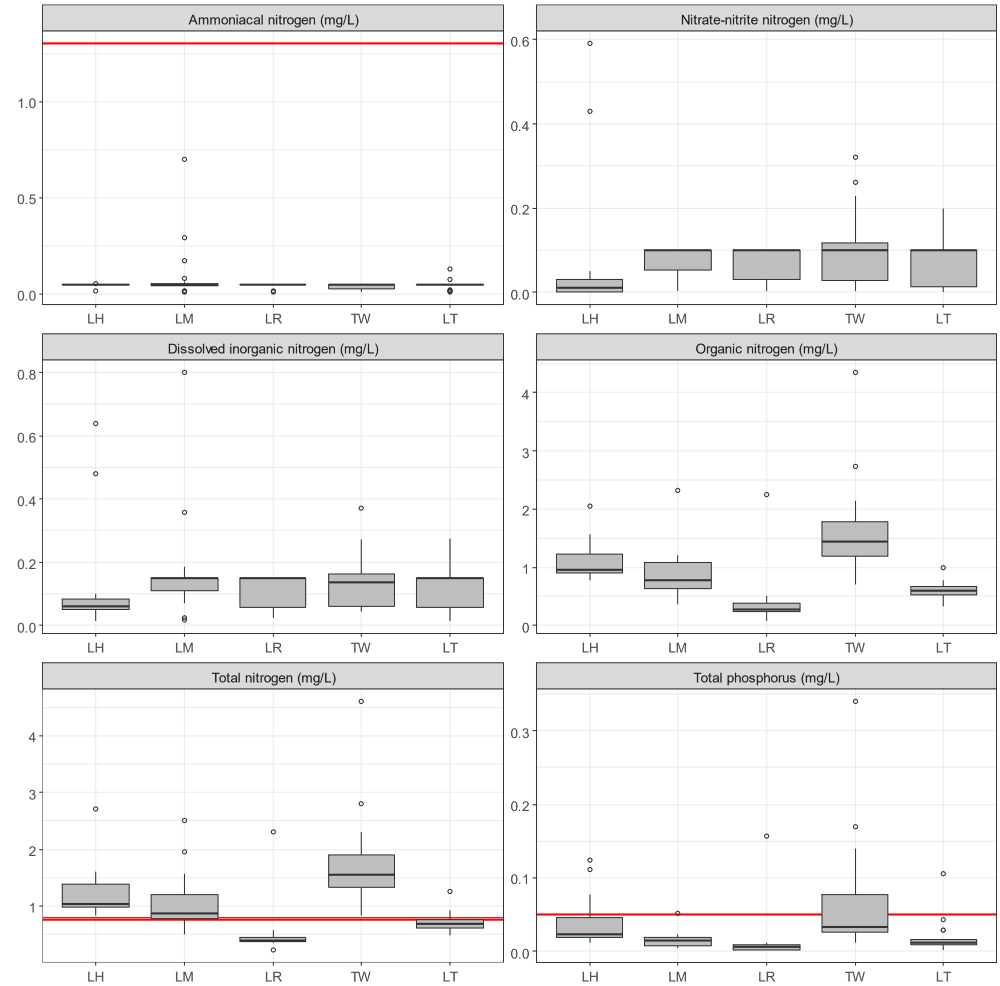


Figure 41: Summary of lake nutrient concentrations during the 2014-2018 monitoring period. Horizontal red line represents NPS-FM (2017) national 'bottom-line' value (annual median ammoniacal-nitrogen; annual median TN (brackish =0.75 mg/L; polymictic = 0.8 mg/L); annual median TP).

Summarised results following these analyses are presented in (Table 16). Results from trend analysis were not presented if yielding fewer than one meaningful result (i.e. categorised as 'Significant' or 'Probable') for a respective, variable, and year combination.

Table 16: Summary trend analysis on nutrient parameters across Chatham Island lake sites (5 year, 10 year and 14 year trends)

	Total Nitrogen (mg/L)			Ammoniacal-nitrogen (mg/L)			Total Phosphorus (mg/L)		
Trend (years)	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year
Lake Huro	?	↓↓ 0.059	↓↓ 0.046	DL	-	-	?	↓↓ 0.018	↓↓ 0.02
Lake Marakapia	↑↑ 0.102	↑↑ 0.053	↑↑ 0.044	?	?	-	↑↑ 0.002	?	↓↓ 0.001
Lake Rangitai	↑↑ 0.02	-	-	DL	-	-	?	-	-
Lake Te Wapu	?	?	?	↔	↔	-	?	?	↓↓ 0.003
Tennants Lake	?	↑↑ 0.045	↑↑ 0.032	DL	?	-	↑↑ 0.002	↔	↔

Notes:

↑↑ = 'Significantly Increasing; ↓↓ = 'Significantly Decreasing''; ↑ = 'Probably Increasing'; ↓ = 'Probably Decreasing'; ↔ = 'Stable'; '?' = 'Indeterminant'; 'DL' indicates too few values were above minimum detection level to complete analysis; '-' indicated that too few data points were available to complete analysis.

Green *colour coding = 'improving' water quality trend;* ***red*** *= 'degrading' water quality trend*

Total Nitrogen

Median TN concentrations during the 2014-2018 monitoring period were variable, ranging from 0.4 mg/L at Lake Rangitai to 1.55 mg/L at Lake Te Wapu (Figure 41). Median 95th percentile values varied similarly, ranging between 0.66 mg/L at Lake Rangitai to 2.89 mg/L at Lake Te Wapu.

Median TN concentrations surpassed NPS-FM (2017) national bottom-line values at Lakes Huro, Marakapia, and Te Wapu, with values from these monitoring sites categorised as Attribute State D. At this level, TN concentrations likely indicate excessive phytoplankton growth in the form of phytoplankton cells with corresponding habitat loss and negative impacts on ecosystem health.

Table 17: Summary of total nitrogen levels for Chatham Island lake sites during the 2014-2018 period

	Total Nitrogen (g/m3³)	NPS-FM (2017) Attribute State		
Site Name	Annual median	Annual Median[1]	Annual Median[2]	National Bottom Line
Lake Huro	1.03	-	**D**	**Fail**
Lake Marakapia	0.87	-	**D**	**Fail**
Lake Rangitai	0.40	-	**B**	**Pass**
Lake Te Wapu	1.55	D	**-**	**Fail**
Tennants Lake	0.69	-	**C**	**Pass**

Notes:
1. *Numeric attribute state allocated to seasonally stratified and brackish lakes.*
2. *Numeric attribute state allocated to polymictic lakes.*

Trend analysis was variable amongst sites, with results indicating that TN concentrations are generally decreasing at supertrophic Lake Huro, but increasing (degrading) at Lakes Marakapia, Rangitai, and Tennants Lake. Trends were relatively consistent but small for most sites over time. However, variation in trends for Lake Marakapia shows that average annual increases in TN concentrations at this site increased approximately two-fold during the most recent monitoring period.

Ammoniacal-nitrogen

Ammoniacal-nitrogen typically enters waterways from either anoxic (reducing) conditions, or through direct discharge to surface water, such as agricultural run-off or point source discharges including raw sewage, or can be internally generated from anoxic conditions in the lake bed. Ammonia is a plant-available dissolved nitrogen compound; therefore, concentrations of ammoniacal-nitrogen influence the growth of phytoplankton and macrophytes. High ammoniacal-nitrogen concentrations under favourable biotic and abiotic conditions can drive phytoplankton blooms. In addition, ammoniacal-nitrogen represents the sum of ionised ammonium (NH_4^+) and highly toxic unionised ammonia (NH^3). The relative concentrations of ammonium and ammonia present in aquatic systems correlates with temperature and pH, whereby warm alkaline waters have a higher concentration of toxic ammonia compared to ammonium. This relationship is particularly relevant to the shallow alkaline lakes on Chatham Island, whereby spikes in water temperature are likely to result in increased ammonia toxicity with corresponding impacts on ecosystem health.

Annual median ammoniacal-nitrogen concentrations recorded during the 2014-2018 monitoring period were consistently below detection limits, and data was transformed following the criteria defined in Section 1.1.1 (Figure 41; Table 18). No variance in annual median concentrations was observed between lake sites and annual maximum concentrations were variable between sites. Concentrations were highest for Lake Marakapia (0.7 mg/L), followed by Tennants Lake (0.13 mg/L), Lake Te Wapu (0.055 mg/L), Lake Huro (0.052 mg/L), and Lake Rangitai which did not exceed detection limits.

Annual maximum ammoniacal-nitrogen concentrations were consistently below ‘bottom line’ values stipulated within the NPS-FM (2017) (Table 18). Most sites were within Attribute State B, representing 95% species protection; however, Lake Marakapia received a ‘C’ grade, representing only 80% species protection and reduced survival of the most sensitive species.

Table 18: Summary of ammoniacal-N data for Chatham Island lake sites during the 2014-2018 period

	Ammoniacal-nitrogen (mg/L)		NPS-FM (2017) Attribute State			
Site Name	Annual Median	Annual Maximum	Annual Median	Annual Maximum	Overall	National Bottom Line
Lake Huro	0.05	0.052	B	B	**B**	**Pass**

Table 18: Summary of ammoniacal-N data for Chatham Island lake sites during the 2014-2018 period

	Ammoniacal-nitrogen (mg/L)		NPS-FM (2017) Attribute State			
Lake Marakapia	0.05	0.7	B	C	**C**	**Pass**
Lake Rangitai	0.05	0.05	B	B	**B**	**Pass**
Lake Te Wapu	0.05	0.055	B	B	**B**	**Pass**
Tennants Lake	0.05	0.13	B	B	**B**	**Pass**

Trend analysis results indicate that during the most recent five and ten year monitoring periods (2014-2018 and 2009-2018, respectively), average annual ammoniacal-nitrogen concentrations were stable over time for Lake Te Wapu (Table 16).

Nitrate -nitrite nitrogen

Nitrate-nitrite nitrogen typically leaches to freshwater environments following excessive land application of nitrogenous fertiliser, animal and human waste, and soil cultivation. Farming on the Chatham Islands is very different to mainland New Zealand. Subsistence farming, where there is little or no fertiliser use, no animal effluent collections and very little cultivation means that excessive application of nitrogen does not occur; however, on grazed pastures, animal urine patches can be a significant source (Meredith & Croucher, 2007). Nitrate-nitrite nitrogen is a group of plant-available dissolved inorganic nitrogen compounds; therefore, concentrations influence the growth and reproduction of phytoplankton and macrophytes and can promote phytoplankton blooms in lake systems. Nitrate-nitrite nitrogen represents the sum of nitrate (NO_3^-) and to a far lesser extent nitrite (NO_2^-). The prominence of nitrite compared to nitrate ions increases in reducing conditions such as water stagnation and deoxygenation of standing water.

Monitoring data from the 2014-2018 period indicates that median nitrate-nitrite nitrogen concentrations were consistently low amongst lake sites and did not exceed respective detection limits (Figure 41). Likewise, 95th percentile values did not exceed detection limits for Lakes Marakapia and Rangitai; however, these values ranged from 0.454 mg/L at Lake Huro, 0.263 mg/L at Lake Te Wapu, and 0.105 mg/L at Tennants Lake.

Phosphorus

Dissolved reactive forms of phosphorus and nitrogen are the primary nutrients used for lake phytoplankton growth. TP represents the sum of the dissolved and particulate, organic and inorganic phosphorus content present within aquatic systems. Thus, this parameter provides an indication (albeit limited) of the susceptibility of lake systems to eutrophication. Only one site (Lake Huro) had recorded excess DRP concentrations over the 2014-2018 period. Concentrations were low; median concentration was 0.004 mg/L, maximum 0.009 mg/L.

Median TP concentrations varied amongst lake sites during the 2014-2018 monitoring period (Figure 41; Table 19). Median concentrations ranged from 0.006 mg/L at Lake Rangitai to 0.0325 mg/L at Lake Te Wapu. Within this range, none of the lakes surpassed NPS-FM (2017) national bottom-line values for lake ecosystem health (Table 19). Lake Rangitai falls within Attribute State A, indicating that ecological communities are likely healthy and resilient; Lake Marakapia and Tennants Lake are within Attribute State B, indicating that ecological communities are likely slightly impacted by increased phytoplankton growth; and Lakes Huro and Te Wapu are within Attribute State C, indicating that ecological communities are likely moderately impacted by excessive plant growth.

Maximum concentrations recorded during this period were markedly higher than medians. These values ranged between 0.052 mg/L at Lake Marakapia and 0.34 mg/L at Lake Te Wapu; at these levels, lakes are highly susceptible to phytoplankton blooms and associated ecosystem impacts (NPS-FM 2017).

Table 19: Summary of TP for Chatham Island lake sites during the 2014-2018 period

	Total Phosphorus (mg/L)	**NPS-FM (2017) Attribute State**	
Site Name	Annual median	Annual Median	National Bottom Line
Lake Huro	0.024	**C**	**Pass**
Lake Marakapia	0.014	**B**	**Pass**
Lake Rangitai	0.006	**A**	**Pass**
Lake Te Wapu	0.033	**C**	**Pass**
Tennants Lake	0.012	**B**	**Pass**

Temporal trends were variable amongst sites, with results indicating that TP concentrations are steadily decreasing at Lakes Huro and Te Wapu; however, TP trends for the 2014-2018 monitoring period at Lake Marakapia represent a shift from a decreasing trend between 2005 and 2018, to one that is increasing. TP trends for the 2014-2018 monitoring period at Tennants Lake represent a shift from a stable trend for 2005-2018 and 2009-2018, to one that is increasing.

Annual TP reductions measured at the Lake Huro monitoring site were an order of magnitude greater than trends at the remaining sites. Long-term TP trend results indicate the water quality at Lake Huro is likely improving, while more recent trend results indicate that Lake Marakapia and Tennants Lake are slightly degrading.

9.3 Results - Watercourses

Median annual results from water quality monitoring across all sites and monitoring years are presented in Appendix D. Long term data is presented in this section, summary analysis of additional data collected are provided in Appendix E.

A total of 14 watercourse sites were monitored between April 2005 and June 2019 (Table 9). Sites were sampled approximately quarterly throughout this period. However, the full suite of physicochemical parameters was not collected consistently per sampling occasion.

Physical characteristics and general observations made for each watercourse are presented in Table 20.

Table 20: General description of physical characteristics of monitored watercourses and surrounding land-use

Reference ID	Watercourse	Sediment type	Surrounding land use
AWS	Awamata Stream	Bedrock, Cobbles and large boulders	Open grassland – sheep grazing
AC	Awatotara Creek	Bedrock, Cobbles and gravel	Native bush – extensive stream cover
BJ	Blind Jims Creek	Peat, Sand, and silt	Open peat grassland – cattle and sheep farming
MAS	Mangahou Stream	Bedrock, Cobbles and gravel	Secondary scrub – tributary stream of Te Awainanga River

Table 20: General description of physical characteristics of monitored watercourses and surrounding land-use

Reference ID	Watercourse	Sediment type	Surrounding land use
MP	Mangape Creek	Peat, Mud/clay	Open wetland and grassland – extensive sheep farming, some cattle (stream drains from Lake Huro)
NR	Nairn River	Peat, silt and sand	Tidal wetland, pasture and lake edges.
TAR	Te Awainanga River	Cobbles, boulders, and gravel	Peat basins, Secondary scrub intermixed with native trees
TOC	Te One Creek	Boulders, cobble, and gravel	Open scrub and grassland with sheep farming
TDR	Unnamed Northern Trib/ Rakautahi Stream	Cobbles, gravel, and silt	Lower catchment – open grassland with cattle farming. Upper catchment – secondary growth
WMC	Waimahana Creek	Cobbles and gravel	Mixture of open grassland and secondary scrub
WC	Waitaha Creek	Sand, gravel, and silt	Scrub and patches of open grassland
WTC	Waitamaki Creek	Sand, silt, and peat	Secondary scrub
WAC	Washout Creek	Peat and sand	Mixture of scrub and gorse with some grassland for cattle farming
WIS	Whangamoe Inlet Stream	Sand and peat	Secondary scrub – some cattle farming but no open grass areas

Notes:
Description of physical properties are based on Meredith & Croucher (2007) and may be subject to change.
Descriptions of Nairn River physical properties and surrounding land use not available.

9.3.1 General Water Quality – Long-term

Physicochemical water quality data for the full monitoring period (2005-2019) represent the long-term state of water quality amongst watercourses on Chatham Island. Summarised data for a range of physicochemical water quality parameters are presented in Figure 42 and visual representation of the full dataset is provided in Appendix F. Comparisons to national policy guidance levels are provided in section 0.

Long-term median values were highly variable within and amongst sites. Median pH values ranged between acidic (pH 5.1) and slightly alkaline (pH 8) (Figure 42).

Median alkalinity (as HCO_3) likewise ranged between 3.2 and 155 mg/L, with higher alkalinity values generally corresponding with higher pH values.

Median water clarity values ranged between 16 and 100+ cm, indicating that some watercourses on Chatham Island support high colour and concentrations of particulate matter (Figure 42). Peak (95th percentile) water clarity readings ranged between 50 and 100+ cm. Sites with 95th percentile water clarity measurements of 100+ cm were few, including Blind Jim's Creek, Waimahana Creek, Waitamaki Creek and Te One Creek, while most sites measured below 80 cm. It is therefore likely that some sites remain highly coloured and/or turbid year-round.

Water conductivity is a measure of its capability to pass electrical current. This is directly related to the concentration of ions in the water, which can be strongly influenced by natural and anthropogenic processes such as salinity, geology, and organic pollution. Conductivity measurements collected from Chatham Island watercourse sites were typically moderate, ranging between 15 and 74 µS/m (Figure 42). However, the median conductivity measurement for Nairn River was markedly higher, measuring 330.4 µS/m representative of the tidal seawater influence at the sampling location. Peak (95th percentile) conductivity measurements varied similarly between sites, with the highest values recorded for Waitamaki Creek, Washout Creek, Whangamoe Inlet Stream, and Nairn River (396.9, 955.7, 2766.2, and 3713.2 µS/m, respectively), representing markedly higher conductivity levels compared to the remaining sites that ranged between 20 and 183.6 µS/m. This is likely due to tidal saltwater influence within the watercourses.

DOC concentrations represent interactions with organic material. Thus, high DOC concentrations can be indicative of organic pollution from anthropogenic sources; or, in the case of most Chatham Island catchments, may represent the extensive peat basins from which water is sourced. Median DOC concentrations ranged between 4.1 and 40 mg/L and showed large variation consistently between and amongst sites, with no apparent outlying sites (Figure 42). A similar pattern was observed amongst 95th percentile (12.6-71.3 mg/L) and maximum values (17-83 mg/L), indicating that DOC inputs are variable between sites but relatively stable.

DO concentrations in watercourses are influenced by a number of biotic and abiotic factors. For example, fast flowing, turbulent, cold water will typically have high DO concentrations with high reaeration and a high DO carrying capacity, while slow flowing, nutrient enriched, warm water will typically have low DO concentrations due to increased biochemical oxygen demand (BOD) low aeration, and a lower DO carrying capacity. For waterways sourced from catchments where pastoral agriculture is the dominant land-use practice, low DO concentrations can indicate organic pollution from agricultural sources (i.e. livestock excreta). DO concentrations measured from Chatham Island watercourses were variable within and amongst sites (Figure 42). Median concentrations ranged between 5 and to 11 mg/L, at which concentrations aquatic organisms can experience moderate stress. However, assessment of minimum DO concentrations across sites indicates that several are susceptible to anoxia (i.e. minimum recorded values for Whangamoe Inlet Stream, Mangape Creek, Waitamaki Creek, Waitaha Creek, and Washout Creek were <1 mg/L). Median DO saturation levels varied similarly, with sites ranging from 52.2% (Washout Creek) to 102% (Awamata Stream) saturation. Minimum values were also notably low for some sites, with Whangamoe Inlet Stream, Mangape Creek, Waitamaki Creek, Waitaha Creek, and Washout Creek all falling below 10% saturation.

Median water temperature varied little amongst sites, ranging between 10.2 and 15.1°C (Figure 42). Seasonal variation amongst sites is clear, yet not consistent, potentially indicating variation in canopy cover, source (i.e. spring-fed or hill-fed) or distance from the source.

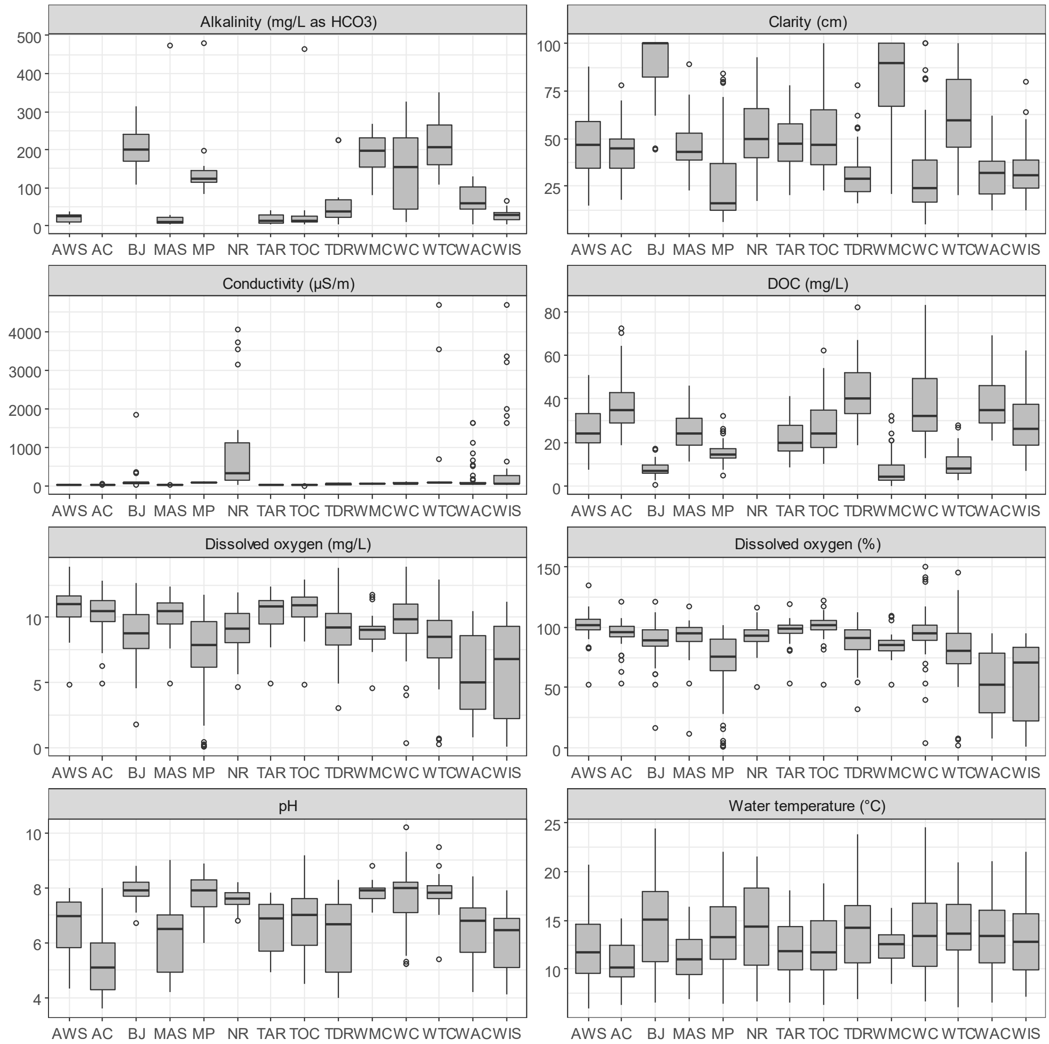


Figure 42: Results from long-term physicochemical water quality monitoring for 14 Chatham Island watercourse sites between 2005 and 2019

9.3.2 Watercourse Nutrient Concentrations – Long-term

Nutrient concentrations over the full monitoring period (2005-2019) were summarised to establish the long-term status of watercourse nutrient concentrations amongst the 14 monitored sites on Chatham Island. Summarised data for a range of key parameters are presented in Figure 43.

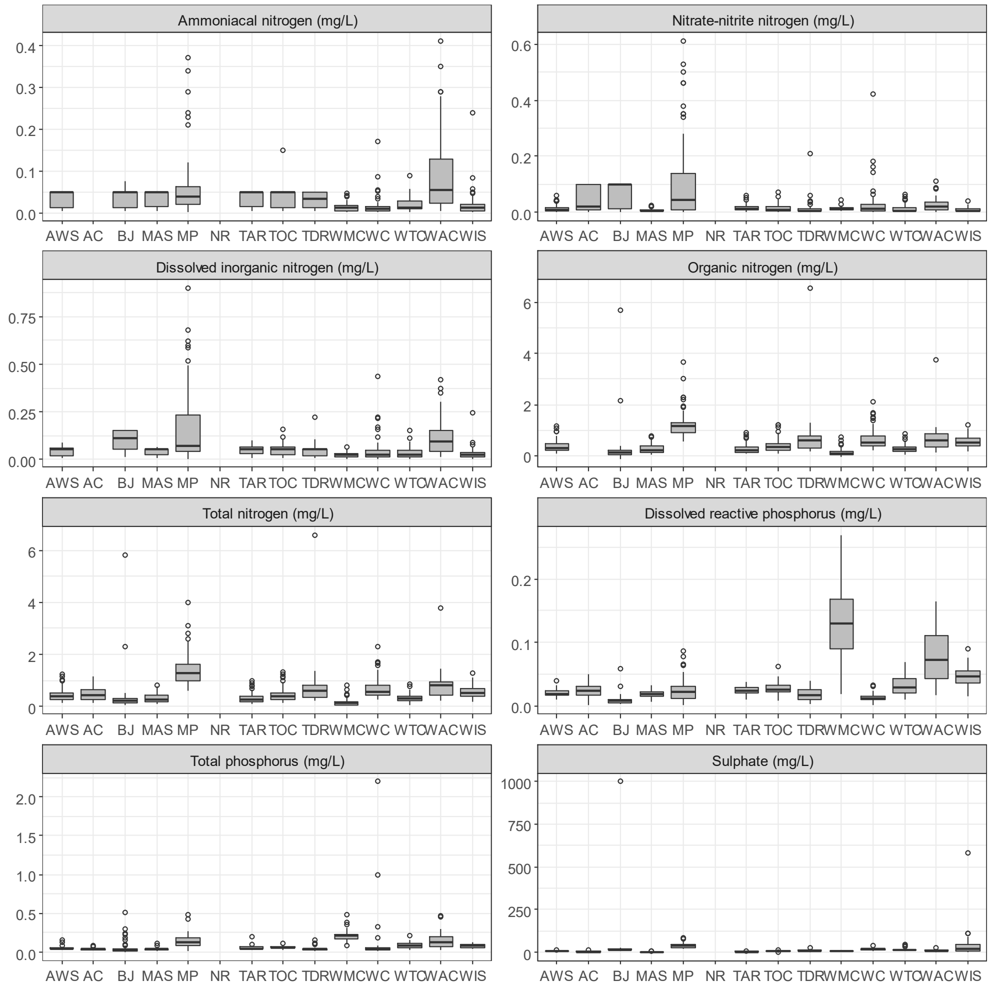


Figure 43: Results from long-term water quality (nutrient) monitoring for 14 Chatham Island watercourse sites between 2005 and 2019.

Median TN concentrations varied between 0.12 and 1.3 mg/L amongst sites (Figure 43). Variation amongst sites was typically stable, with median concentrations at most sites ranging between 0.12 and 0.81 mg/L; however, the median concentration at Mangape Creek (1.3 mg/L) represents a noteworthy difference (degradation) from the other sites. 95^{th} percentile concentrations varied similarly, ranging from 0.44 to 2.64 mg/L, with Mangape Creek again presenting the highest (most degraded) value. This may largely be because Mangape Creek is the lake-outlet stream for the nutrient enriched Lake Huro, and so is reflecting high lake phytoplankton biomass in these stream samples.

Ammoniacal-nitrogen is a plant-available dissolved nitrogen compound, typically sourced from anoxic environments, agricultural run-off and point-source discharges (i.e. raw sewage), due to its limited capacity to leach through soil. High ammoniacal-nitrogen concentrations in lotic environments can result in nuisance macrophyte and periphyton growth, with corresponding habitat loss and impacts on resident biota and at high levels can be toxic to aquatic life. As lotic systems typically provide a conduit between land-use activities and receiving waterbodies (i.e. lakes and Te Whanga Lagoon), ammoniacal-nitrogen concentrations in these systems can also indicate to what extent individual stream sites are contributing to eutrophication on receiving waters. In addition, relative concentrations of ammonium and ammonia present in aquatic systems positively correlates with temperature and pH, whereby spikes in water temperature are likely to result in increased ammonia toxicity with corresponding impacts on ecosystem health and toxicity.

Median ammoniacal-nitrogen concentrations were consistently low, ranging from 0.012 to 0.055 mg/L (Figure 43). Peak (95th percentile) values follow a similar pattern, albeit with much higher values presented for Mangape and Washout Creek, representing five-and six-fold increases compared to the next highest value (i.e. Waitaha Creek: 0.053 mg/L). This may be because these are sluggish waterways draining lakes or wetlands. They may therefore frequently be anoxic and ammonia is being generated as a compound in these anoxic reducing conditions.

Nitrate-nitrite nitrogen forms following the nitrification of ammoniacal nitrogen, a process that occurs in freshwater environments; however, high concentrations of nitrate-nitrite nitrogen can be toxic to aquatic life. It typically leaches to lotic environments following excessive leaching from the land of application of nitrogenous fertiliser, disposal of animal and human waste) and poorly managed soil cultivation. On grazed pastures, animal urine patches can be a significant source, as well as losses from nitrogen fixing plants (clovers, gorse, broom etc.). Median nitrate-nitrogen concentrations recorded were low but highly variable, ranging between 0.005 (Mangahou Stream) and 0.1 mg/L (Blind Jim's Creek). Highest concentrations recorded for Blind Jim's Creek were noteworthy, being almost two-fold the next highest site median (i.e. Mangape Creek: 0.044 mg/L). Peak (95th percentile) concentrations were similarly variable, ranging between 0.018 mg/L (Mangahou Stream) and 0.47 mg/L (Mangape Creek), indicating that some sites (i.e. Mangape Creek) are more susceptible to occasional high nitrate-nitrite nitrogen inputs.

Median phosphorus concentrations were typically high or elevated amongst the watercourse sites, ranging between 0.033 and 0.21 mg/L (Figure 43). Variation in median phosphorus concentrations was relatively evenly distributed amongst sites, with no sites presenting as clear outliers. Peak (95th percentile) values are similarly distributed; however, assessment of maximum TP concentrations reached at sites during this period indicate that Waitaha Creek, for which a maximum TP value of 2.2 mg/L was recorded (four-fold the next highest recorded site value), may be susceptible to occasional high phosphorus inputs.

Soluble phosphorus (DRP) represents the portion of TP available for plant uptake, and therefore, limits nuisance macrophyte and algal growth in lotic and receiving standing-water environments. Median DRP concentrations were highly variable between sites, ranging from 0.007 (Blind Jim's Creek) to 0.13 mg/L (Waimahana River). Variation amongst sites was reasonably evenly distributed, although concentrations measured from Washout and Waimahana Creek were notably higher than the next highest scoring site (i.e. 0.073 and 0.13 mg/L, respectively, compared to 0.046 mg/L at Whangamoe Inlet Stream). Peak (95th percentile) values varied similarly between sites, ranging from 0.018 for Blind Jim's Creek to 0.23 mg/L for Waimahana Creek, with Washout and Waimahana Creek presenting notably higher concentrations than the next highest scoring site (i.e. 0.13 and 0.23 mg/L, respectively, compared to 0.071 mg/L at Whangamoe Inlet Stream).

9.3.3 Nutrient Ratios

Watercourse sites were also assessed to determine their respective degree of potential nutrient limitation. Table 21 presents both the total and soluble nutrient ratios for the monitored Chatham Island watercourses for the five-year period of 2014-2019.

Table 21: Median five year (2014-2019) watercourse DIN/DRP and TN/TP ratios ranked and grouped by nutrient limitations category.

Site	TN/TP	Site	DIN/DRP
Waimahana Creek	0.66	Waimahana Creek	0.18
Waitamaki Creek	5.35	Whangamoe Inlet Stream	0.33
Te Awainanga River	6.75	Waitamaki Creek	0.76
Whangamoe Inlet Stream	7.33	Washout Creek	1.06
Washout Creek	7.39	Te One Creek	2.15
Te One Creek	7.95	Te Awainanga River	2.35
Awamata Stream	10.50	Awamata Stream	2.73
Mangahou Stream	10.50	Rakautahi Stream	2.74
Blind Jims Creek	15.00	Waitaha Creek	2.79
Mangape Creek	15.15	Mangahou Stream	2.80

Table 21: Median five year (2014-2019) watercourse DIN/DRP and TN/TP ratios ranked and grouped by nutrient limitations category.

Site	TN/TP	Site	DIN/DRP
Awatotara Creek	16.40	Mangape Creek	3.94
Rakautahi Stream	21.03	Blind Jims Creek	30
Waitaha Creek	23.94	Awatotara Creek	-
Nairn River	-	Nairn River	-

Notes:
TN:TP ratio - P limited (>20); Co-limited by N and P (10 - 20); N limited (<10)
DIN:DRP ratio - P limited (>15); Co-limited by N and P (7 - 15); N limited (<7)

TN:TP limitation thresholds are sourced from Croucher &Meredith (2007) for direct comparison. DIN:DRP thresholds are sourced from McDowell et al., 2009.

"-" indicates insufficient data to calculate ratio.

Median total nutrient ratios were >5 for most sites (Table 21), with six sites nitrogen limited, five sites co-limited by nitrogen and phosphorus and two sites phosphorus limited. Disparity between ratios of median dissolved and total nutrient concentrations at these sites suggests that the nitrogen content is largely bound amongst organic material such as in peat particles and dissolved peat compounds.

Median dissolved nutrient ratios were very low (i.e. <4) representing nitrogen limitation at all sites except for Blind Jim's Creek (Table 21). The dissolved nutrient ratios presented indicate that aquatic plant growth and reproduction (i.e. macrophytes, periphyton, and phytoplankton) is highly likely to be limited by dissolved nitrogen concentrations for most sites, indicating DRP is relatively abundant. Aquatic plant and algae growth for Blind Jim's Creek is limited by dissolved phosphorus availability, indicating that the dissolved nitrogen levels at this site are high.

9.3.4 General Watercourse Water Quality – Short-term Status and Trends

Physicochemical water quality data for the five most recent full monitoring years (2014-2018) represent the current state of water quality in the watercourses on Chatham Island. From these summarised values, it is possible to make inferences regarding how the current state and trends compare with water quality policy in New Zealand (i.e. NPS-FM (2017)). Data was truncated, excluding monitoring conducted in 2019, for comparability with trend analysis which was not conducted on the 2019 dataset.

Summarised data for a range of physicochemical water quality parameters are presented in Figure 44. Where feasible, seasonal and non-seasonal Mann Kendall tests for correlation (trend analysis) were conducted to establish to what extent average physicochemical water quality parameters changed annually during the 2005-2018, 2009-2018, and 2014-2018 monitoring periods. Summarised results following these analyses are presented in Table 22. Results from trend analysis were not presented if yielding fewer than one meaningful result (i.e. categorised as 'Significant' or 'Probable') for a respective site, variable, and year combination.

Trend analysis

Temporal trend analysis was limited by a number of factors, primarily relating to the availability of quarterly data and the influence of censored values on analysis (see Section 9.1.4 for further detail). Observable directional trends across many site-variable combinations could therefore not be established statistically with confidence. Indeterminant trends and trends that were not analysed due to data deficiency are not described in detail below, but can be seen in temporal scatterplots provided in Appendix F.

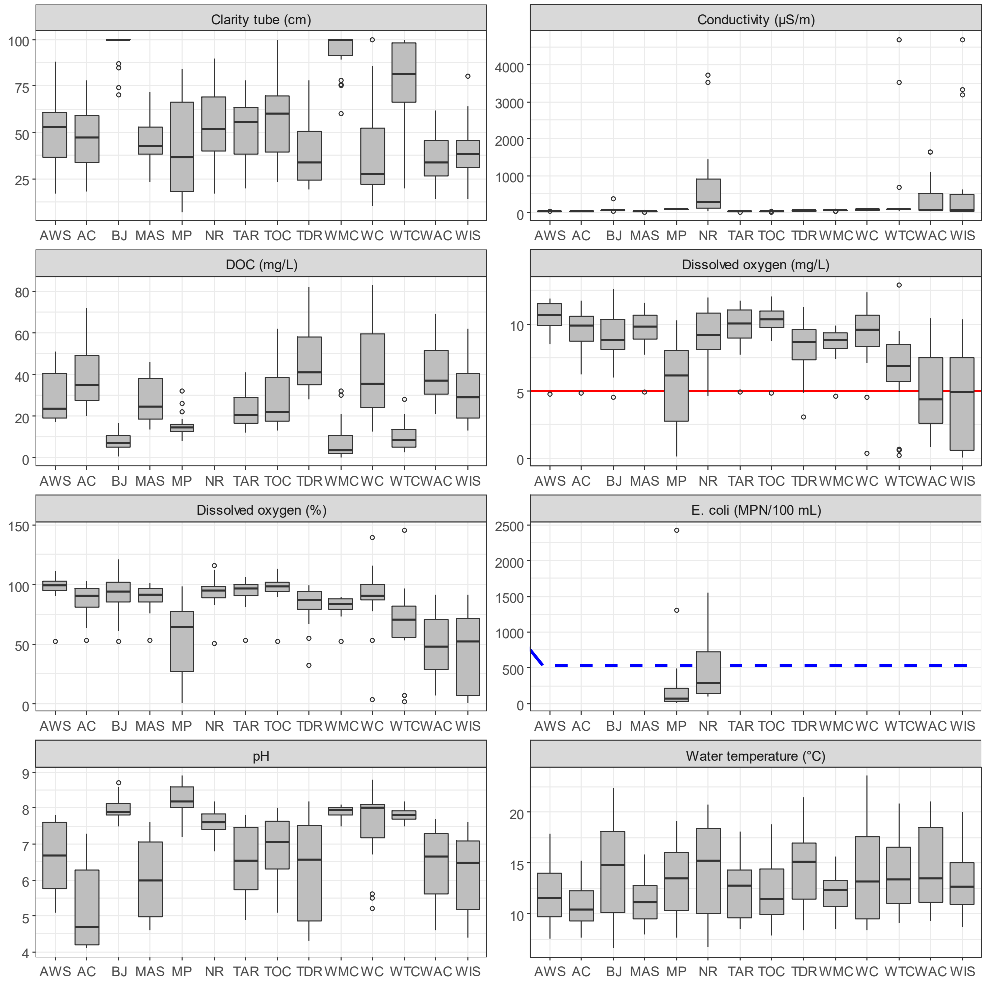


Figure 44: Summary of physicochemical water quality data at fourteen monitored Chatham Island watercourse sites during the 2014-2018 monitoring period. Horizontal red line represents NPS-FM (2017) 'bottom-line' (7-day DO minimum); dashed blue line represents the draft NPS-FM (2019) 'bottom-line' (95th percentile *E. coli* concentration).

Table 22: Trend analysis results for physicochemical water quality parameters measured from monitored Chatham Island watercourse sites

	Temperature (°C)			DO (mg/L)			pH			Conductivity (µS/m)			Clarity (cm)			DOC (mg/L)		
Site	**5 year**	**10 year**	**14 year**	**5 year**	**10 year**	**14 year**	**5 year**	**10 year**	**14 year**	**5 year**	**10 year**	**14 year**	**5 year**	**10 year**	**14 year**	**5- year**	**10 year**	**14 year**
Awamata Stream	↔	?	?	?	↓↓ 0.13	?	↓↓ 0.27	↔	?	-	↑↑ 1.34	-	?	?	↔	?	?	↑↑ 0.72
Awatotara Creek	?	?	?	?	↓↓ 0.17	↓↓ 0.13	?	↔	?	-	↑↑ 0.87	-	?	?	?	?	↔	↑↑ 0.91
Blind Jims Creek	?	?	?	?	?	?	?	?	?	-	↑↑ 1.37	-	-	-	-	?	?	?
Mangahou Stream	?	?	?	?	↓↓ 0.13	?	↓↓ 0.38	?	?	-	↑↑ 0.79	-	-	?	-	↑↑ 5.06	?	↑↑ 0.75
Mangape Creek	-	-	-	-	-	-	?	-	-	-	-	-	-	-	-	↑↑ 1.31	-	-
Nairn River	?	-	-	?	-	-	↓↓ 0.15	-	-	-	-	-	-	-	-	-	-	-
Te Awainanga River	↔	?	?	?	?	?	↓↓ 0.39	?	?	-	-	-	↓↓ 5.46	?	?	↑↑ 3.57	?	↑↑ 0.73
Te One Creek	?	?	?	?	↓↓ 0.14	?	↓↓ 0.43	↔	?	-	↑↑ 1.44	-	↓↓ 7.73	?	?	↑↑ 5.88	?	?
Rakautahi Stream	?	?	?	?	↓↓ 0.17	?	?	?	↔	-	↑↑ 1.89	-	?	?	↑↑ 0.67	↑↑ 6.12	?	↑↑ 1.00
Waimahana Creek	?	?	?	↔	↔	-	↔	?	?	-	↑↑ 1.06	-	?	↑↑ 2.13	-	?	?	↔

Table 22: Trend analysis results for physicochemical water quality parameters measured from monitored Chatham Island watercourse sites

Waitaha Creek	?	?	?	?	?	-	?	?	?	-	↑↑ 4.82	-	?	↑↑ 1.51	-	?	?	?
Waitamaki Creek	?	?	?	?	↓↓ 0.55	↓↓ 0.22	?	?	?	-	↑↑ 3.41	-	?	↑↑ 2.83	-	↑↑ 2.36	?	?
Washout Creek	?	?	↑↑ 0.20	↑↑ 0.92	?	?	?	?	?	-	↑↑ 5.32	-	↔	?	↑↑ 1.09	?	?	↑↑ 1.00
Whangamoe Inlet Stream	?	-	-	?	-	-	?	-	-	-	-	-	?	-	-	?	?	↑↑ 0.75

Notes:

↑↑ = 'Significantly Increasing; ↓↓ = 'Significantly Decreasing''; ↑ = 'Probably Increasing'; ↓ = 'Probably Decreasing'; ↔ = 'Stable'; '?' = 'Indeterminant'; 'DL' indicates too few values were above minimum detection level to complete analysis; '-' indicated that too few data points were available to complete analysis.

***Green** colour coding = 'improving' water quality trend; **red** = 'degrading' water quality trend*

Temperature

Median water temperatures during the 2014-2018 period ranged between 10.5°C at Awatotara Creek and 15.2°C at Nairn River (Figure 44). Peak (95th percentile) temperatures ranged between 14.7°C at Awatotara Creek and 22.5°C at Waitaha Creek.

Trend analysis indicates that water temperature at Awamata Stream and Te Awainanga River remained stable during the 2014-2018 monitoring period (Table 22). Water temperatures at Washout Creek significantly increased during 2005-2018, with trend analysis indicating that water temperatures increased 0.2°C annually throughout this monitoring period.

Dissolved Oxygen

Median DO concentrations were typically favourable, indicating that the water quality at these sites is capable of supporting a diverse range of aquatic life. Median DO concentrations ranged between 4.4 mg/L at Washout Creek and 10.7 mg/L at Awamata Stream (Figure 44). Concentrations were highly variable at Washout Creek, Mangape Creek, and Whangamoe Inlet Stream, and frequently approached anoxia. Minimum concentrations also revealed the occasional tendency for Waitaha and Waitamaki creeks to approach anoxic conditions (i.e. <1 mg DO L^{-1}). Minimum DO concentrations across all monitored watercourse sites ranged between 0.06 and 5 mg/L, at these minimum levels it is likely that resident aquatic communities were stressed. Amongst sites for which DO concentrations fell below 1 mg/L, aquatic communities would have undergone significant stress corresponding with local extinctions and loss of ecological integrity.

Trend analysis indicates that DO concentrations have been declining annually at most sites (range of 0.13 – 0.55mg/L). This could be related to a range of factors including time of day sampled, flow levels, temperature and instream plant growth. It should be noted that concentrations measured from Washout Creek improved significantly between 2014 and 2018, with an average annual increase of 0.92 mg/L (Table 22).

pH

Median pH values ranged between 4.7 (Awatotara Creek) to 8.2 (Mangape Creek) (Figure 44), representing acidic to slightly alkaline conditions, respectively. pH was highly variable between monitoring rounds and amongst sites; however, levels at Blind Jim's Creek, Mangape Creek, Nairn River, Waimahana Creek, and Waitaha Creek were notably less variable over time.

Trend analysis indicates that sites are either reducing in pH (i.e. becoming more acidic) or are not changing temporally (Table 22). Significant negative (reducing) trends established for the 2014-2018 monitoring period at Awamata Stream and

Te One Creek are superseded by the stable trend established for longer monitoring periods and reflect the annual variability at these sites.

Conductivity

Median electrical conductivity levels were moderate ranging between 17.7 µS/m (Te Awainanga River) and 81.1 µS/m (Waitamaki Creek), except for Nairn River where median conductivity exceeded Waitamaki Creek close to four-fold (291.2 µS/m) (Figure 44). Peak (95th percentile) values varied substantially for Washout Creek, Nairn River, Whangamoe Inlet Stream, and Waitamaki Creek, where values of 1635.7, 3581.4, 3678.2, and 3771.5 µS/m were recorded, respectively. These values represent the high concentrations of ions occasionally present at these sites. In contrast, 95^{th} percentile values collected from the remaining sites ranged between 21.1 and 133.8 µS/m.

Trend analysis results were limited to the 2009-2018 monitoring period, during which time all meaningful trends indicate that electrical conductivity has increased by 0.79 (Mangahou Stream) to 5.32 µS/m (Washout Creek) annually (Table 22). Increasing trends for other sites, although not significant, can be seen in Appendix F.

Colour and Clarity

Descriptions of Chatham Island watercourse colouration ranges amongst sites, from colourless, to red/brown and coffee (indicative of staining from organic peat compounds), and green.

Sites were described as colourless, indicating the presence of minimal dissolved or suspended material, between 0% (Awamata Stream, Awatotara Creek, Mangahou Stream, Te Awainanga River, Te One Creek, Rakautahi Stream, Washout Creek, and Whangamoe Inlet Stream) and 89.5% (Blind Jim's and Waimahana Creeks) of occasions. The low frequency of clear water observations reflects the propensity for these sites to be influenced by organic peat compounds, resulting in red/brown and coffee coloured water. For example, sites were described as having coffee coloured water on 0% (Blind Jim's, Mangape, and Waimahana Creeks) to 72% of observations (Whangamoe Inlet Stream) and red/brown coloured water on 0% (Mangape Creek) to 89.5% of observations (Awamata Stream and Te One Creek). Green colouration, likely indicative of high phytoplankton density, was occasionally observed at Blind Jim's, Mangape, Waitaha, and Waitamaki creeks between 5.3 and 16.7% of occasions.

Median water clarity values reflected observations of colouration (Figure 44). Median clarity values ranged between 27.5 (Waitaha Creek) and 100+ cm (Blind Jim's and Waimahana creeks). Sites for which colouration was most often clear received high median water clarity measurements (i.e. median values for Blind Jim's, Waimahana, and Waitamaki creeks ranged between 80 and 100+ cm).

Assessment of peak (95th percentile and maximum) water clarity values indicates that water clarity at most sites, except for Blind Jim's, Te One, Waimahana, Waitaha, and Waitamaki creeks, were likely permanently opaque during the 2014-2018 period.

Microbial Water Quality

E. coli was scarcely measured from Chatham Island watercourse sites between 2014 and 2018 because of the difficulty of transferring samples in a timely manner to the mainland laboratory, which require samples within 24 hours of collection. Data was limited to only Mangape Creek and Nairn River (Figure 44).

Median *E. coli* concentrations were 78 MPN/100 mL for Mangape Creek and 238 MPN/100 mL for Nairn River (Table 23). Peak (95th percentile) values were substantially higher for the two sites, with Mangape Creek measuring 1,412 MPN/100 mL and Nairn River measuring 1,015 MPN/ 100 mL. Overall, both sites are categorised by Attribute State E following the NPS-FM (2017) guidelines (Table 23), indicating that on average, the risk of *Campylobacter* infection to swimmers is >7%. Comparisons with the Proposed draft NPS-FM (2019) likewise conclude that peak (95th percentile) *E. coli* concentrations at both monitored watercourse sites exceed proposed national' bottom-line' values for primary contact sites.

Table 23: Summary of *E. coli* levels at Chatham Island watercourse sites during the 2014-2018 period

Site Name	*E. coli* (MPN/100 ml)		NPS-FM (2017) Attribute State			NPS-FM (2019) Draft Attribute State[1]	
	Annual Median	Annual 95th Percentile	Annual Median	95th Percentile	Overall	Overall	Bottom-line
Mangape Creek	78	1412	A	E	**E**	**D**	**Fail**
Nairn River	283	1015.25	E	C	**E**	**D**	**Fail**

Notes:

1. *Attribute states are derived from the draft NPS-FM (2019) numeric attribute states. Values may be subject to change.*

Dissolved Organic Carbon (DOC)

Median DOC concentrations were variable amongst sites, ranging from 3.95 mg/L (Waihamana Creek) to 41 mg/L (Rakatuhai Stream) (Figure 44). Variation in median DOC concentrations was relatively even between sites, with no sites presenting as clear outliers. Peak (95th percentile) concentrations ranged from 13.76 mg/L (Blind Jim's Creek) to 83 mg/L (Waitaha Creek), with no clear outlying sites.

Trend analysis produced meaningful trends for 11 sites throughout the three defined monitoring periods (Table 24). Amongst the reported results, most indicate that DOC concentrations have been increasing annually. Trends for the most recent monitoring period (2014-2018) indicate that concentrations have been increasing by 1.31-6.12 mg/L; however, as long-term trend analysis (2005-2018) for these sites indicates substantially lower annual increases (0.73-1 mg/L), these results are likely indicative of the temporal variability associated with DOC concentrations in Chatham Island watercourses.

9.3.5 Watercourse Nutrient Concentrations – Short-term Status and Trends

Nutrient concentrations over the most recent full five-year monitoring period (2014-2018) were summarised to establish the current state of nutrients amongst 14 monitored watercourse sites on Chatham Island. From these summarised values, it was possible to make inferences regarding how the current state and trends compare with water quality policy in New Zealand (i.e. NPS-FM (2017); see below). Data was truncated, excluding monitoring conducted in 2019, for comparability with trend analysis which was not conducted on the 2019 dataset. Summarised data for nutrient parameters, key for describing water quality, are presented in Figure 45.

Seasonal and non-seasonal Mann Kendall tests for correlation (trend analysis) were conducted, establishing to what extent average physicochemical water quality parameters changed annually during the 2005-2018, 2009-2018, and 2014-2018 monitoring periods. Summarised results following these analyses are presented in Table 24. Results are only presented for parameters that yielded one or more meaningful trend (i.e. categorised as 'Significant' or 'Probable').

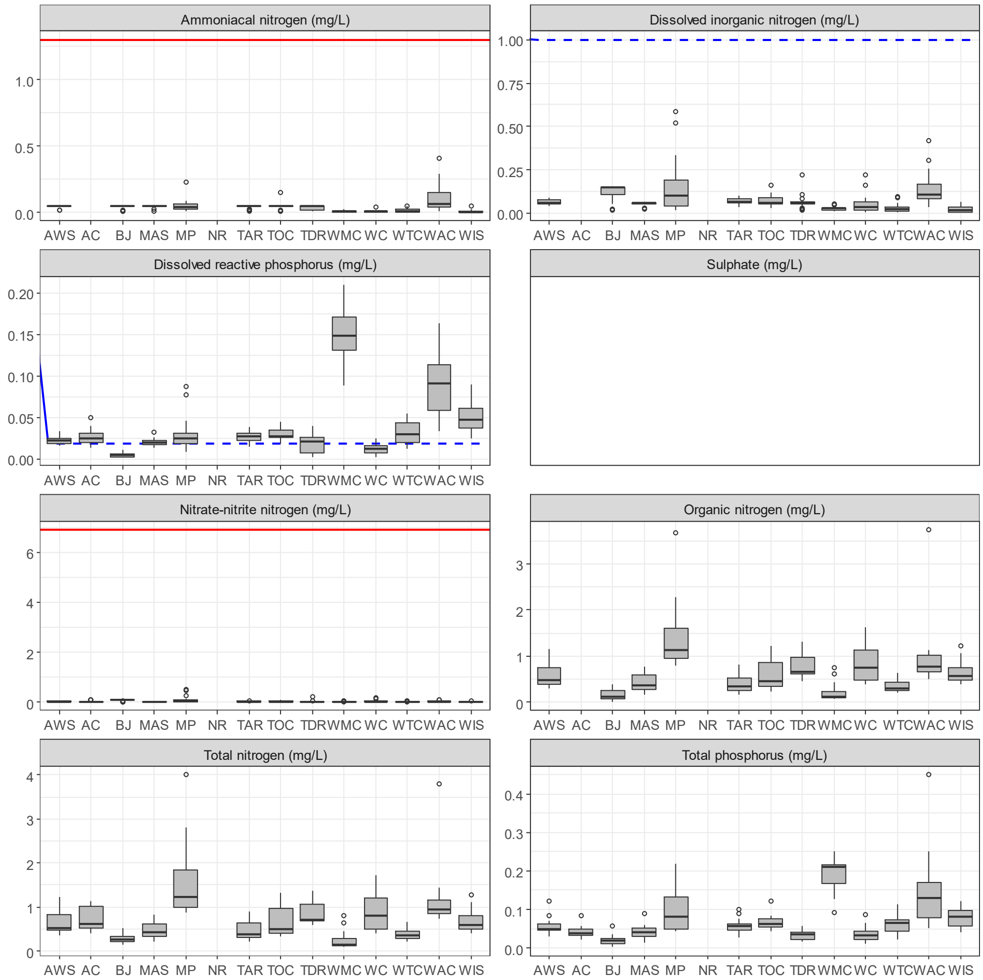


Figure 45: Summary of nutrient concentrations at 14 Chatham Island watercourse sites during the 2014-2018 monitoring period. Horizontal red lines represent NPS-FM (2017) national 'bottom-line' values (annual median ammoniacal nitrogen; annual median nitrate-nitrite nitrogen). Dashed blue line represents proposed NPS-FM (2019) national 'bottom-line' (annual median dissolved inorganic nitrogen).

Table 24: Trend analysis results for nutrient parameters measured from monitored Chatham Island watercourse sites

Site	Total Nitrogen (mg/L)			Ammoniacal Nitrogen (mg/L)			Nitrate-nitrite Nitrogen (mg/L)			Total Phosphorus (mg/L)			DRP (mg/L)		
	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year	5 year	10 year	14 year
Awamata Stream	↑↑ 0.091	↑↑ 0.059	↑↑ 0.036	DL	?	?	?	↑↑ 0.001	?	↔	?	?	?	↑↑ 0.001	?
Awatotara Creek	↑↑ 0.08	↑↑ 0.062	↑↑ 0.046	DL	↔	?	?	↑↑ 0	?	?	?	?	?	?	?
Blind Jims Creek	↑↑ 0.034	↑↑ 0.026	↑↑ 0.018	DL	?	?	?	?	?	?	↓↓ 0.003	↓↓ 0.002	?	↓↓ 0.001	↓↓ 0
Mangahou Stream	↑↑ 0.091	↑↑ 0.052	↑↑ 0.031	DL	?	?	?	?	?	?	?	?	↔	↑↑ 0.001	?
Mangape Creek	?	-	-	?	-	-	?	-	-	?	-	-	?	-	-
Nairn River	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Te Awainanga River	↑↑ 0.106	↑↑ 0.047	↑↑ 0.029	DL	?	?	↑↑ 0.007	↑↑ 0.002	↑↑ 0.001	?	?	?	↑↑ 0.003	↑↑ 0.001	↑↑ 0.001
Te One Creek	↑↑ 0.152	↑↑ 0.052	↑↑ 0.034	DL	?	?	?	?	?	?	?	?	↑↑ 0.003	?	?
Rakautahi Stream	↑↑ 0.119	↑↑ 0.068	↑↑ 0.046	?	?	?	?	↑↑ 0.001	↑↑ 0	?	?	↓↓ 0.001	?	?	↔
Waimahana Creek	?	↑↑ 0.016	↑↑ 0.009	?	?	?	?	↑↑ 0.001	↑↑ 0	?	?	?	↓↓ 0.011	?	↑↑ 0.004
Waitaha Creek	?	↑↑ 0.068	?	?	?	?	?	?	?	?	↓↓ 0.002	↓↓ 0.003	?	↔	?

Table 24: Trend analysis results for nutrient parameters measured from monitored Chatham Island watercourse sites

Waitamaki Creek	↑↑ 0.058	↑↑ 0.03	↑↑ 0.016	↑↑ 0.005	?	↔	?	?	?	?	↓↓ 0.005	↓↓ 0.004	↔	?	?
Washout Creek	↑↑ 0.079	↑↑ 0.081	↑↑ 0.051	?	?	?	?	?	?	↓↓ 0.016	?	?	↓↓ 0.005	?	?
Whangamoe Inlet Stream	↑↑ 0.117	?	↑↑ 0.02	?	?	?	?	?	?	?	↓↓ 0.002	?	↓↓ 0.007	?	?

Notes:

↑↑ = *'Significantly Increasing;* ↓↓ = *'Significantly Decreasing'';* ↑ = *'Probably Increasing';* ↓ = *'Probably Decreasing';* ↔ = *'Stable'; '?' = 'Indeterminant'; 'DL' indicates too few values were above minimum detection level to complete analysis; '-' indicated that too few data points were available to complete analysis.*

↑↑ 0 or ↓↓ 0 represent that values is more than three decimal places.

Green *colour coding = 'improving' water quality trend;* ***red*** *= 'degrading' water quality trend*

Total Nitrogen

Median TN concentrations recorded during the 2014-2018 monitoring period were variable, ranging from 0.14 mg/L (Waimahana Creek) to 1.24 mg/L (Mangape Creek) (Figure 45). Variation amongst sites was relatively even, although values reported for Mangape Creek were much higher, likely attributed to being the outlet stream for Lake Huro, which is nutrient enriched. Peak (95th percentile) values varied similarly, ranging between 0.41 mg/L (Blind Jim's Creek) to 2.86 mg/L (Mangape Creek). Peak (95th percentile) values recorded at Mangape Creek were 1.19 mg/L higher than the site with the next highest recorded concentration (Waitaha Creek), indicating a high nitrogen source in the Mangape Creek catchment (i.e. lake algal blooms).

Trend analysis produced meaningful results for 12 of the 14 monitored sites across the three monitoring periods for which analysis was conducted (Table 24). In all cases, trend analysis produced significantly positive results, indicating that TN concentrations increased by on average 0.009-0.51 mg/L per year between 2005 and 2018, 0.016-0.081 mg/L per year between 2009 and 2018, and 0.034-0.152 mg/L per year between 2014 and 2018. Annual increases in TN increased in magnitude during more recent monitoring periods (i.e. 2009-2018 and 2014-2018), reflecting recent increases in total nitrogen concentrations/ nitrogen inputs.

Ammoniacal-nitrogen

Median ammoniacal-nitrogen concentrations ranged from 0.005 (Whangamoe Inlet Stream) to 0.062 mg/L (Washout Creek) (Figure 45; Table 25). Annual median values were all categorised within NPS-FM (2017) Attribute State A and B bands for ammonia toxicity, indicating 95-99% species protection.

Annual maximum concentrations also showed a high number of censored values, with six sites not exceeding laboratory threshold values. Of the reported values, annual maximum values ranged from 0.023 (Waimahana Creek) to 0.41 mg/L (Washout Creek), indicating that most sites were categorised within the NPS-FM (2017) Attribute State A or B bands, except for Washout Creek which was within Attribute State C, indicating 80% species protection. National bottom-line values were not exceeded on any occasion.

Trend analysis produced meaningful trends for two sites: Awatotara Creek and Waitamaki Creek. Results indicate that median concentrations remained stable at Waitamaki Creek and Awatotara Creek between the 2005 and 2018 and 2009-2018 monitoring periods, respectively. Average concentrations at Waitamaki Creek increased by 0.005 mg/L annually between 2014 and 2018.

Table 25: Summary of ammoniacal-nitrogen for Chatham Island watercourse sites during the 2014-2018 period

Site Name	Ammoniacal-nitrogen (mg/L)		NPS-FW (2017) Attribute State			
	Annual Median	Annual Maximum	Annual Median	Annual Maximum	Overall	Bottom -line
Awamata Stream	0.05	0.05	B	B	**B**	**Pass**
Awatotara Creek	-	-	-	-	**-**	**-**
Blind Jims Creek	0.05	0.05	B	B	**B**	**Pass**
Mangahou Stream	0.05	0.05	B	B	**B**	**Pass**
Mangape Creek	0.043	0.23	B	B	**B**	**Pass**
Te Awainanga River	0.05	0.05	B	B	**B**	**Pass**
Te One Creek	0.05	0.15	B	B	**B**	**Pass**
Rakautahi Stream	0.05	0.05	B	B	**B**	**Pass**
Waimahana Creek	0.0115	0.023	A	A	**A**	**Pass**
Waitaha Creek	0.0125	0.04	A	A	**A**	**Pass**
Waitamaki Creek	0.014	0.054	A	B	**B**	**Pass**
Washout Creek	0.062	0.41	B	C	**C**	**Pass**
Whangamoe Inlet Stream	0.005	0.05	A	B	**B**	**Pass**
Nairn River	-	-	-	-	**-**	**-**

Nitrate-nitrite nitrogen

Median nitrate-nitrite nitrogen concentrations were highly variable amongst watercourse sites, ranging between 0.004 (Waitamaki Creek) and 0.049 mg/L (Mangape Creek) (Figure 45; Table 26). A median concentration of 0.1 mg/L was reported for Blind Jim's Creek; however, this value represents a transformed censored dataset and therefore, is not reliable. Variation in nitrate-nitrite nitrogen concentrations was typically minimal amongst sites; however, Mangape Creek represents a two-fold increase compared to the next highest reported concentration (Washout Creek; 0.025 mg/L). Peak (95th percentile) concentrations varied similarly, ranging from 0.014 (Mangahou Stream) to 0.46 mg/L (Mangape Creek), with Mangape Creek representing a more than three-fold increase compared to the next highest reported concentration (Waitaha Creek; 0.14 mg/L). This originates from the nutrient enriched Lake Huro.

In lieu of a consistent nitrate-nitrogen dataset, nitrate-nitrite nitrogen concentrations were compared against NPS-FM (2017) nitrate toxicity guidelines. Annual median concentrations at sites were consistently categorised by Attribute State A (Table 26) indicating that there is unlikely to be effects even on sensitive species. Peak (95^{th} percentile) concentrations were typically categorised by Attribute State A or B, indicating that few to no aquatic organisms are impacted by nitrate toxicity (i.e. 5% of organisms). High concentrations measured at Mangape Creek are categorised as Attribute State C, indicating up to 20% of aquatic organisms could be impacted by chronic nitrate toxicity. Despite likely impacts on resident communities, nitrate-nitrite nitrogen concentrations did not surpass national bottom-line values for any site.

Table 26: Summary of nitrate-nitrite nitrogen for Chatham Island watercourse sites during the 2014-2018 period.

Site Name	Nitrate-nitrite Nitrogen (mg/L)		NPS-FM (2017) Attribute State[1]			
	Annual Median	Annual 95th Percentile	Annual Median	95th Percentile	Overall	Bottom-line
Awamata Stream	0.011	0.040	A	A	**A**	**Pass**
Awatotara Creek	0.010	0.100	A	B	**B**	**Pass**
Blind Jim’s Creek	0.100	0.100	A	B	**B**	**Pass**
Mangahou Stream	0.007	0.014	A	A	**A**	**Pass**
Mangape Creek	0.049	0.462	A	C	**C**	**Pass**
Te Awainanga River	0.021	0.053	A	B	**B**	**Pass**
Te One Creek	0.010	0.055	A	B	**B**	**Pass**
Rakautahi Stream	0.011	0.066	A	B	**B**	**Pass**
Waimahana Creek	0.014	0.030	A	A	**A**	**Pass**
Waitaha Creek	0.024	0.144	A	B	**B**	**Pass**
Waitamaki Creek	0.004	0.043	A	A	**A**	**Pass**
Washout Creek	0.025	0.090	A	B	**B**	**Pass**

Table 26: Summary of nitrate-nitrite nitrogen for Chatham Island watercourse sites during the 2014-2018 period.

Site Name	Nitrate-nitrite Nitrogen (mg/L)		NPS-FM (2017) Attribute State[1]			
	Annual Median	Annual 95th Percentile	Annual Median	95th Percentile	Overall	Bottom-line
Whangamoe Inlet Stream	0.007	0.030	A	A	**A**	**Pass**
Nairn River	-	-	-	-	-	-

Notes:
1. *Attribute state derived from NPS-FM threshold **nitrate** values.*

Trend analysis produced significant trends for five of the 14 Chatham Island watercourse sites (Table 24). These results consistently indicate that nitrate-nitrite nitrogen concentrations had very small, but significant increases (0.0004-0.007 mg/L annually) throughout the reported monitoring periods; however, it should be noted that trends were variable amongst monitoring periods. Where analysis was conducted across several monitoring periods (i.e. Te Awainanga River), a higher average annual nitrate-nitrite nitrogen concentration increase was consistently reported for more recent monitoring periods, likely indicating increased nutrient inputs.

Dissolved Inorganic Nitrogen (DIN)

DIN concentrations represent the sum of nitrate-nitrite nitrogen and ammoniacal-nitrogen concentrations measured. As this parameter was calculated in this manner, values are representative of monitoring rounds from which both nitrate-nitrite and ammoniacal-nitrogen were collected, and values were above detection limits. Therefore, median DIN concentrations differ from the sum of median nitrate-nitrite nitrogen and ammoniacal nitrogen concentrations.

Median DIN concentrations ranged between 0.016 (Whangamoe Inlet Stream) and 0.15 mg/L (Blind Jim's Creek). Variation amongst monitoring sites was relatively even, with no sites representing clear outliers (Figure 45; Table 27). Peak (95th percentile) values ranged between 0.05 (Waimahana Creek) and 0.52 mg/L (Mangape Creek). Variation amongst 95th percentile concentrations was mostly minimal; however, measurements from Mangape Creek (0.52 mg/L) and Washout Creek (0.32 mg/L) were approximately two-and three-fold the next highest value recorded from Waitaha Creek (0.16 mg/L).

The proposed NPS-FM (2019) has attribute states and bottom-line values for DIN, with annual median and 95th percentile DIN concentration bands. All Chatham Island watercourse sites were within Attribute State A, indicating no adverse effects attributable to DIN enrichment are expected.

Table 27: Summary of dissolved inorganic nitrogen (DIN) for Chatham Island watercourse sites during the 2014-2018 period

Site Name	DIN (mg/L)		NPS-FM (2019) Draft Attribute State[1]			
	Annual Median	Annual 95th Percentile	Annual Median	95th Percentile	Overall	Bottom -line
Awamata Stream	0.060	0.090	A	A	**A**	**Pass**
Awatotara Creek	-	-	-	-	-	-
Blind Jims Creek	0.150	0.150	A	A	**A**	**Pass**
Mangahou Stream	0.056	0.064	A	A	**A**	**Pass**
Mangape Creek	0.099	0.523	A	A	**A**	**Pass**
Te Awainanga River	0.064	0.095	A	A	**A**	**Pass**
Te One Creek	0.058	0.122	A	A	**A**	**Pass**
Rakautahi Stream	0.058	0.114	A	A	**A**	**Pass**
Waimahana Creek	0.026	0.045	A	A	**A**	**Pass**
Waitaha Creek	0.034	0.162	A	A	**A**	**Pass**
Waitamaki Creek	0.022	0.087	A	A	**A**	**Pass**
Washout Creek	0.110	0.321	A	A	**A**	**Pass**
Whangamoe Inlet Stream	0.016	0.049	A	A	**A**	**Pass**
Nairn River	-	-	-	-	-	-

Notes:
1. *Attribute states are derived from the proposed NPS-FM (2019) numeric attribute states. Values may be subject to change.*

Organic Nitrogen

Organic nitrogen concentrations measured from the monitored sites ranged between 0.12 (Waimahana Creek) and 1.14 mg/L (Mangape Creek) (Figure 45). Variation was low amongst most sites; however, median concentrations were markedly higher from Mangape Creek compared to the next highest median concentration at Washout Creek (0.78 mg/L). Peak (95th percentile) concentrations varied similarly ranging between 0.38 (Blind Jim's Creek) and 2.36 mg/L (Mangape Creek), concentrations were considerably higher for Mangape Creek compared to the next highest 95th percentile value from Washout Creek (1.53 mg/L).

Total Phosphorus

Median TP concentrations varied amongst sites, ranging by an order of magnitude between Blind Jim's (0.018 mg/L) and Waimahana Creek (0.21 mg/L) (Figure 45). Variation amongst sites was typically even, although concentrations measured from Waimahana Creek were notably high compared to the next highest median value from Washout Creek (0.13 mg/L). Peak (95th percentile) concentrations ranged between 0.037 (Blind Jim's Creek) and 0.26 mg/L (Washout Creek), and varied relatively evenly amongst most sites; with the exception of Washout Creek (0.26 mg/L), Waimahana Creek (0.24 mg/L) and Mangape Creek (0.2 mg/L) which were notably higher than the next highest concentration from Whangamoe Stream (0.11 mg/L).

Trend analysis produced meaningful results for half of the monitored sites (Table 24). Results indicate that over the three monitoring periods assessed, small but significant annual decreases in TP concentrations occurred. Decreases ranged from 0.001 (Rakautahi Stream) to 0.016 mg/L (Washout Creek). Results for Awamata Stream indicate that TP concentrations remained stable at this site between 2014 and 2018.

Dissolved Reactive Phosphorus (DRP)

Median DRP concentrations showed a similar trend to TP, with high variation amongst sites. Median concentrations range from 0.005 mg/L (Blind Jim's Creek) to 0.148 mg/L (Waimahana Creek), with Waimahana Creek and Washout Creek (0.092 mg/L) showing distinctly higher median concentrations to the other sites (0.005-0.047 mg/L) (Figure 45; Table 28). Peak (95th percentile) concentrations varied similarly, with a range of 0.009 mg/L (Blind Jim's Creek) to 0.191 mg/L (Waimahana Creek). Concentrations were again much higher for Waimahana and Washout creeks (0.143 mg/L) compared to the other sites (0.009-0.078 mg/L).

DRP is not a parameter covered in the NPS-FM (2017); however, it is present within the proposed NPS-FM (2019) to measure ecosystem health. Median concentrations categorised most Chatham Island sites within Attribute State D (Table 28). At this level, DRP concentrations surpass the proposed national bottom-line value (0.018 mg/L), indicating that ecological communities are possibly impacted by excessive aquatic plant and/or algal growth. The exceptions were Blind Jim's and Waitaha creeks, which were characterised by the proposed A and C attribute states, respectively.

Trend analysis produced meaningful results for 11 sites (Table 24). Results were variable amongst monitoring periods and sites. Available results indicate that concentrations increased annually at Awamata Stream (0.001 mg/L), Te Awainanga River (0.001-0.003 mg/L), and Te One Creek (0.003 mg/L). Results from Te Awainanga River indicate that annual DRP concentrations increased in magnitude during the most recent monitoring period analysed. Concentrations showed very small but statistically significantly decreases within the analysed monitoring periods for Blind Jim's Creek (0.0005-0.0007 mg/L), Washout Creek (0.005 mg/L), and Whangamoe Inlet Stream (0.007 mg/L). Trend directions were variable for Mangahou Stream and Waimahana Creek. Trends shifted from significantly increasing to stable for Mangahou Stream between the 2009-2018 and 2014-2018 monitoring periods, respectively, and from significantly increasing (0.004 mg/L annually) to significantly decreasing (0.011 mg/L annually) between the 2005-2018 and 2014-2018 monitoring periods, respectively for Waimahana Creek.

Table 28: Summary of dissolved reactive phosphorus (DRP) for Chatham Island watercourse sites during the 2014-2018 period

Site Name	DRP (mg/L)		Proposed NPS-FM (2019) Attribute State[1]			
	Annual Median	Annual 95th Percentile	Annual Median	95th Percentile	Overall	Bottom -line
Awamata Stream	0.022	0.030	D	C	**D**	**Fail**
Awatotara Creek	0.024	0.040	D	C	**D**	**Fail**
Blind Jims Creek	0.005	0.009	A	A	**A**	**Pass**
Mangahou Stream	0.02	0.026	D	B	**D**	**Fail**
Mangape Creek	0.025	0.078	D	D	**D**	**Fail**
Te Awainanga River	0.027	0.038	D	C	**D**	**Fail**
Te One Creek	0.027	0.042	D	C	**D**	**Fail**
Rakautahi Stream	0.021	0.034	D	C	**D**	**Fail**
Waimahana Creek	0.148	0.191	D	D	**D**	**Fail**
Waitaha Creek	0.012	0.021	C	B	**C**	**Pass**
Waitamaki Creek	0.029	0.053	D	C	**D**	**Fail**
Washout Creek	0.0915	0.129	D	D	**D**	**Fail**
Whangamoe Inlet Stream	0.0465	0.076	D	D	**D**	**Fail**
Nairn River	-	-	-	-	**-**	**-**

Table 28: Summary of dissolved reactive phosphorus (DRP) for Chatham Island watercourse sites during the 2014-2018 period

Site Name	DRP (mg/L)		Proposed NPS-FM (2019) Attribute State[1]			
	Annual Median	Annual 95th Percentile	Annual Median	95th Percentile	Overall	Bottom-line

Notes:
1. *Attribute states are derived from the proposed NPS-FM (2019) numeric attribute states. Values may be subject to change.*
2. *Nairn River was excluded from this analysis due to lack of data*

9.3.6 Grouping by Stream Type and Cluster Analysis

A cluster diagram and NMDS plot, illustrating relative differences amongst the 14 monitored watercourse sites, were produced based on measurements of pH, water clarity, electrical conductivity, DOC, dissolved oxygen, DIN, ammoniacal nitrogen, nitrate-nitrite nitrogen, and DRP.

Cluster analysis indicates that sites form six major groupings, albeit with a high degree of crossover amongst the stream sites (

Figure 46; Figure 47).

- Cluster 1 represents the largest grouping of sites, within which all sites were included except Mangape Creek, Blind Jim's Creek, Rakautahi Stream, Waimahana Creek, Washout Creek, and Whangamoe Inlet Stream. Only a single data point from Waitaha and Waitamaki creeks were represented in this group, while the remaining sites were more evenly represented.
- Cluster 2 predominantly included datapoints Rakautahi Stream, Waitaha Creek and Awatotara Stream - two datapoints representing each of Mangahou Stream, Whangamoe Inlet Stream, and Awamata Stream, as well as single datapoints representing Te Awainanga Creek and Te One Creek. Based on NMDS results, cluster 2 is most similar to cluster 1, with some observed overlap between groups.
- Cluster 3 included a single datapoint, representing median values calculated during 2007 at Waitaha Creek. NMDS results indicate that this cluster is highly distinct from the others.
- Cluster 4 included all datapoints for Blind Jim's and Waimahana Creeks, as well as the majority of datapoints for Waitamaki Creek. Cluster 4 was relatively distinct from the other groupings, with minimal overlap of sites within the cluster, and no overlap amongst clusters. Sites in cluster 4 differed from the others based on a combination of high pH and water clarity, as well as low DOC levels. Organic nitrogen concentrations were

also consistently lower at these sites; however, this parameter was not included in the analysis

- Cluster 5 included all datapoints for Mangape Creek, as well as the majority of datapoints for Washout Creek, as well as scarce representations from Waitamaki Creek and a single datapoint from Waitaha Creek.
- Cluster 6 included most datapoints from Whangamoe Inlet Stream, as well as scarce representation from Washout Creek, Rakautahi Stream, and Waitaha Creek. NMDS results indicate there was a high degree of overlap between clusters 5 and 6, while cluster 6 also slightly overlapped with cluster 2.

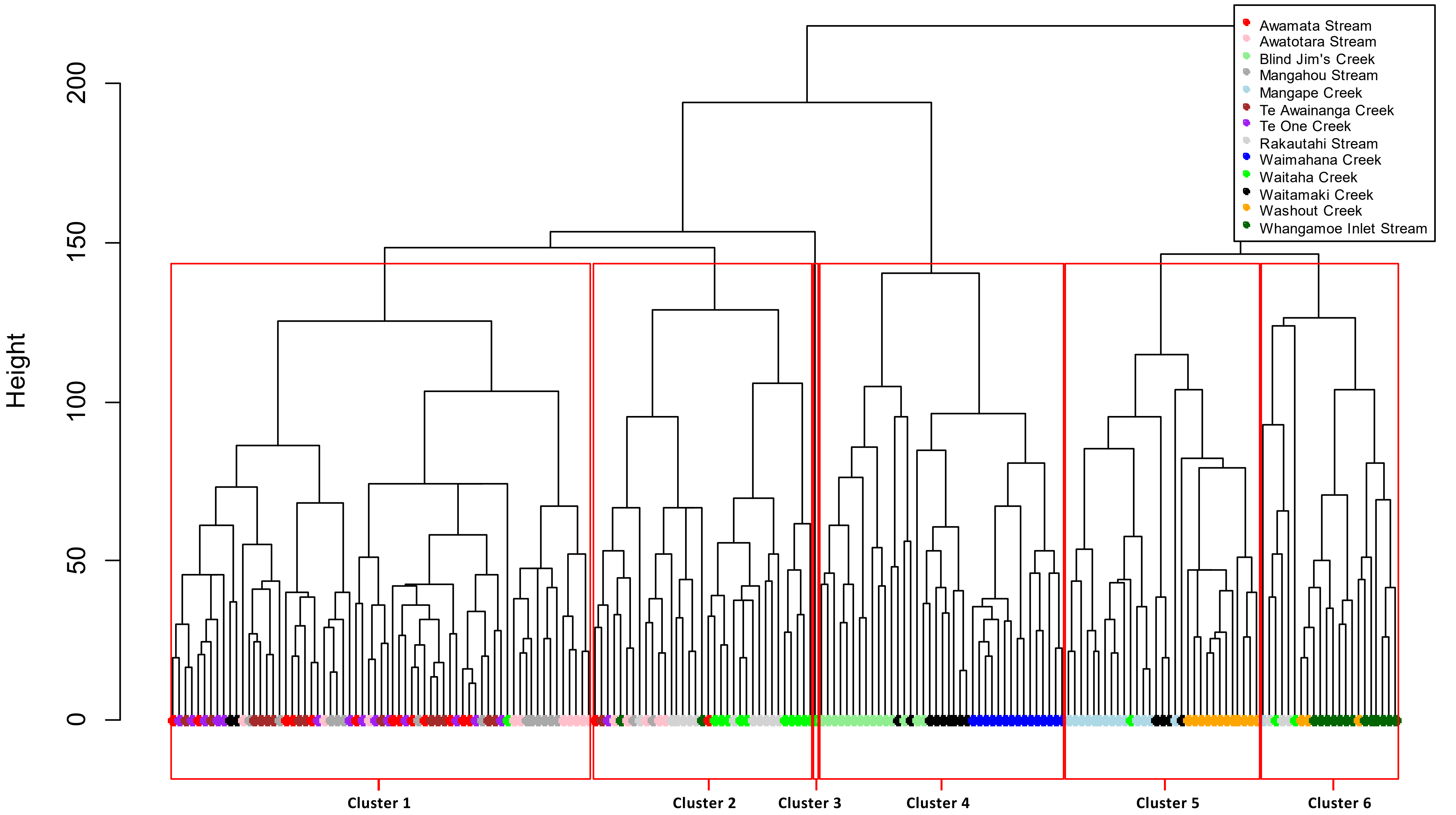


Figure 46: Cluster analysis dendrogram showing grouping of replicate samples at different similarity levels (Y axis) from all watercourse monitoring sites on Chatham Island based on water quality characteristics

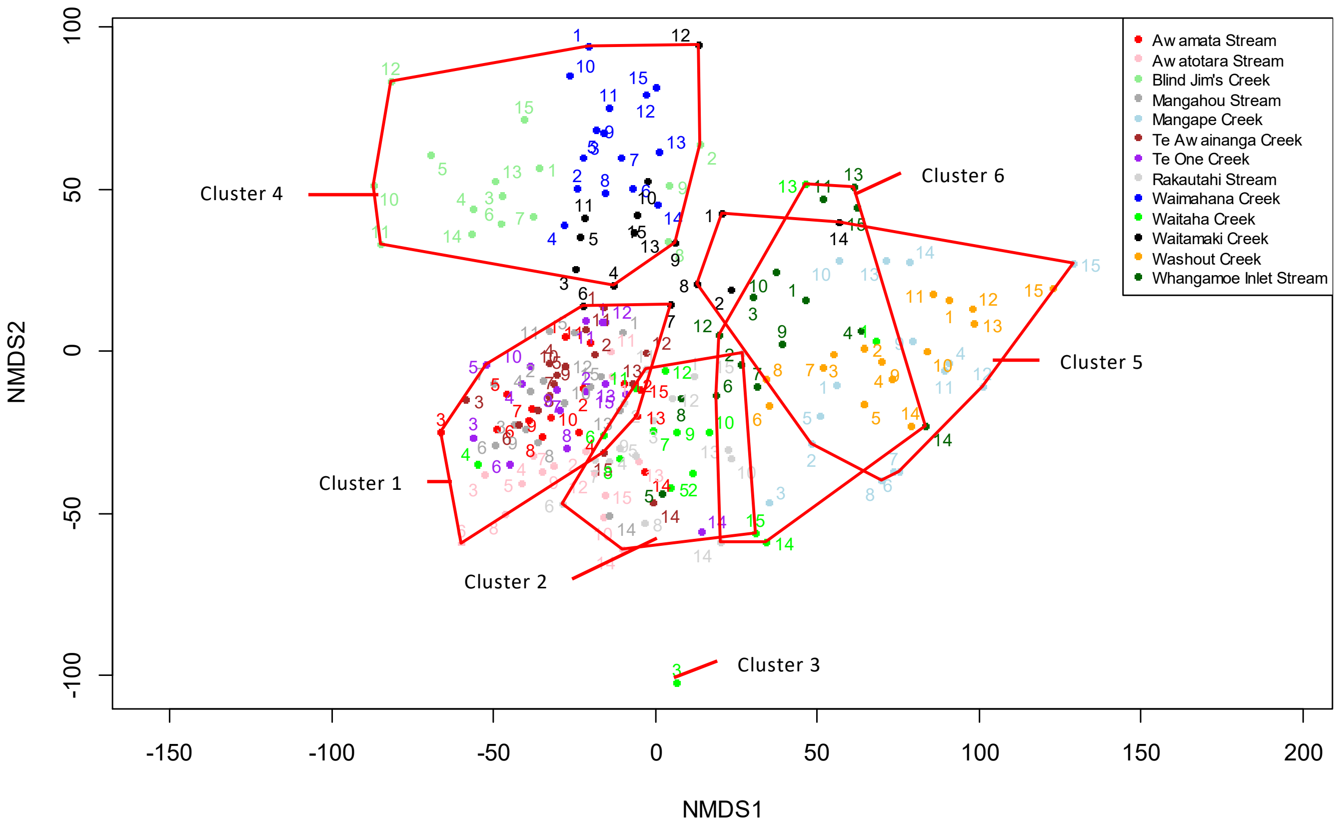


Figure 47: NMDS plot representing similarities in water chemistry between and within sites over time. Overlay following cluster analysis indicates grouping of stream 'type'. Numeric labels (1-15) denote monitoring years in chronological order

9.3.7 Biological Sampling

Benthic Macroinvertebrates

No systematic biological sampling has occurred since the 2007 Chatham Islands SOE report and therefore no additional analysis has been conducted. A full description of the field methodology and data analysis completed for the 19 sites assessed in the 2007 SOE report can be found in Meredith & Croucher (2007).

Meredith & Croucher (2007) document that benthic macroinvertebrate communities from all sites were composed of very similar and simple (low taxa diversity) communities, as shown in Figure 48. In particular, the common 'sensitive stream insect taxa' (EPT) were either absent (mayfly larvae (Ephemeroptera) and stonefly larvae (Plecoptera) or represented by few taxa and were not abundant (Trichoptera). 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. Crustaceans were also frequently present, and in four streams the freshwater shrimp *Paratya curvirostris* was common.

The Chatham Island streams therefore do not contain classically diverse macroinvertebrate communities found elsewhere in mainland New Zealand and cannot be compared to commonly used New Zealand biotic indices such as the Macroinvertebrate Community Index (MCI), or percent of Ephemeroptera (mayfly), Plecoptera (stoneflies) and Trichoptera (caddisfly) (%EPT) taxa. Communities appear to be represented by simple filter and collector browser based food webs, composed of crustaceans or midges. Meredith & Croucher (2007) note that 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).

Meredith & Croucher (2007) also note that 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 (Meredith & Croucher 2007).

Meredith & Croucher (2007) concluded that due to the low macroinvertebrate diversity observed macroinvertebrate communities may not be particularly useful as monitoring tools or indicators of the health or change in health of Chatham Island streams. It is for this reason that the biological monitoring programme has not been continued. It would be beneficial to replicate the study in the future, to determine any changes to the communities since the last survey, however, a Chatham Islands specific biotic index may need to be developed to gain meaningful insight into community change over time.

Meredith & Croucher (2007) also note that while systematic freshwater fish surveys have not been conducted as part of the quarterly Chatham Island monitoring, a variety of native freshwater species have been recorded by different agencies and during monitoring visits. Fish species identified from those samples included bullies (*Gobiomorphus* sp., *Gobiomorphus huttoni*.), elvers (*Anguilla* spp.), Galaxiids (*Galaxias fasciatus, Galaxias brevipinnis*), and Smelt (*Retropinna retropinna*). No exotic fish have been recorded on the island. Natural and artificial fish passage barriers are common on the island and should be mitigated, where possible.

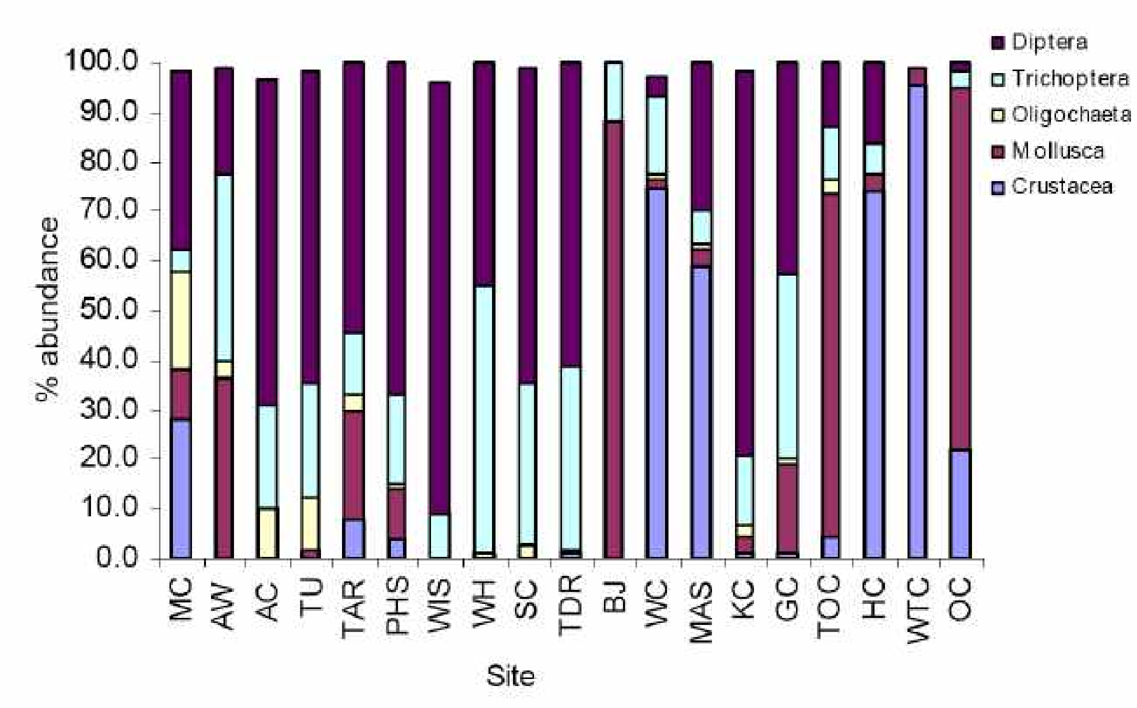


Figure 48: Relative abundance of major macroinvertebrate groups collected in Chatham Island watercourses.

Periphyton, Macrophytes and Sedimentation

Limited information on percent cover of periphyton and macrophyte cover were recorded during the quarterly water quality monitoring. Summary data on these parameters for each site that has records is provided in Appendix E.

One sampling round showed 100% cover of periphyton at Mangahou Stream, while 50% total periphyton cover was observed at Awamata Stream and Awatotara Creek. Te One Creek, Waitahi Creek and Te Awainanga River had between 30 and 45% total periphyton cover recorded.

Macrophyte cover was high at Waimahana Creek for both submerged (85-100% cover) and emergent (35-60% cover) macrophytes on two separate sampling occasions. Blind Jim's Creek also recorded high submergent and emergent macrophyte cover levels (30 and 60%, respectively).

Sedimentation, the amount of fine sediment material settled on the bed of the watercourse, was recorded at 0% for most. Mangape Creek showed high levels of sedimentation, with 95% cover on the one event it was recorded.

9.4 Results – Te Whanga

9.4.1 General Water Quality

Median annual results from water quality monitoring across all sites and monitoring years are presented in Appendix D. Long term data is presented in this section (general water quality), summary analysis of additional data collected are provided in Appendix E.

Physicochemical water quality data for the full monitoring period (2005-2019) represent the available long-term state of water quality at Te Whanga Lagoon. Summarised data for a range of physicochemical water quality parameters are presented in Figure 49.

Some median values for water quality parameters were variable amongst Te Whanga sites, while all were variable amongst sampling occasions. Median pH values were consistently slightly alkaline (pH 8.1-8.2) (Figure 49), although measured concentrations have been variable throughout the monitoring programme, ranging from slightly acidic (pH 6-6.7) to alkaline (pH 8.4-9.1). Median alkalinity (as HCO_3) was slightly more variable, ranging between 153 and 167 mg/L; however, data was more scarcely collected for this parameter.

Median water clarity values ranged between 75 and 100+ cm (Figure 49). However, throughout the monitoring programme, water clarity values have varied substantially, with minimum values ranging from 0-24 cm and maximum values consistently 100+ cm amongst sites.

Table 29: Te Whanga Lagoon surface water monitoring sites	
Reference ID	**Te Whanga Lagoon site**
NBJ	Te Whanga Lagoon beach 300m north of Blind Jim's Creek
W	Te Whanga Lagoon southern basin (west)
AR	Te Whanga Lagoon lake shore at Waitamaki Creek Beach (Air Base Road)

Median salinity values were consistently high amongst Te Whanga Lagoon sites throughout the monitoring programme, ranging between 25.9 and 27.1 ppt (Figure 49). However, values have been highly variable throughout the monitoring programme, with minimum values ranging from 0.4-11.7 ppt and maximum values ranging between 32.7 and 33.5 ppt amongst sites, indicating periods when the lagoon was closed or open to the sea. Conductivity measurements reflect these variable levels of salinity, with high median concentrations (3790-4052 µS/m) varying markedly from minimum (78-2180 µS/m) and maximum values (4992-6400 µS/m).

Median DOC concentrations varied slightly amongst the Te Whanga monitoring sites, ranging between 4.2 and 5.7 mg/L (Figure 49). Minimum values ranging between 0.8 and 1.6 mg/L and maximum concentrations ranging between 12 and 17 mg/L, showing the influence of seasonal tributary inputs.

Median DO concentrations varied little amongst Te Whanga Lagoon sites, ranging between 9.5 and 10 mg/L (Figure 49). Concentrations were variable over time; however, concentrations were never low enough to produce more than slightly hypoxic conditions, with minimum values ranging between 4.7 and 5.0 mg/L. DO saturation levels varied similarly, with high median values ranging between 105 (southern basin (west) and lake shore at Waitamaki Creek Beach sites) and 112% (beach site 300 m north of Blind Jim's Creek). Minimum saturation levels ranged between 52 (beach site 300 m north of Blind Jim's Creek) and 54% (southern basin (west)).

Sulphate concentrations were scarcely measured at Te Whanga Lagoon throughout the monitoring programme, and no measurements were collected for the southern basin (west) site. Measured concentrations were high, with median values ranging between 1600 and 1700 mg/L, while minimum and maximum concentrations were 1400-1500 mg/L and 2100 mg/L, respectively (Figure 49).

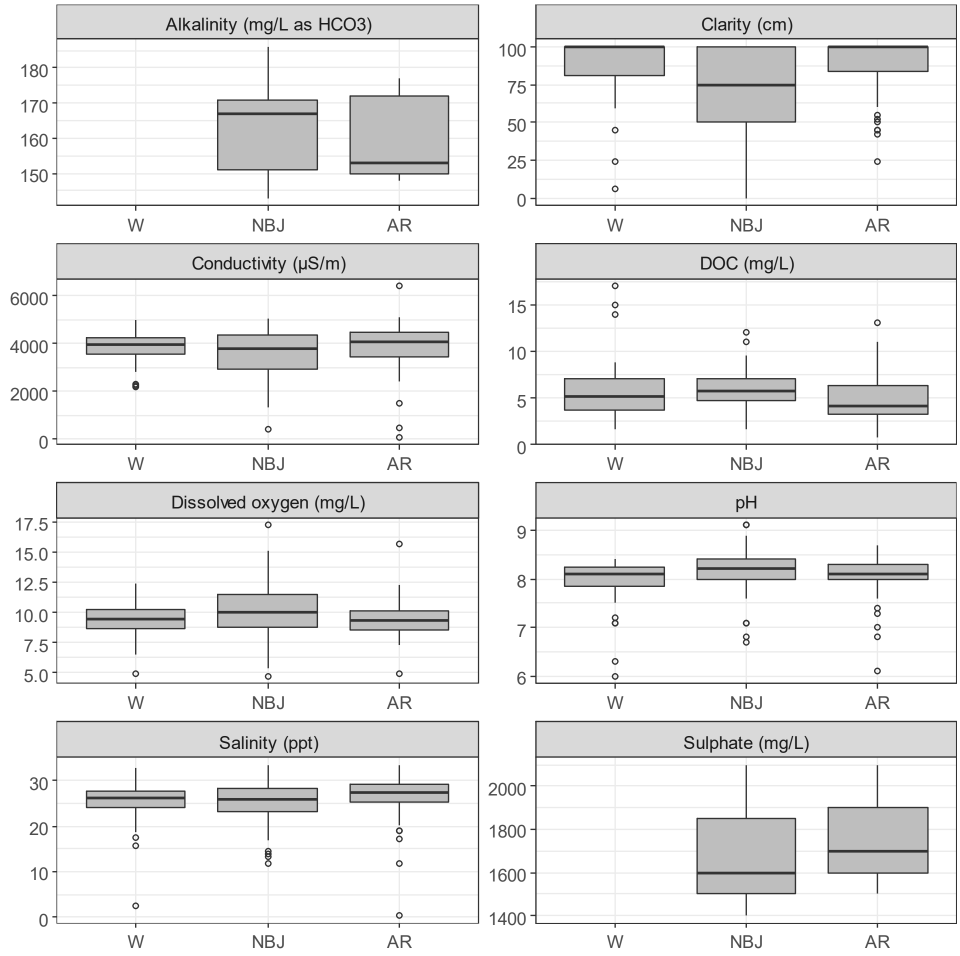


Figure 49: Summary of physicochemical water quality measurement collected from monitored Te Whanga Lagoon sites between 2005 and 2019.

9.4.2 Te Whanga Lagoon Nutrient Concentrations – Long-term

Nutrient concentrations over the full monitoring period (2005-2019) were summarised to establish the long-term status of Te Whanga Lagoon nutrient concentrations amongst the three monitored sites on Chatham Island. Summarised data for a range of key parameters are presented in Figure 50.

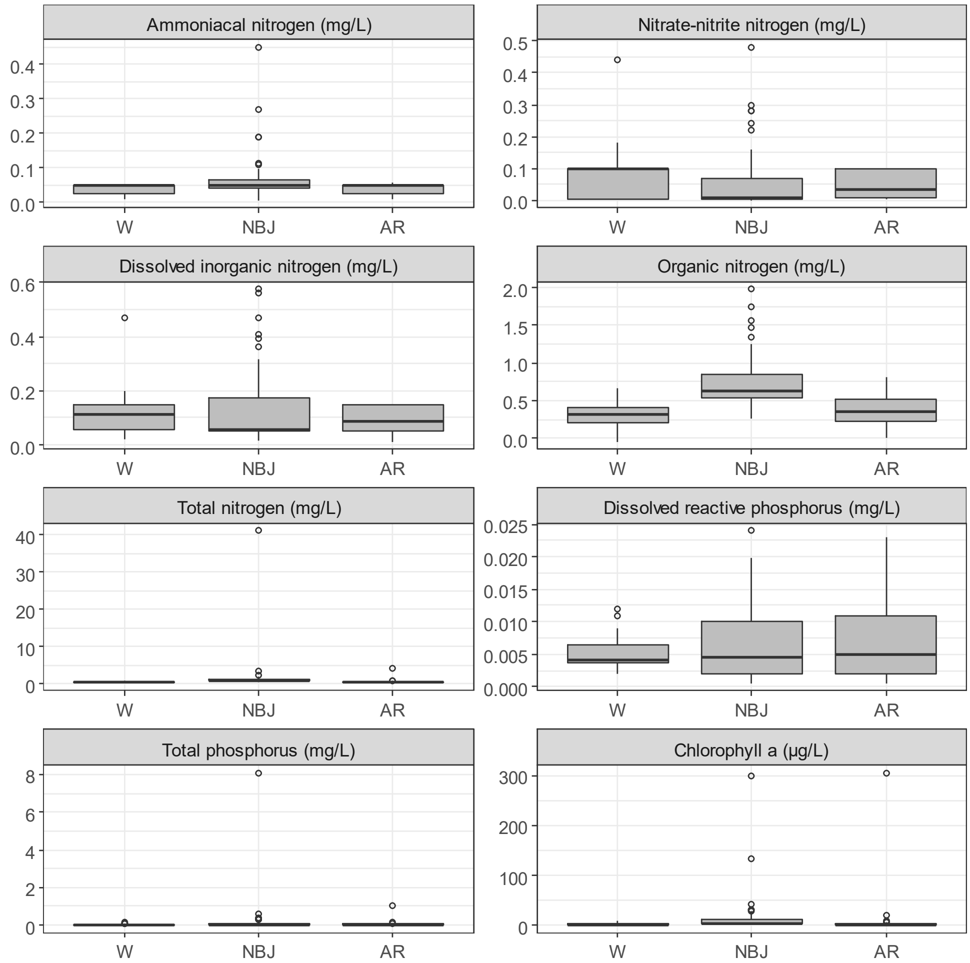


Figure 50: Summary of water quality (nutrient) measurement collected from monitored Te Whanga Lagoon sites between 2005 and 2019.

Median TN concentrations ranged between 0.4 and 0.83 mg/L amongst Te Whanga Lagoon sites (Figure 50). Minimum and maximum values range between 0.04 and 0.32 mg/L and 0.71 and 41 mg/L, respectively. The substantially higher maximum value recorded from the monitoring site located 300 m north of Blind Jim's Creek (NBJ) of 41 mg/L represents a distinct outlier, as the 95th percentile concentration for this site is much lower (1.98 mg/L). Analyst comments indicate that this sample was collected following heavy rainfall and during gale-force easterly winds which had caused lagoon bed sediments to become suspended.

As much of the ammoniacal-nitrogen dataset consisted of censored values, the median concentrations for all sites represented the transformed value of 0.05 mg/L. Minimum and maximum concentrations were within the range of 0.006-0.009 mg/L and 0.05- 0.45 mg/L, respectively (Figure 50). Median nitrate-nitrite nitrogen concentrations ranged between 0.007 and 0.1 mg/L (Figure 50), while minimum and maximum concentrations were within the range of 0.0005-0.001 mg/L and 0.1-0.48 mg/L, respectively.

Median TP concentrations varied similarly, ranging between 0.023 and 0.045 mg/L (Figure 50). Minimum concentrations ranged between 0.002 and 0.01 mg/L, while maximum concentrations were much more variable, ranging between 0.12 and 8.1 mg/L. 95th percentile concentrations ranged between 0.09 and 0.35 mg/L, indicating that as seen in the TN results, the high maximum value measured from the site 300 m north of Blind Jim's Creek (8.1 mg/L) is an outlier caused by adverse weather conditions.

Median DRP concentrations ranged between 0.004 and 0.005 mg/L (Figure 50). Minimum concentrations represented censored data, ranging between 0.0005 and 0.002 mg/L, while maximum concentrations ranged between 0.012 and 0.024 mg/L.

Median concentrations of chlorophyll-*a* ranged between 1.2 and 3.2 µg/L, and while minimum recorded concentrations varied little between sites (0.1-0.5 µg/L), maximum concentrations showed a high range (8.3 - 306.4 µg/L). Assessment of maximum concentrations indicates that phytoplankton density is highly spatiotemporally variable amongst Te Whanga Lagoon sites and that the sites located 300 m north of Blind Jim's Creek (NBJ) and at the lake shore at Waitamaki Creek Beach (Air Base Road) are susceptible to planktonic algae blooms. Peak (95th percentile) concentrations ranged between 6.5 and 33.3 µg/L, with concentrations recorded from the site located 300 m north of Blind Jim's Creek representing a five-fold increase compared to the remaining sites; this indicates that phytoplankton blooms were less frequent at the lake shore at Waitamaki Creek Beach (Air Base Road) compared to the site located 300 m north of Blind Jim's Creek.

9.4.3 Nutrient Ratios

Te Whanga Lagoon monitoring sites were assessed to determine the extent to which phytoplankton growth is limited by nutrient concentrations. Assessment of total nutrient limitation for Te Whanga Lagoon sites in the last five years of data (2014-2019) is presented in Table 30.

Table 30: Median five year (2014-2019) Te Whanga Lagoon TN:TP and DIN/DRP ratios ranked and grouped by nutrient limitations category.

Site Name	TN	TP	TN:TP[1]
W	0.375	0.016	23.44
AR	0.44	0.019	23.78
NBJ	0.8	0.032	25

Table 30: Median five year (2014-2019) Te Whanga Lagoon TN:TP and DIN/DRP ratios ranked and grouped by nutrient limitations category.

Site Name	TN	TP	TN:TP[1]
Site Name	**DIN**	**DRP**	**DIN:DRP[1]**
NBJ	0.055	0.007	8.42
W	0.054	0.005	10.19
AR	0.085	0.006	14.17

Notes:

TN:TP ratio - P limited (>20); Co-limited by N and P (10-20); N limited (<10)
DIN:DRP ratio - P limited (>15); Co-limited by N and P (7 – 15); N limited (<7)

TN:TP limitation thresholds are sourced from Croucher &Meredith (2007) for direct comparison. DIN:DRP thresholds are sourced from McDowell et al., 2009.

NBJ = Te Whanga Lagoon beach 300 m north of Blind Jim's Creek
W = Te Whanga Lagoon southern basin (west)
AR = Te Whanga Lagoon lake shore at Waitamaki Creek Beach (Air Base Road)

TN:TP ratios indicate that all sites are phosphorus limited; however, as most of this total nutrient concentration could be stored within phytoplankton biomass, dissolved soluble ratios give a better indication of nutrient limitation at each site.

DIN:DRP ratios indicate that all sites are co-limited by nitrogen and phosphorus. The site located 300 m north of Blind Jim's Creek is shown to be slightly more limited by phosphorus, while the lake shore site at Waitamaki Creek Beach (Air Base Road) is slightly more limited by nitrogen.

9.4.4 Trends in Te Whanga Nutrient Concentrations

Average annual trends in nutrient concentrations were calculated for Te Whanga Lagoon monitoring sites over three monitoring periods: 2005-2018 (14-year trends), 2009-2018 (10-year trends), and 2014-2018 (5-year trends). Trend analysis established meaningful annual trends for ammoniacal nitrogen, nitrate-nitrite nitrogen, DRP, TP, and chlorophyll-*a*. No meaningful trends were established for the southern basin (west) site. Summarised results are presented in Table 31 and scatterplots presenting the temporal variability of reported water quality parameters across sites are presented in Appendix F.

The lake shore site at Waitamaki Creek Beach (Air Base Road) was the only Te Whanga Lagoon site for which a meaningful annual trend in ammoniacal-nitrogen could be established (Table 31). This result indicates concentrations significantly increased, albeit by a low level (0.002 mg/L) between 2014 and 2018.

Further meaningful trends were established for the Te Whanga Lagoon site located 300 m north of Blind Jim's Creek (Table 31). For this site, trend analysis indicates that average annual nitrate-nitrite nitrogen, DRP, and TP concentrations showed a small, but significant increase of 0.002 mg/L, 0.003 mg/L, and 0.007 mg/L, respectively, between 2014 and 2018. In contrast, average annual chlorophyll-*a* concentrations remained stable throughout this period.

Table 31: Trend analysis results for nutrient water quality parameters and chlorophyll-*a* at monitored Te Whanga Lagoon sites

	Ammoniacal-nitrogen (mg/L)			Nitrate-nitrite nitrogen (mg/L)			Dissolved Reactive Phosphorus (mg/L)			Total Phosphorus (mg/L)			Chlorophyll-*a* (µg/)		
Site	**5-year trend**	**10-year trend**	**14-year trend**	**5-year trend**	**10-year trend**	**14-year trend**	**5-year trend**	**10-year trend**	**14-year trend**	**5-year trend**	**10-year trend**	**14-year trend**	**5-year trend**	**10-year trend**	**14-year trend**
NBJ	?	-	-	**↑↑0.002**	-	-	**↑↑0.003**	-	-	**↑↑0.007**	-	-	↔	-	-
W	?	-	-	DL	-	-	?	-	-	?	-	-	?	-	-
AR	**↑↑ 0.002**	-	-	?	-	-	?	-	-	?	-	-	?	-	-

Notes:

↑↑ = 'Significantly Increasing; ↓↓ = 'Significantly Decreasing''; ↑ = 'Probably Increasing'; ↓ = 'Probably Decreasing'; ↔ = 'Stable'; '?' = 'Indeterminant'; 'DL' indicates too few values were above minimum detection level to complete analysis; '-' indicated that too few data points were available to complete analysis.

***Green** colour coding = 'improving' water quality trend; **red** = 'degrading' water quality trend*

10.0 Te Whanga Nutrient Flux

Monthly nutrient sampling was conducted between November 2010 and May 2012 for 13 watercourses flowing into Te Whanga Lagoon (Figure 51). The main purpose of the sampling was to estimate the nutrient flux from these watercourses into the lagoon and determine any high load catchments where mitigation could be focused.

The catchments from these monitored waterways comprise a total area of approximately 120 km² and capture the majority of the Te Whanga contributing catchment area which is estimated at 160 km². The remaining 40 km² not captured by this sampling programme is predominantly the 'esplanade' area between the north and south of the Island and the contributing catchment area downstream of the southern monitoring sites. All catchments monitored contribute water and nutrients to Te Whanga.

To enable the calculation of the monthly nutrient flux, monthly flow volumes were estimated for each of the 13 catchments:

- For the Te Awainanga River the recorded flow at the Te Awainanga River at Falls was used. This is the largest contributing catchment and makes up over 60% of the total monitored catchment area flowing into the lagoon. Monthly flow volumes for this recorder could be derived directly from the flow record;
- For six sites, a regression equation could be used to translate the monthly flow (and volume) from the relevant primary recorder to the catchment of interest; and,
- For the remaining six sites with no recorder data or regression equations available, monthly flows were estimated by scaling the flow based on the relative catchment area (between the primary recorder and the catchment of interest).

Of the three primary recorders, only the Te Awainanga River had a complete record over the full sampling period. The Tutuiri River was missing flow data in November and December 2010 whilst Awamata was missing flow data in March, April and May 2011. Therefore, the flux analysis was restricted to only using data from June 2011 to May 2012.

Catchment areas for all but three sites were available from the previous ECan study (Ritson, 2010). For the three remaining sites, Blind Jim's (North) Trib at North Rd, Nikau Reserve Stream at North Road and Wharekauri Stream at North Road, the catchment areas were delineated using the Topo50 map series.

Table 1, Appendix G shows the average monthly flow contributed from each catchment to Te Whanga and Table 32 shows the minimum, median and maximum nutrient concentrations (TN,TP, Nitrate-Nitrite and DRP) for each site. These four nutrients were sampled for each of the 13 catchments at a monthly frequency with the exception of the Waimahana Creek at Chudleigh Reserve which was not sampled for TN, TP or nitrate-nitrite for the November 2011 sampling round due to access issues.

Figure 52 shows the total nutrient load derived from all monitored catchments for each monthly interval. Figure 52 shows that highest nutrient loads generally occur in winter, autumn and spring. The exception to this is April 2012 which reports low loading for all nutrients. Further inspection of the data shows that this is primarily due to relatively low flow (compared to the other winter, autumn and spring months) for all rivers and low nutrient concentrations (especially TN and nitrate-nitrite) reported in the Te Awainanga River which provides most of the nutrient load (~60-70%).

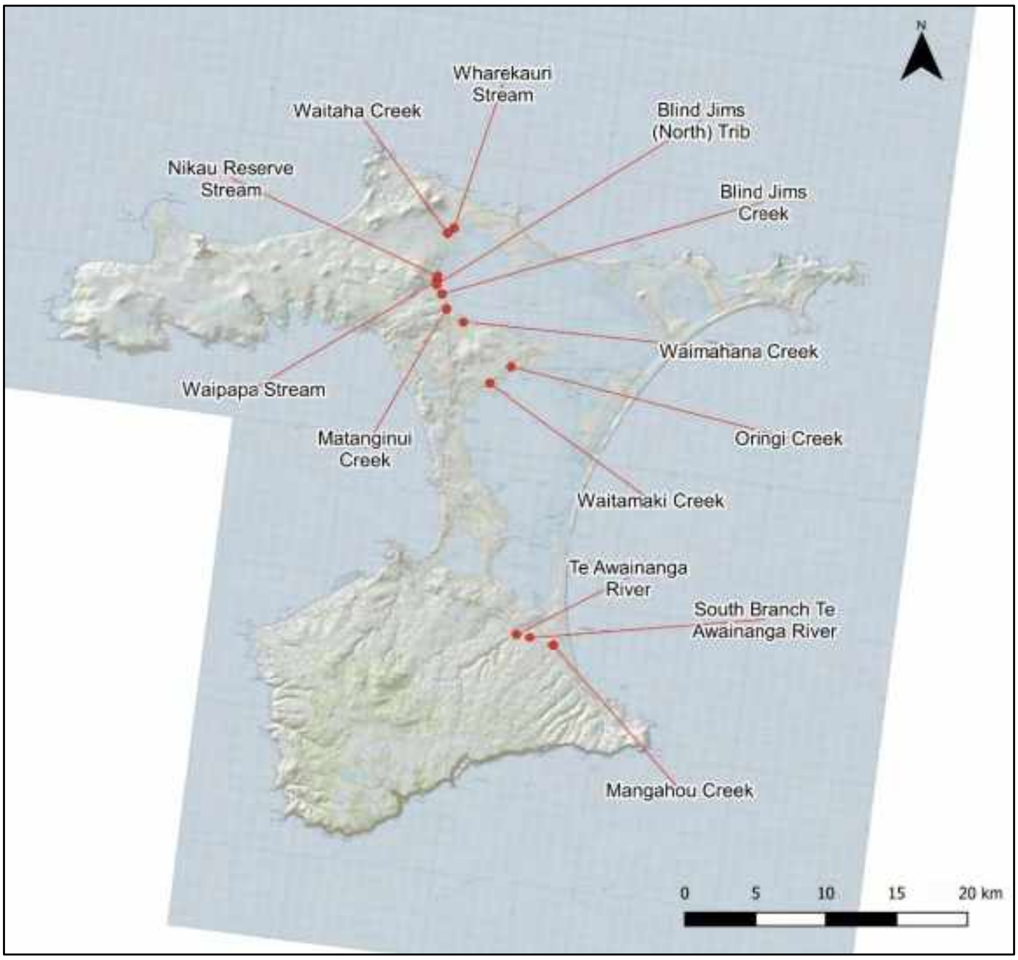


Figure 51: Nutrient monitoring locations

Table 32: Summary of nutrient concentrations from June 2011 to May 2012

Site	Total Nitrogen (g/m^3)			Nitrate-Nitrite (g/m^3)			Total Phosphorous (g/m^3)			Dissolved Reactive Phosphorous (g/m^3)		
	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
North sites												
Blind Jim's (North) Trib at North Rd	0.040	0.200	5.400	0.003	0.004	0.011	0.058	0.125	0.730	0.003	0.004	0.011
Blind Jim's Creek at North Road	0.040	0.130	0.560	0.003	0.003	0.017	0.026	0.067	0.230	0.003	0.003	0.017
Matanginui Creek at North Road	0.040	0.115	1.700	0.010	0.033	0.045	0.084	0.145	0.350	0.010	0.033	0.045
Oringi Creek at Air Base Road	0.040	0.140	0.720	0.003	0.003	0.011	0.014	0.054	0.074	0.003	0.003	0.011
Nikau Reserve Stream at North Road	0.200	0.490	1.500	0.003	0.030	0.180	0.078	0.115	0.550	0.003	0.030	0.180
Wharekauri Stream at North Road	0.190	0.350	1.400	0.003	0.003	0.011	0.020	0.049	0.590	0.003	0.003	0.011
Waimahana Creek at Chudleigh Reserve Stream	0.040	0.040	0.470	0.003	0.005	0.017	0.130	0.220	0.320	0.003	0.005	0.017
Waipapa Creek at North Road	0.040	0.220	1.300	0.003	0.009	0.046	0.046	0.080	0.240	0.003	0.009	0.046
Waitaha Creek at North Road	0.200	0.325	1.700	0.003	0.009	0.040	0.023	0.043	0.077	0.003	0.009	0.040
Waitamaki Creek at Air Base Road Bridge	0.040	0.225	0.630	0.003	0.014	0.050	0.047	0.099	0.130	0.003	0.014	0.050
South sites												
Te Awainanga River- South Branch	0.040	0.095	0.540	0.003	0.003	0.016	0.040	0.059	0.140	0.003	0.003	0.016
Te Awainanga River	0.040	0.160	0.860	0.003	0.005	0.027	0.034	0.050	0.130	0.003	0.005	0.027
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	0.040	0.145	0.820	0.003	0.003	0.009	0.021	0.033	0.044	0.003	0.003	0.009

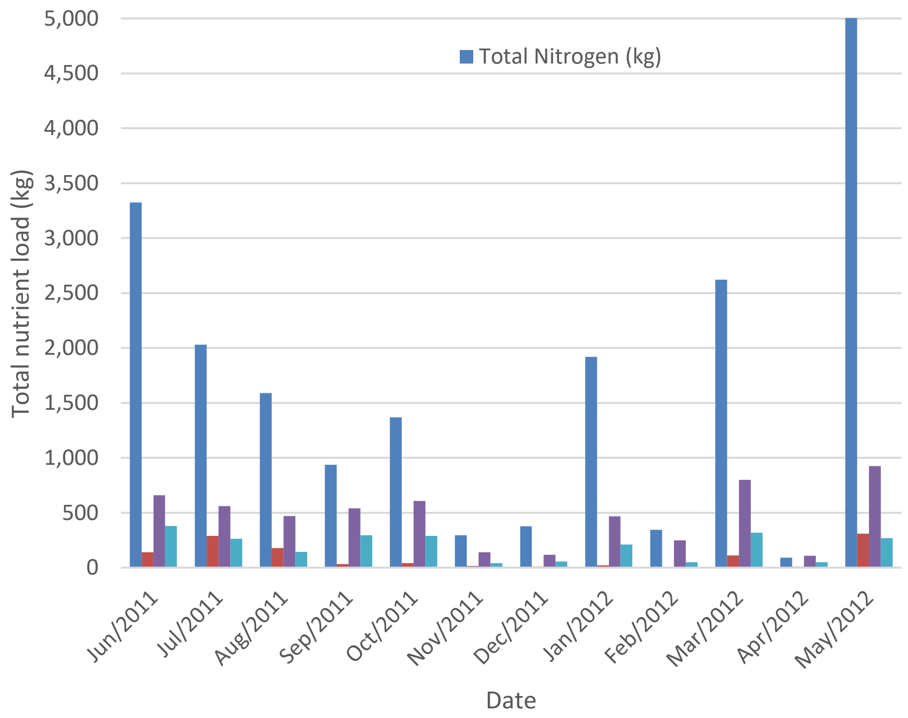


Figure 52: Calculated total nutrient load (kg) by month

Table 2 to Table 5 (Appendix G) show the monthly nutrient loads for TN, TP, nitrate-nitrite and DRP, respectively.

It is noted that the available data provides a snapshot of the nutrient flux into the lagoon. Due to the limitations of the dataset and the short length of record available, caution is advised when drawing conclusions. However, the data is considered suitable for drawing high level conclusions regarding relative differences in nutrient flux to the lagoon from the contributing catchments.

Total Nitrogen and Nitrate Nitrogen

Table 33 tabulates TN and nitrate-nitrite load for each catchment, while Figure 53 shows the TN load for each catchment. Figure 54 shows the TN load for each catchment on a per km^2 basis. Approximately 25,700 kg of TN was calculated to be discharged to Te Whanga for the June 2011 to May 2012 period. Almost 19,000 kg of this was discharged from the Te Awainanga River, followed by Mangahou Creek (2,500 kg) and Waitamaki Creek (1,000 kg). The combined load from the three southern sites (Te Awainanga River, Te Awainanga River South Branch and Mangahou Creek) is around 21,700 kg which is 85% of the total load from all the monitored sites combined. These three southern sites effectively all flow into Te Whanga Lagoon via the Te Awainanga River mouth.

Although by far the greatest TN load into Te Whanga Lagoon comes from the southern sites, it is useful to look at the total load per km^2 of catchment area for each of the watercourses, as this provides an indication of localised 'hotspots' in nutrient load (and nutrient concentrations) into Te Whanga Lagoon.

The highest TN load on a per km^2 basis was from the Nikau Reserve Stream, a relatively small catchment (1.14 km^2) on the north-western side of the lagoon. Other sites with relatively high TN loads (on a per km^2 basis) include the three southern sites discussed above, Waitaha Creek, Blind Jim's (North) trib and Matanginui Creek (all greater than 150 kg/km^2).

The combined TN load on a per km^2 basis from the three southern sites (261 kg/km^2) was over double that of the ten northern sites (116 kg/km^2).

Table 33 shows the total calculated nitrate-nitrite discharge over the June 2011 – May 2012 period was almost 1,150 kg with the three southern sites accounting for approximately 84% of the load. The highest load on a per km^2 basis was again from the Nikau Reserve catchment (25.95 kg/km^2). Other sites with relatively high nitrate-nitrite loads (on a per km^2 basis) are Matanginui Creek, Te Awainanga River, and Waitamaki, Waitaha and Waipapa Creek. The combined load per km^2 of catchment area from the three southern sites (11.5 kg/km^2) was over double that of the ten northern sites (5.5 kg/km^2).

Total Phosphorous and Dissolved Reactive Phosphorous

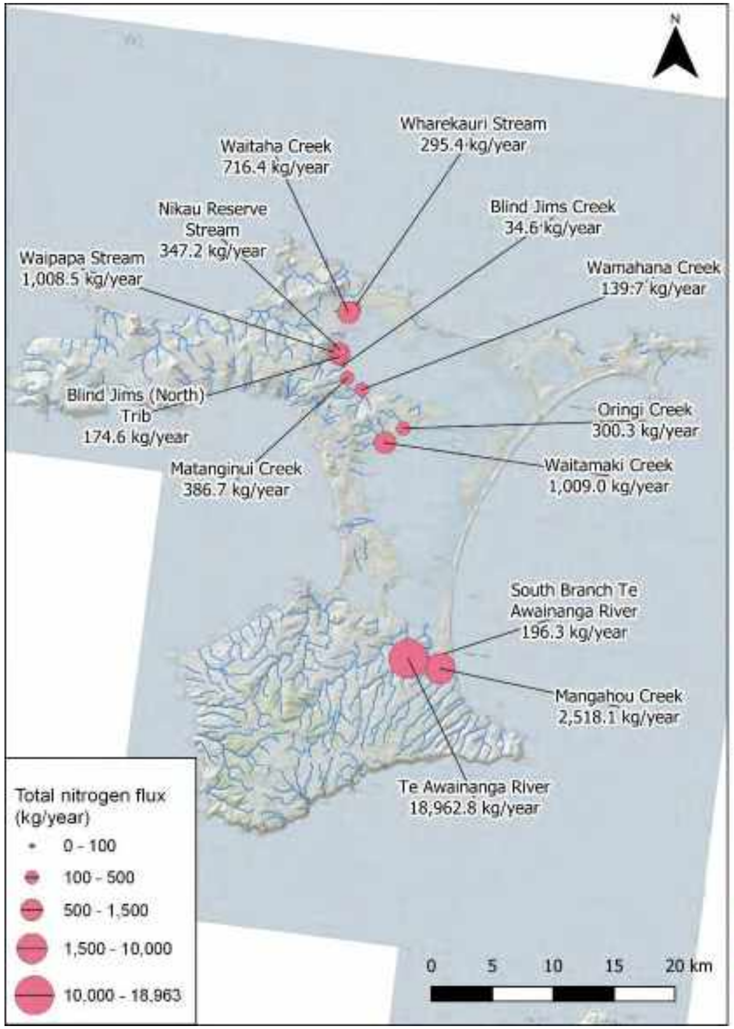
Table 33 tabulates TP and DRP load for each catchment. Figure 53 shows TP load from each catchment and Figure 54 shows TP load for each catchment on a per km^2 basis.

Approximately 5,600 kg of TP was calculated to be discharged to Te Whanga for the June 2011 to May 2012 period. Almost 4,000 kg of this was discharged from the Te Awainanga River, followed by Mangahou Creek (400 kg) and Waitamaki Creek (320 kg). The combined load from the three southern sites is around 4,450 kg which is 80% of the total load from all the monitored sites combined.

The highest TP load on a per km^2 basis was from Blind Jims (North) Trib (101 kg/km^2). Other sites with relatively high TP load (on a per km^2 basis) include the Te Awainaga River, Te Awainanga River South Branch and Matanginui Creek (all greater than 50 kg/km^2).

The combined TP load on a per km^2 basis from the three southern sites (54 kg/km^2) was significantly greater that of the ten northern sites (34 kg/km^2).

Table 33 shows the total DRP discharge over the June 2011 – May 2012 period was almost 2,360 kg with the three southern sites accounting for approximately 85% of the load. The highest load on a per km^2 basis was from the Te Awainanga River South Branch (30 kg/km^2). Other sites with relatively high DRP loads (on a per km^2 basis) are Te Awainanga River, Matanginui Creek, Mangahou Creek, Nikau Reserve Stream and Waitamaki Creek. The combined load per km^2 of catchment area from the three southern sites (24 kg/km^2) was over double that of the ten northern sites (11 kg/km^2).



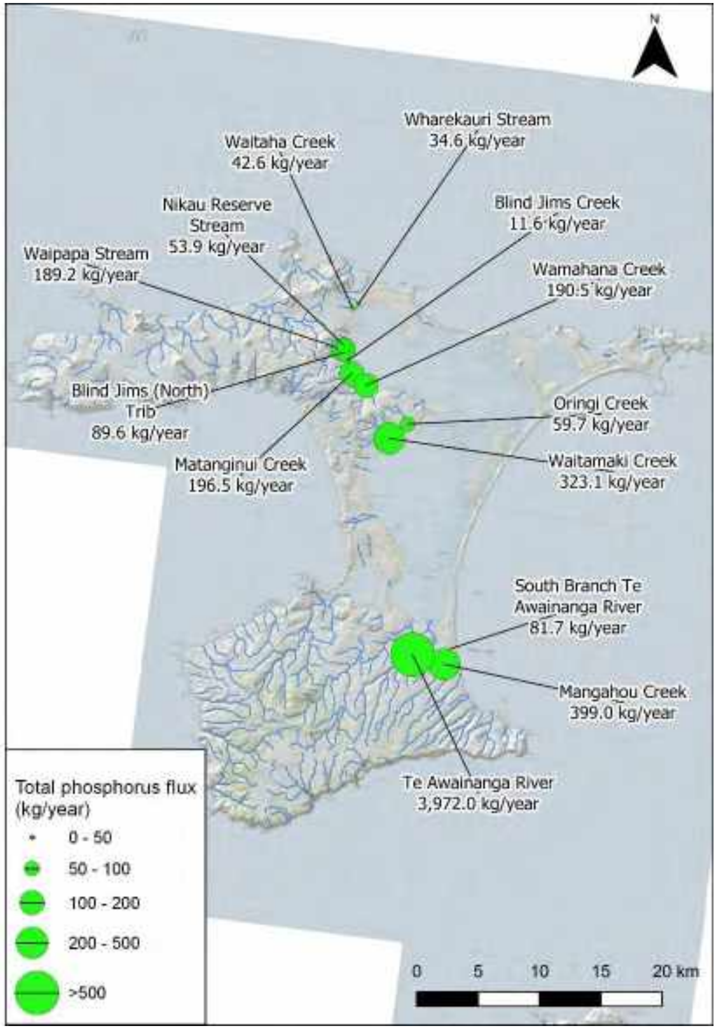


Figure 53: Total nitrogen and total phosphorous load (kg/year) from monitored catchments over the period June 2011 to May 2012

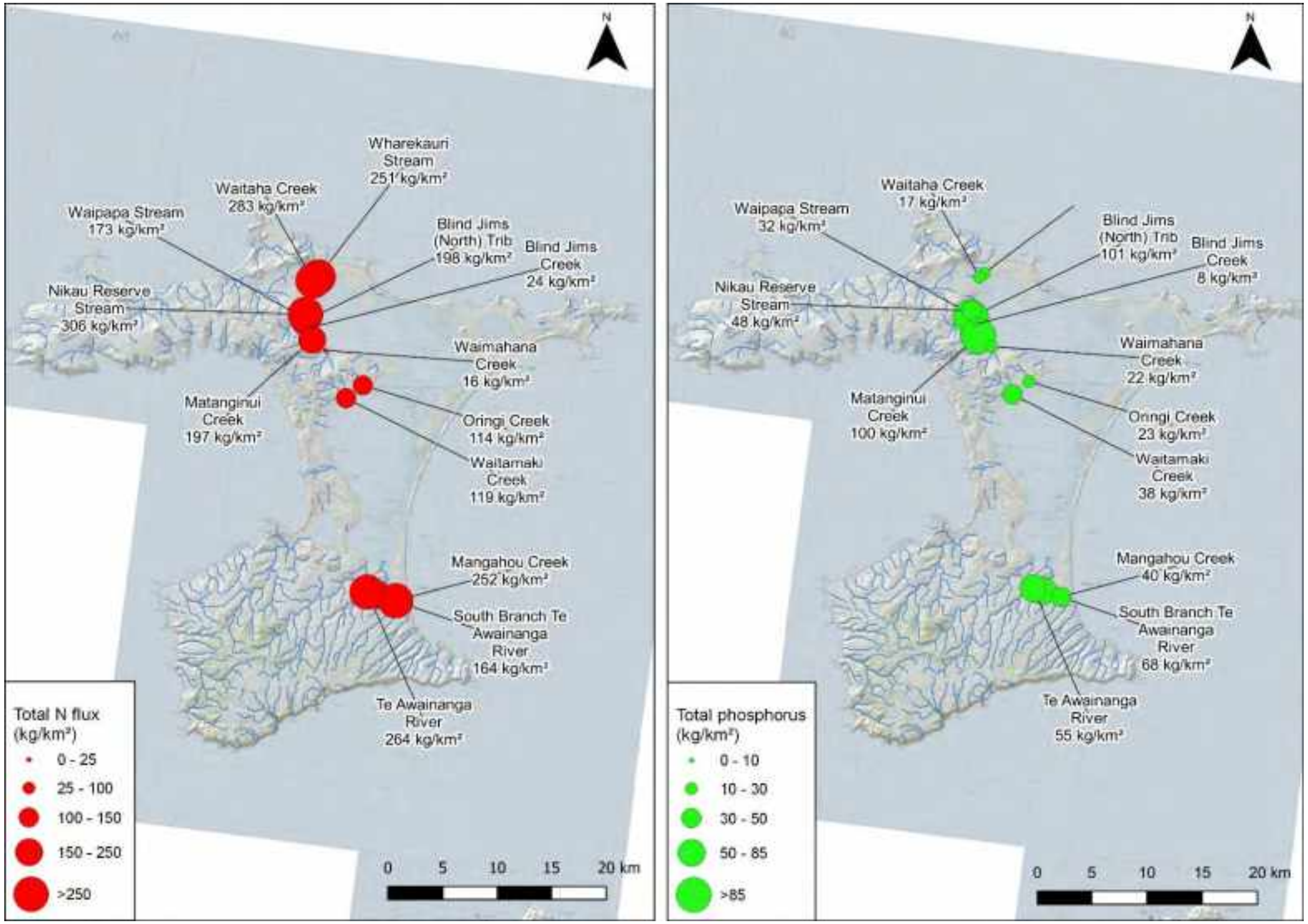


Figure 54: Total nitrogen and total phosphorous on a per km² basis (kg/km²) from monitored catchments over the period June 2011 to May 2012

Table 33: Nutrient loads for water quality sites

Site	Catchment Area (km²)	Annual nutrient discharge rate				Annual Load			
		Total Nitrogen (kg/km²)	Nitrate-Nitrite (kg/km²)	Total Phosphorous (kg/km²)	Dissolved Reactive Phosphorous (kg/km²)	Total Nitrogen (kg)	Nitrate-Nitrite (kg)	Total Phosphorous (kg)	Dissolved Reactive Phosphorous (kg)
Blind Jims (North) Trib at North Rd	0.883	197.76	3.58	101.49	8.85	174.62	3.16	89.62	7.81
Blind Jims Creek at North Road	1.44	24.02	1.19	8.07	2.13	34.58	1.72	11.61	3.07
Matanginui Creek at North Road	1.96	197.30	15.27	100.23	24.77	386.71	29.93	196.46	48.54
Oringi Creek at Air Base Road	2.64	113.75	2.14	22.61	3.01	300.29	5.65	59.70	7.95
Nikau Reserve Stream at North Road	1.135	305.88	25.95	47.52	18.38	347.17	29.46	53.94	20.86
Wharekauri Stream at North Road	1.175	251.42	1.08	29.42	6.20	295.42	1.27	34.57	7.29
Waimahana Creek at Chudleigh Reserve Stream	8.48	16.47	0.92	22.46	9.19	139.65	7.80	190.46	77.96
Waipapa Creek at North Road	5.84	172.69	8.78	32.40	9.20	1,008.53	51.26	189.22	53.70
Waitaha Creek at North Road	2.53	283.16	7.07	16.83	5.76	716.40	17.89	42.57	14.56
Waitamaki Creek at Air Base Road Bridge	8.48	118.98	7.07	38.10	14.32	1,008.95	59.99	323.07	121.39
North Sites	34.563	127.66	6.02	34.47	10.51	4,412.33	208.13	1,191.23	363.15
Te Awainanga River- South Branch	1.2	163.61	4.71	68.08	29.85	196.33	5.65	81.70	35.82
Te Awainanga River	71.85	263.92	12.77	55.28	24.53	18,962.76	917.70	3,971.98	1,762.35
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	9.98	252.31	3.74	39.98	20.10	2,518.10	37.28	399.02	200.55
South Sites	83.03	261.08	11.57	53.63	24.07	21,677.20	960.64	4,452.70	1,998.71
TOTAL FLUX	117.59	221.86	9.94	48.00	20.09	26,089.52	1,168.77	5,643.93	2,361.86

11.0 Review of Different Monitored Water Bodies Suitable for or Limited for Potable and Domestic Uses

This section reviews the suitability of the Chatham Island waterbodies for potable and domestic use in terms of the available amount of water as well as water quality. As previously indicated, there is no or only a very limited amount of groundwater data and as such this section only comments on the surface water resource.

As detailed in section 4.0, the large rivers with significant catchments in the southern hills have perennial (year round) flow. Examples of this are the Te Awainanga, Tuku a Tamatea River and the Nairn River. From a water quantity perspective these rivers would be suitable for potable and domestic use, with no or a very limited amount of storage.

Awamata Stream and also the Tutuiri River in the northern part of the Island both generally have perennial flow except during periods of extreme drought. Over the available record period (1986 – 2019 for Awamata Stream and 1986 – 1994 plus 2006-2019 for Tutuiri River at Schist) these rivers ran dry for a period of approximately three weeks. As such from a water quantity perspective these rivers would be suitable for potable and domestic use, with a limited amount of storage. Other (smaller) rivers can be expected to run dry more frequently, especially in the northern part of Chatham Island where rainfall totals are relatively low. For smaller streams significant amounts of storage may be required to ensure reliability of supply for potable and domestic water.

It is noted that it is common practice in New Zealand (and often a requirement by regional councils) for reticulated (community) surface water supplies to have water saving measures in place to protect instream values during times of low flow. This may restrict the amount of water able to be taken from watercourses during times of low flow. However, it is noted that generally speaking the quantities of water needed on Chatham Island for potable and domestic use are estimated to be relatively small (refer to section 6.0) especially compared to flows in the large waterways on the Island.

In order to provide an indication of the suitability of the surface water resource for potable and domestic use from a water quality perspective, the available water quality data for all the water quality sites were compared with the Drinking-water Standards for New Zealand 2005 (Revised 2018) (DWSNZ).

Water quality data was available for a limited number of determinands. The parameters sampled for with relevant Maximum Acceptable values (MAV) and Guideline values (GV) in the DWSNZ are:

- *E. coli*

- pH
- Fluoride
- Chloride
- Sulphate
- Nitrate
- Nitrite
- Nitrate-nitrite
- Ammoniacal-nitrogen

The results of the sampling show no exceedances of the relevant drinking water standards for fluoride, chloride and the nitrogen species (nitrate, nitrite, nitrate-nitrite and ammoniacal-nitrogen). It is noted that fluoride and chloride was sampled only once in 2005 at the sample locations shown in Figure 35. However, no samples were taken at Lake Marakapia, Lake Te Wapu, Whangamoe Inlet Stream and the Nairn River. Nitrate was only analysed during one sampling round in 2011 for all watercourses but not the Nairn River. Nitrite was only analysed during one sampling round in 2011 for all watercourse and lakes but not the Nairn River and Blind Jim's Creek.

With the exception of the Nairn River all lakes, watercourses in Figure 35 are sampled for nitrate-nitrite and ammoniacal-nitrogen approximately quarterly.

Only two rivers and one lake are sampled regularly for *E. coli*; being the Nairn River, Mangape Creek and Lake Rangitai. The MAV for *E. coli* is less than one in 100 mL of sample. *E. coli* was detected during all sampling rounds in all three water bodies. The minimum recorded concentrations were 1, 11 and 9 MPN per 100 mL for Lake Rangitai, Mangape Creek and the Nairn River, respectively. Median concentrations were 11, 142 and 299 MPN per 100 mL, respectively and maximum concentrations were 2,420 MPN per 100 mL for all three waterbodies.

Sulphate was sampled regularly (approximately quarterly) for all watercourse sites (with the exception of the Nairn River) between 2005 and 2011. Lakes were sampled in 2005 and 2006 on two (Lake Marakapia), three (Lake Te Wapu) and four (Lake Huro, Lake Rangitai and Tennants Lake) occasions. The GV for sulphate (250 mg/L) was exceeded during one sampling round for two watercourse and one lake sites. Concentrations were 1,000, 260 and 580 mg/L for Blind Jim's Creek, Lake Te Wapu and Whangamoe Inlet Stream, respectively. It is noted that the GV value for sulphate is a taste threshold only.

pH is monitored approximately quarterly at all lakes and watercourse sites from 2005 onwards. The exception to this is the Nairn River where quarterly sampling commenced in 2013. The DWSNZ provide a GV between 7.0 and 8.5 for pH. At times all watercourse and lake sites have recorded pH values outside this range.

The recorded pH when outside this range generally show pH values less than 7.0 for watercourse sites whereas for the lakes the recorded pH outside this range are generally greater than 8.5. The exceptions to this are Waimahana and Waitamaki Creeks. Waimahana Creek has no pH readings less than 7.0 and one reading with a pH of 8.8. Waitamaki Creek has two pH readings greater than 8.5 and one reading less than 7.0. For this site this may be due to the sampling site being located relatively close to Te Whanga. ECan (personal communication Kerrie Mears) has indicated that the comment file for the historical flow recorder at this location is that it is regularly flooded due to high lagoon levels.

With the exception of one sample in Lake Rangitai, the available water quality data indicates that *E. coli* was detected in all samples for the watercourses and lakes regularly being sampled. *E. coli* detections are very common in surface water bodies and should surface water be used for drinking water, treatment is required. At times, the pH values in the watercourses are below the GV specified in the DWNZ. Most waters with a low pH have a high plumbosolvency. This means that the water may have the ability to dissolve lead. In water supplies this is an undesirable property as in (usually older) consumer’s premises plumbosolvent water can attack lead pipes, lead service lines and any lead solder used to join copper. Plumbosolvency of water can be countered by achieving a pH of 7.5 by increasing the pH with lime or sodium hydroxide dosing.

It is noted that the analyses described above only compare the available water quality data with the DWSNZ. Only a limited range of determinands has been sampled for and more comprehensive chemical analyses are required to determine the suitability of the monitored water bodies for potable and domestic use.

One of the matters that need to be considered is the dark brown colour of most of the rivers and streams on Chatham Island. This colour is due to the large peat deposits being drained by the watercourses. These reducing (low pH) peat environments can cause elevated concentrations of heavy metals if they are present in the surrounding strata. Testing for these determinands will be important in determining the suitability of the watercourses for drinking water, particularly if there are any areas where streams gain from groundwater, although there is little information to confirm these areas at present. Chemical treatment and filtration may be required to ensure the water is suitable for potable and domestic use. The dark brown colour of most of the waterbodies is caused by tannins and lignins leaching from the peat which can be removed by ultrafiltration. This process is likely to be only viable for large community schemes and/or large commercial operations and may therefore not be feasible for the Chatham Islands. Therefore, should surface water be considered as a potable water source further investigations should focus on waterbodies that are free of tannins and lignins leaching from the peat (i.e. avoid waterbodies with dark brown colours that are likely to drain peat basins). These are limited to very few streams, and only the dune lakes. For this reason alone, much of the water on Chatham Island is not suitable or appealing for use as domestic or potable water. This makes such water a limiting resource that should be explicitly identified and strategies put in place to manage it sustainably, particularly if higher uses develop and recharge of these resources reduce. This can result in water mining and unsustainable use as these sources reduce or dry up.

12.0 Summary and Discussion

12.1 Rainfall and Evapotranspiration

There is a wide variety of rainfall data available across Chatham Island although it is inconsistent and there are no rainfall stations that have a reliable, long term (i.e. greater than 20 year) record. Based on the available rainfall data, rainfall appears to be higher in the south of Chatham Island compared to the north and it is likely, although there are no rainfall stations present, that rainfall across the southern uplands is higher than elsewhere.

Seasonally, rainfall is generally greatest in late autumn and winter, and generally lowest in late spring/summer. Long term patterns of changes in rainfall are uncertain due to the lack of a consistent long term record. The long term record that can be derived from stations at Waitangi suggests that between 1990 and 2012, rainfall was generally greater than the long term average. However, information from recent seasonal data indicates that at least in the summers of 2017/2018 and 2018/2019, rainfall was lower than average (and the lowest recorded in the summer of 2017/2018). However, the long term trend to 2020 is not clear due to a lack of available data.

Potential evapotranspiration data is sparse across the island with only four stations recording data. The available data implies that there is relatively little variation in potential evapotranspiration data between the stations at Waitangi and at the Chatham Islands airport. Unsurprisingly, potential evapotranspiration data shows strong seasonal variations, and is greatest in summer.

12.2 Hydrology

There are four current and two historical continuous flow recorders on Chatham Island monitoring flow on most of the larger rivers on the island. Only the Te Awainanga at Falls and Awamata at Old Hydro Intake have good long term data with record lengths of approximately 33 years. The other sites have much shorter record lengths with significant gaps in the data.

The Te Awainanga River is the main watercourse on Chatham Island and has the highest mean flow. As expected, flows for all recorder sites are generally high in winter and low in summer. The larger rivers that drain the southern hills generally maintain flow during the summer low flow period whereas the Awamata (at Old Hydro Intake), a relatively small watercourse in the south and the Tutuiri River (at Schist Outcrop) located in the northern part of the island run dry during periods of extreme drought. The Te Awainanga and Tuku a Tamatea River have relatively high specific discharges at mean flow due to a relatively large portion of their headwaters being in the elevated parts of the southern hills which are likely to receive higher annual rainfall.

Inter-annual variability plots of mean annual flow for the two long term recorder sites (Te Awainanga and Awamata) indicate that flows can vary greatly from year to year. The 4 year moving average trendline of the mean annual flow indicates no obvious increasing or decreasing trend in mean annual flow. There is no statistically significant difference in the mean annual flow between the last ten years of data (2010-2019) and the historical data (1986-2009) for the Te Awainanga River and Awamata Stream.

The Nairn River at Jack Daymonds flow recorder site was closed in 2018 and only a relatively short (seven year) record is available. To determine whether this site should be reinstated regression analyses with the three current continuous flow recorder sites in the southern part of the island (Te Awainanga River at Falls, Tuku a Tamatea River at Waitangi Tuku Road and Awamata at Old Hydro Intake) was undertaken. All three sites correlated well with the Nairn River with Tuku a Tamatea providing the best correlation.

A total of 27 spot gauging sites were analysed by comparing gaugings with flows at the primary recorder sites. The southern spot gauging sites generally correlated well with the primary sites nearby (Te Awainanga, Awamata and Tuku a Tamatea). The sites in the northern part of the island generally correlated best with the Tutuiri River at Schist flow recorder. There are nine sites in this area that had either insufficient gauging data or did not show a clear correlation with any of the primary recorder sites. Most of these sites (seven out of nine) are catchments on the north-western side of Te Whanga draining into the lagoon.

There are only three sites with sufficient gaugings to undertake regression analyses using flows below the median only. As such 7DMALF estimates should be used with caution.

The results of the regression analyses indicate that the specific discharge at mean and median flow for the southern catchments tend to be higher compared to the northern catchments which is likely to be a reflection of relatively high rainfall and the underlying geology.

12.3 Groundwater

There is very little available data for groundwater across the main Chatham Island, although it is reported that bores are in use across the island. Some information can be gleaned from the geological mapping data, which implies that groundwater resources are likely to be low yielding and typically target fractured basalts and/or shallow strata including peat basins. These low yielding sources could be suitable for domestic supplies but there is a significant data gap in this regard and more information is required.

12.4 Abstractive Pressures

Very few consents to take water have been issued across the island and generally water use appears to be very limited. The greatest use occurs from a groundwater take supplying the community in Waitangi, where the rate of take is typically less than around 60 m^3/day. Assuming most water use is for domestic requirements and allowing for some water use at the fish factories, the total water use across the island is likely to be less than 250 m^3/day or up to 91,250 m^3/year. In comparison, the total area of the island is around 900 km^2 with a total rainfall of around 900 mm/year on average. This equates to a total rainfall volume of around 81 x 10^7 m^3/year suggesting that abstractive pressures amount to much less than 1% of total rainfall. Although this proportion is small, seasonally low rainfall has occurred recently meaning that seasonally increased pressures on the resource can occur.

12.5 Water Balance

It is not possible to define accurate water balances for the gauged catchments across the island due to the lack of soil data as well as some uncertainty regarding rainfall across the southern uplands area. However, the estimates that can be completed suggest that generally, groundwater recharge is likely to be a small part of the water balance, with most rainfall accounted for in the catchment runoff totals and evapotranspiration, although there is uncertainty due to the simplistic nature of the calculations and potential for gains and losses above the recorder sites. The exceptions appear to be the Nairn (upstream of the gauging station) and, possibly, the Tutuiri catchments where the water balance appears to potentially imply some groundwater recharge, although the Tutuiri catchment is uncertain.

12.6 Climate Change

Climate change projections for the Chatham Islands are similar to mainland New Zealand with increased temperatures, an increase in the number of hot days, and decrease in the number of frost days and an increase in rainfall and sea level rise. The magnitude of the projected changes depends on future greenhouse gas emissions, which are uncertain.

Overall, the projected changes in temperature and rainfall are expected to have limited effect on the annual water balance and potable water supplies on the Chatham Islands, although we note the recent low rainfall in the summer of 2017/2018 and 2018/2019 and that climate change could result in increased frequencies of drought. A general increase in rainfall may benefit recharge to the underlying strata and shallow soils/peat basins (depending on the balance between rainfall and evapotranspiration) and increase water levels in lakes and rivers but this is likely to be in part offset by the increase in temperature resulting in an increase in evapotranspiration. Although annual rainfall is predicted to increase it is noted that under climate change it can be expected that there will be an increased frequency and intensity of droughts over time, particularly under a high emissions scenario which may affect recharge of strategic storages such as Lake Rangitai, and small fractured rock structures that groundwater is abstracted from. In addition, increased frequency and intensity of droughts is likely to affect Chatham Island residents who rely on rainwater tanks for their water supply.

Although the groundwater resource in the Chatham Islands is limited, a rise in sea level does have the potential to impact the resource by increasing the likelihood of saline intrusion into low ground level water bearing strata. In particular, the community supply bore at Waitangi may be at increased risk depending on its depth It is possible that the rise in sea level may be in part offset by increased rainfall and increased groundwater recharge, although the relationship between these effects is not well understood for Chatham Island.

12.7 Water Quality

Overall, water quality is good in the waterbodies on Chatham Island; however, there are some waterbodies that are showing degradation seen through upward trends in nitrogen and phosphorus. Evidence of recent droughts were not observed in current state or trend analysis; however, some evidence of stressed systems (high water temperature and low DO levels) can be seen in the temporal scatterplots in Appendix F, and highlight the negative effect that droughts can have on water quality and subsequently instream ecology.

A summary of key findings for each waterbody type is provided below, along with key management considerations for the Chatham Island Council.

Lakes

Lakes on Chatham Island can be characterised as either Dune Lakes or Peat Lakes. Dune Lakes are located along the northern and western coastal fringe of the island, whereas Peat Lakes occur throughout, but are concentrated in the north and east of the island around Kaingaroa.

Water quality data from the past 14 years indicates that all monitored lakes are alkaline (high pH) with a high natural phosphorus presence. High DOC is present in Peat Lakes, as expected due to naturally occurring processes of underlying peat, while Dune Lakes are represented by high water clarity. Most of the monitored lakes are minimally influenced by seawater, as indicated by low conductivity readings, although higher conductivity readings at Lake Te Wapu are indicative of the intermittent connection between this site and the sea during storm events, as confirmed by water quality sampler comments. Lower median water clarity at lakes Te Wapu and Huro coincided with markedly higher mean planktonic chlorophyll-*a* concentrations (5.95 and 17.85 μg/L, respectively), indicative of planktonic algal blooms. This is further supported by the TLI values presented for Lakes Huro and Te Wapu below, which are consistent with a high potential for plant and algal growth particularly during warm settled periods, while this potential is likely intermediate-to-low for the remaining monitored lakes.

Lake Te Wapu is a Peat Lake that has elevated chlorophyll *a* concentrations, indicating algal blooms occur under suitable conditions. This is confirmed by green surface scum and high levels of algae growth observed during sample collection from 2007 to 2011. Lake Te Wapu shows the highest levels of degradation when assessing the last five years of data, with the highest TLI grade of all monitored lakes (supertrophic) representative of very high nutrient enrichment and high algal growth. Lake Te Wapu has shown high interannual variation, ranging from hypertrophic (saturated in nutrients, excessive algal growth) to eutrophic (green and murky, with higher amounts of nutrients and algae) since assessed in 2007 (Meredith & Croucher, 2007: PDP, 2018). The variation in this lake could be due to the improvements to the Kaingaroa Rubbish dump that previously leached in an uncontrolled manner to Lake Te Wapu, and the long-term improvements in TP.

Lake Huro is a large shallow lake (< 0.5 m depth), that has sustained persistent historical algal blooms (Meredith & Croucher 2007). Lake Huro had the next highest TLI grade (eutrophic), and while this indicates a nutrient enriched lake, this is a large improvement on the hypertrophic TLI recorded in 2007. Annual TLIs calculated in PDP (2018) show a consistent improving trend since the lake was last classified as hypertrophic in 2011, consistent with improving long term trends in TN, TP and chlorophyll-*a*. It also no longer appears to suffer "persistent year round algal blooms" as seen in the improving trend in chlorophyll-*a* concentrations.

Lake Marakapia has a TLI grade of mesotrophic, which is an improvement to the TLI reported in Meredith & Croucher (2007) of eutrophic. Minimal interannual variation has occurred, indicating a stable system with moderate levels of nutrients and algae (PDP, 2018). The change from eutrophic to mesotrophic is likely associated with the long term (14 year) trend showing a reduction in TP concentration. However, an increasing TP trend over the last five years is concerning and could lead to a degradation of the lake, which is phosphorus limited. Trend analysis also indicates increasing trends in TN, efforts to reduce TN within the catchment migrating to the lake should be initiated to maintain the current state of the lake.

Tennants Lake has shown no change in TLI grade, remaining in a mesotrophic state representative of moderate levels of nutrients and productivity. Long-term (10 and 14 year) increasing trends in TN concentration have been observed, along with recent (5 year) increasing TP trends. Tennants Lake has been phosphorus limited in the last five years, and therefore recent increasing trends in TP are a concern for lake management and should be investigated.

Lake Rangitai has a TLI of 3.28 (mesotrophic), which is the same as recorded in Meredith & Croucher (2007). Annual TLIs have shown some variation at Lake Rangitai, ranging from a eutrophic state to an oligotrophic state (clear with low levels of nutrients and algae) (PDP, 2018). The lake has historically had high water clarity, however elevated TN and chlorophyll-*a* concentrations have been recorded in the last five years of monitoring, likely associated with the high potable abstractions greatly reducing the lake wetted area and shallowing or concentrating lake nutrients. If the lake refilled and maintained a more natural level regime, chlorophyll-*a* concentrations would likely improve. As it is the potable water supply source for Kaingaroa, maintaining the low levels of nutrients and other contaminants is very important. Analysis of recent data (last five years) shows Lake Rangitai is phosphorus limited, thus any increase in phosphorus could cause an increase in algal blooms. It is noted (in sampler comments) that cattle have been recorded grazing on the shore. This could lead to negative impacts such as increased sedimentation, nutrients and faecal material entering the lake if not controlled.

Watercourses

Watercourses on the Chatham Islands are typically small (range in width from 0.5 – 10 m), and drain to either the coast, lakes or Te Whanga lagoon. They are distinguished by their dark tannin stained waters that flow over peat soil catchments (Meredith & Croucher 2007). Impacts from channelisation, water takes, and manmade drainage are minor; however, agricultural land use (subsistence farming) and pugging of the riparian peat soils affects most watercourses on the island (Meredith & Croucher 2007).

Biological sampling was last completed in 2007, communities are a simple ‘filter and collector browser’ food web, with many species from mainland New Zealand missing. As stated in Meredith & Croucher (2007) the reasons for such simple food webs could include geographical isolation, short geological history, the acidic nature of the environments, and/or the poor water clarity.

No systematic formal fish surveys have been conducted on the island, although opportunistic recordings were taken during biological sampling, as discussed in Meredith & Croucher (2007). No exotic fish species that prey on native fish (i.e. trout) are present on the island; however, natural (waterfalls, chutes) and man-made (dams and culverts) fish passage barriers are common. These structures are unlikely to meet passage requirements in the New Zealand Fish Passage Guidelines (2017) and should be mitigated, where possible.

Long term water quality monitoring results show the watercourses on Chatham Island fall within groups that are largely dependent on their physical location on the island. Watercourse sites can be grouped into the following:

Southern coastal

Watercourses in this area include Awamata Stream, Awatotara Creek and Nairn River on the southwestern end of the island, and Te One Creek on the southeastern side of the island. Awamata Stream and Awatotara Creek appear to be in a relatively healthy state, with little bank erosion. This is because these are steeper hard rock rivers with greater quantities of mineralised rather than peat soils. They are largely more resilient river systems and bank vegetation does not readily pug and erode. These rivers show a small increasing trend in TN (both short and long term) possibly as a result of increase livestock stocking rates. As the watercourses in the Southern area all flow to sea, the risk of increased nutrient levels in freshwater receiving environments (lakes and lagoons) are low. However, these nutrient increases can and do lead to an increase in instream nuisance algae on the bedrock stream beds if increases continue. Excessive periphyton growth, above the 30% bed cover guideline for aesthetics/recreation (Biggs 2000) has been recorded at Awamata Stream and Awatotara Creek, and high macrophyte levels have also been observed at Awatotara Creek, therefore the source of nitrogen inputs may warrant further investigation to maintain the health of these watercourses.

Nairn River flows through the town of Waitangi and is influenced by Lake Huro, Mangape Creek, extensive flats and tidal waters. It has recreational values and is used as a recreational bathing site. Minimal water quality data is available to discuss the state of the river, but *E. coli* data shows that contamination is high, with the monitoring site falling below the national bottom line for *E. coli* under the NPS-FM (2017), indicating at least a moderate risk to swimmers at this site.

Mangape Creek

Mangape Creek is located on the southern end of Lake Huro and is an outflow tributary of the lake, it then flows over farmed lowland plains before joining the Nairn River. It has deep sluggish flow, with obvious stock access and signs of damage (e.g. muddy banks, pugging, high sedimentation, and dead sheep observed). Long term monitoring data shows that Mangape Creek has the highest levels of nitrate-nitrogen concentration of all watercourse sites on the island. These nitrate levels within the creek are within nitrate toxicity Attribute State C of the NPS-FM (2017), meaning 20% of species are impacted by chronic nitrate toxicity. Proposed amendments to national bottom lines (2020) would place this site above new national bottom lines.

The 2007 SOE report (Meredith & Croucher, 2007) noted that the streambed is largely unprotected from stock, which is contributing to its degraded state through high turbidity, nutrients and microbial contamination and high maximum temperatures. While some of the nutrient load in this watercourse is from Lake Huro, Mangape Creek has not seen the improvement in nutrient levels that Lake Huro has (improved from hypertrophic to eutrophic).

Te Whanga Southern tributaries

Te Awainanga River and Mangahou Stream flow into the southern end of Te Whanga Lagoon through the Te Awainanga River mouth. Te Awainanga River is the largest watercourse on the southern plateau and on the island, drains close to one third of the southern tableland region, and due to its consistent water supply has led to it being considered as a potential source of electricity (hydro-electric scheme) for Chatham Island (Meredith & Croucher 2007).

Water quality monitoring data shows these watercourses have moderate to good water quality, with low nutrient levels; however, due to high flows they are providing the highest nutrient loads to Te Whanga Lagoon, with approximately 80 to 85% of the estimated total nutrient load from the monitored sites entering the lagoon from the Te Awainanga River mouth. Clarity in Te Awainanga River has reduced in the last five years, aligning with a recent increasing trend in DOC in both Te Awainanga River and Mangahou Stream. The source of this is not known but could be related to an increase in erosion of peat, which could lead to cumulative reductions in clarity and an increase in carbon load within Te Whanga Lagoon. Stable flows and hard substrate (stony/rocky) results in occasional excessive periphyton growth in these streams, with Mangahou Stream recording total periphyton cover of 100% over its bedrock bed in 2005 (no further surveys conducted). Excessive growths are likely during times of settled weather, during sunny periods and demonstrate the need for nutrient reduction and shading in these catchments).

Central North

Watercourses in the central north of Chatham Island have small catchments and flow east into Te Whanga Lagoons western shoreline. They are distinguished by their low-lying nature and various peaty, stony or sandy beds and are well oxygenated despite low flow levels (Meredith & Croucher 2007). Land use consists of subsistence farming, scrubland and quarrying. The streams are characterised by high alkalinity and conductivity, and variable DOC, which is expected for catchments that drain peat overlying a mixture of hard and soft limestone deposits (Meredith & Croucher 2007).

Of these sites, Waimahana Stream has high levels of DRP and Waitaha Creek has elevated peak concentration of TP, which were four times higher than the next highest max value and will be adding to the cumulative load of phosphorus entering Te Whanga Lagoon during high flow events. These elevated concentrations are not expected to be related to overland runoff from farming, as subsistence farming does not rely on phosphorus applications as on mainland New Zealand, instead t it could be from soft marine derived limestone sediments in the catchment (Meredith & Croucher 2007). A nutrient flux assessment indicated that Waitamaki Creek provided the third highest load of TN and TP to Te Whanga Lagoon, after Te Awainanga River and Mangahou Stream, while Waitaha Creek provided a high DRP load on a per km^2 basis.

Waimahana Stream and Waitamaki Creek both show excessive instream growth, with the Waimahana Stream channel recorded to be heavily choked with macrophytes on multiple sampling occasions and long filamentous algae recorded at 70% coverage in Waitamaki Creek (sampler notes). Waitaha Stream shows high maximum water temperatures and is particularly susceptible to inputs of sediment from the Waitaha volcanic quarry during periods of rainfall activity, which will also be adding to reduced clarity in Te Whanga Lagoon.

Meredith & Croucher (2007) also note that during summer low flow conditions, Waimahana Stream does not flow continuously, becoming a series of discontinuous ponds. Under these conditions, water quality will be lowered through a combination of soft sedimentary geology, stagnant water during summer low flows and inputs of contaminants from adjacent land activities. Under these conditions there is also increased livestock pugging of stream beds and banks. Nitrogen concentrations were typically low at most sites and high in phosphorus, with DRP levels not meeting proposed NPS-FM (2019) limits in some lagoon tributaries.

While watercourses in the central north area are typically small, draining short catchments, the nutrient flux assessment showed there are ‘hotspot’ sites that are contributing relatively high nutrient loads on a per km^2 to Te Whanga Lagoon for at least two of the four nutrient species sampled for (TN, Nitrate-Nitrite, TP and DRP). In addition to Waitamaki Creek which is discussed above, Nikau Reserve Stream, Blind Jim’s (north) trib, and Matanginui Creek also show high levels of nutrient input to the lagoon.

<u>North-western area</u>

Washout Creek, Whangamoe Inlet Stream and Rakautahi Stream flow across low-lying catchments to the coast on the north western end of the island. Streams are generally well distinguished by their wide, deep incised channels, acidity, dark peat staining and stagnant / slow moving water. This results in poor water clarity, low DO and high DOC.

The nutrient data show streams are potentially nitrogen limited, and concentrations of nitrogen and phosphorus indicate impacts from activities in the catchments. Recent reductions in DRP have been shown for both Washout Creek and Whangamoe Inlet Stream, although a small increasing trend in TN is observed at all sites in recent and long term data.

Sample notes indicate that unrestricted stock access to Washout Creek and Rakautahi Stream has occurred in the past, with obvious signs of stock damage and nuisance algal mats and filaments observed at Rakautahi Stream. Whangamoe Inlet Stream has occurrences of saline intrusion, while both Whangamoe Inlet Stream and Washout Creek both have occurrences of blocked river mouths, which can cause slow-moving stagnant flows in Washout Creek that leads to low concentrations of dissolved oxygen. It is therefore unlikely that these streams are able to support a diverse instream ecosystem year round, due to occasional saline and hypoxic conditions.

Te Whanga Lagoon

Te Whanga is New Zealand's largest shallow saline lake/lagoon and is considered locally as part of the freshwater resources. 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 (Meredith & Croucher 2007).

The lagoon is highly prized by Moriori and Maori for its abundant supply of mahinga kai, patiki (flounder), tuna (eels), inanga (smelt-whitebait) and a variety of water fowl including black swans and duck, which could be collected in almost total safety due to the shallow, protected nature of the lagoon. Today Te Whanga Lagoon is used by local families for swimming, boating, fishing and gathering swan eggs, and remains highly regarded for its cultural, historic and botanical values (Meredith & Croucher 2007).

The lake outlet to the ocean is open for only some of the time, as shown through high salinity concentration fluctuations. A sand beach along the eastern shore stretches from Okawa Point almost to Owenga, a distance of 44 km (Meredith & Croucher 2007). Te Whanga Lagoon 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).

Long term water quality monitoring data show an overall brackish to saline environment, with high spatiotemporal variability in other water quality measures and spikes in chlorophyll *a* concentration related to algal blooms. Of the three long term lagoon sites, the site 300 m north of Blind Jim’s Creek shows a recent decline in water quality, with increasing trends over the last five years in nitrate-nitrite, TP and DRP. This could be related to high nutrient loads from tributaries flowing into the north-western side of the lagoon, such as Nikau Reserve Stream, Blind Jim’s (North) trib and Matanginui Creek, which have high nutrient loads for their catchment size. The site at the lakeshore by Waitamaki Creek Beach at Air Base Road shows a small increasing trend in ammoniacal-nitrogen and high algal cover on the shoreline, which is likely related to nutrient inputs from Waitamaki Creek.

The nutrient water quality in Te Whanga Lagoon remains as it was classed in 2007; moderately to highly nutrient enriched. The three sites are predominantly co-limited by dissolved forms of both nitrogen and phosphorus. With low sources of phosphorus coming into the lagoon from tributary inputs this may not pose an immediate threat to water quality, but levels of phosphorus and nitrogen should be assessed regularly, as the high nutrient status means that Te Whanga Lagoon is very sensitive to any changes in nutrient state. The nutrient flux assessment shows that the highest nutrient loads are coming from the Southern lagoon tributaries (Te Awainanga River, Te Awainanga River South Branch and Mangahou Creek), which make up 85% and 80% of the total TN and TP loads, respectively from all the monitored sites combined. Other 'hotspot' areas include the following tributaries flowing into the north western shoreline of Te Whanga Lagoon; Waitamaki Creek, Nikau Reserve Stream, Waitaha Creek, a tributary to Blind Jim's Creek and Matanginui Creek.

Spikes of chlorophyll *a* concentration at Blind Jim's monitoring site, located on the north western shoreline indicates Te Whanga Lagoon suffers from occasional excess plant productivity and algal blooms, as reported in 2007. The frequency and duration of blooms is currently unknown due to the quarterly monitoring frequency, but if they become more frequent, due to increased nutrient levels, the lagoon ecological structure (plant, fish and shellfish communities) could be changed over time. Increased duration of blooms can lead to a 'switch' from a plant-based structure to phytoplankton bloom based, which will reduce water clarity and could result in anoxia of the lake and fish mortality. It could also lead to the lagoon being unsuitable for recreational activity.

Due to the location and size of Te Whanga Lagoon, it is the largest receiving environment (excluding the coastal environment) for land runoff, stream inflow and groundwater seepage on Chatham Island. The large size of the lagoon means that water is infrequently flushed from the lagoon, leaving it vulnerable to deterioration in water quality.

12.8 Te Whanga Nutrient Flux

The nutrient flux analysis for the June 2011 to May 2012 period indicates that a significant proportion of the nutrient flux to Te Whanga Lagoon is generated from the southern contributing catchment areas. Approximately 80 to 85% of the total load from the monitored sites enters Te Whanga Lagoon via the Te Awainanga River mouth.

Although by far the greatest nutrient load into Te Whanga Lagoon comes from the southern catchments it is useful to look at the total load per km^2 of catchment area for each of the watercourses, as this provides an indication of localised 'hotspots' in nutrient load into Te Whanga Lagoon. Watercourses identified to have relatively high nutrient loads on a per km^2 for at least two of the four nutrient species sampled for (TN, Nitrate-Nitrite, TP and DRP) include the three southern sites (Te Awainanga River, Te Awainanga River South Branch and Mangahou Creek). Nikau Reserve Stream, Blind Jims (north) trib, Waitamaki Creek, and Matanginui Creek.

12.9 Review of Different Monitored Water Bodies Suitable for or Limiting for Potable and Domestic Uses

The watercourses on Chatham Island with relatively large catchments generally have perennial (year round) flow. This includes the Te Awainanga, Tuku a Tamatea, Nairn and Tutuiri River as well as Awamata Stream. The quantities of water needed on Chatham Island for potable and domestic use are relatively small compared to flows in these waterways. From a water quantity perspective these rivers would be suitable for potable and domestic use, with no or a limited amount of storage. For smaller streams significant amounts of storage may be required to ensure reliability of supply for potable and domestic water.

A review of the available water quality data indicates that:

- There are no exceedances of the relevant drinking water standards for fluoride, chloride and the nitrogen species (nitrate, nitrite, nitrate-nitrite and ammoniacal-nitrogen).
- The GV for sulphate (250 mg/L) was exceeded during one sampling round for two watercourses (Blind Jims Creek, Whangamoe Inlet Stream) and one lake site (Lake Te Wapu) but was below the GV value for all other sampling rounds.
- At times all watercourse and lake sites have recorded pH values outside the GV range (7.0 - 8.5) specified in the DWSNZ.
- With the exception of one sample in Lake Rangitai, the available water quality data indicates that *E. coli* was detected in all samples for the watercourses and lakes regularly being sampled.

Based on these results it is considered that treatment will be required should any of these water bodies be used for drinking water.

Only a limited range of determinands has been sampled for and more comprehensive chemical analyses is required to determine the suitability of the monitored water bodies for potable and domestic use. This should include testing for heavy metals which may be present in the generally dark brown colour of the watercourses that drain the peat deposits on the Island. The peat staining and peat particles, while not strictly a NZDWS parameter, are the feature that limits much of the water of Chatham Island from being considered acceptable domestic water supplies. The limited resources that are clear waters may become a limited supply and may be excessively used, like Lake Rangitai.

As outlined above, there is no available information for groundwater.

13.0 Recommendations

13.1 Rainfall and Evaporation

Broadly, the distribution of rain gauge sites across the island is appropriate, however, a rainfall gauge should be maintained at Waitangi to ensure that a consistent record is available at that site. The historic records at Waitangi are a valuable resource and continued rainfall gauging should be maintained.

A rainfall gauge could also be installed in the southern uplands to better understand the pattern of peak rainfall in that area. This would lead to improved estimates of the water balance for the catchments that drain the southern uplands. However, access to install and maintain such an installation would present a very difficult logistical challenge.

Rainfall sites should also be maintained in line with the NEMS requirements for rain gauges and evapotranspiration sites, given the existing QA coding is unreliable for some of the sites. This may require more regular field visits to maintain the sites and to minimise significant data gaps.

13.2 Hydrology

Most of the recorder sites have a significant amount of gaps in the data. In addition some of the continuous flow recorder data (especially Tuku a Tamatea River at Waitangi Tuku Road) is rated poor or fair under the national Environmental Monitoring Standards (NEMS). It is our understanding (from ECan staff) that the flow recorder sites are currently visited (gauged and maintained) approximately quarterly. The NEMS does not provide a set standard how often a site should be inspected. However, the NEMS does recommend that

'resourcing must be adequate under normal circumstances to ensure stations are visited often enough to ensure quality of the data collected'

It is clear from the available flow recorder data that the sites are currently not visited often enough and it is recommended that the recorder sites are gauged and maintained more regularly to ensure a reliable and continuous record is available for analyses. The required frequency of site visits should be discussed with the ECan field staff or contractors familiar with the sites and/or responsible for undertaking the gaugings and the maintenance of the flow recorder sites. It is recognised that the frequency of the site visits to the hydrometric stations depends on the logistics and accessibility of the sites which (for the Chatham Islands) can be more challenging than other parts of New Zealand or Canterbury.

On the basis that the Nairn River correlates well with the other three continuous flow recorder sites in the southern part of the island it is recommended not to re-instate the Nairn River flow recorder. Concurrent gaugings should be undertaken during both low and normal flow conditions with a focus on the flow range not covered by the current data.

No good correlation could be obtained for a number of the spot gauging sites on the watercourses flowing into the north-western side of Te Whanga and two other streams in the northern part of the island. It is recommended that further work be undertaken to improve flow estimates for the watercourses in this area. The previous Chatham Island Water Resource Report (Ritson, 2010) also recommended further investigation into the northern area to 'clarify the relationships with any recorders'. A temporary recorder site was subsequently installed in Waitamaki Creek along with undertaking spot gaugings in some of the northern watercourses. As discussed in this report the temporary flow recorder provided unreliable data and as such no flow estimates can be obtained for a number of watercourses in this area. On this basis it is recommended to re-instate the recorder in Waitamaki Creek (at a suitable location) or another watercourse in the vicinity. It is crucial that a site will be chosen that will provide a reliable continuous record and is gauged and maintained on a regular basis given the high value of Te Whanga and its tributaries.

Once a recorder site is installed, it is recommended further gaugings be undertaken for some of the northern tributaries of Te Whanga Lagoon. This should include the sites with insufficient data and the sites that do not provide a good regression with Tutuiri. It is also recommended that further gaugings are obtained for Unnamed Stream and Whangamoe Creek which are located in the northern part of the Island but do not flow into Te Whanga lagoon.

If improved knowledge of low flow in some of the smaller Chatham Island watercourses is deemed necessary, then further low flow gaugings are required to improve low flow estimates such as the 7DMALF.

Apart from the recommended changes to the hydrological monitoring outlined above it is considered that the current hydrological network is adequate and fit for purpose.

13.3 Groundwater

If the resilience of the water supply on the island is to be improved by a shift away from reliance on rainwater tanks to groundwater supplies, further information should be gathered regarding potential groundwater sources and the location of bores around the island. A database of bores should be developed and maintained. It would be prudent to ensure that owners of bores are testing their bores to ensure the water is of suitable quality. Groundwater level monitoring should also occur. We would also recommend that a survey of existing bores occurs to identify the location of existing abstractions and to provide additional information regarding bore depths and sources of groundwater. Groundwater quality information should also be logged and recorded where available.

13.4 Climate Change

A rise in sea level has the potential to impact the groundwater resource and in particular the community supply bore at Waitangi. It would be prudent to undertake some assessment of the potential risk of saline intrusion at the community supply bore in Waitangi, and other coastal bores where these can be identified.

Under climate change increased frequency and intensity of droughts is expected, particularly under a high emissions scenario. An increased frequency and intensity of droughts is likely to affect Chatham Island residents who rely on rainwater tanks for their water supply. The anticipated effects of climate change therefore reinforce the need to increase the resilience of the water supply on the Chatham Islands for example by identifying potential other sources of water (groundwater or surface water, refer to section 13.3 and 13.7) and/or increasing the size of the rainwater tanks.

13.5 Water Quality

Recommendations for Monitoring Programme Improvements

Currently, the water quality sampling programme is conducted quarterly, which is considered the minimum effective interval for categorising the likely variability and any seasonal changes in water quality. Analysis of the 2005 – 2019 dataset revealed a number of missing parameters during monitoring rounds (shown in Appendix F), no nutrient data for Nairn River, and lack of explanatory sampler comments in recent years, which limited the statistical analysis of the data and in turn the interpretation of the dataset.

In addition, the frequency of the current monitoring programme is not sufficient to compare water quality of Chatham Islands waterbodies to current and proposed national guidance levels set out in the NPS-FM (2017) and proposed draft NPS-FM (2019). Monthly grab sampling programmes are typical of regional council state-of-environment monitoring programmes and many of the parameters within these guidance documents specifically require monthly sampling, including *E. coli,* chlorophyll-*a,* and periphyton for rivers in the NPS-FM (2017), and DIN, DRP and suspended fine sediment in the proposed draft NPS-FM (2019). For other NPS-FM (2017) attributes, including nitrate, ammoniacal nitrogen, and TN and TP (lakes only) monthly sampling, or at least 30 samples over three years, is recommended for statistical considerations.

Monthly sampling for these parameters is required to enable comparison to attribute states and the meaningful interpretation of data. An example of this is determining the frequency and duration of algal blooms in lakes and Te Whanga Lagoon. Current quarterly sampling only provides a snapshot of levels per season but does not enable a temporal understanding of the blooms. If monthly sampling for chlorophyll-*a* was conducted, a more meaningful interpretation of bloom events would be enabled. Annual TLI calculations would also benefit from monthly collection of TN, TP and chlorophyll-*a,* as quarterly data limits the interpretation of this index and determining trends over time.

In addition to the water quality monitoring, habitat assessments, which include periphyton, macrophyte and substrate surveys should be conducted, to assist with interpretation of results and provide baseline condition data, which is currently limited and compare to national guidance levels set out in the NPS-FM (2017) and proposed draft NPS-FM (2019).

As described above, to be able to correctly interpret current state and trends in Chatham Island waterbodies, it is recommended that monitoring be increased from quarterly to monthly, and that the parameter list be reviewed to ensure a full dataset is collected at each sampling event. More robust collection notes should also be taken, to assist with the interpretation of data in the future.

<u>Recommendations for Lake Management</u>

Improvements to Lake TLI at Lakes Huro and Marakapia are encouraging; however, continued efforts to reduce nutrient and contaminants into these lakes is required if improvements are to be sustained. As Lake Huro drains out through Mangape Creek then Nairn River, improvements to Lake Huro will also benefit these downgradient receiving streams.

An increasing trend in TN and TP at Lake Marakapia over the short term and TN over the long-term is concerning and could lead to a degradation in lake ecosystems. Efforts to reduce nutrients within the catchment migrating to the lake should be initiated before further degradation of this lake occurs.

Efforts are required to retain the current water quality in Lake Rangitai, which has been overutilised in the past few years. As the potable water supply source for the reticulated (council) water supply for Kaingaroa, any degradation to water quality in the lake could adversely affect the Kaingaroa water supply. With limited other potable water options, as discussed in section 11 of this report, efforts to protect this lake from excessive water takes or other forms of degradation should be of high priority to the Council.

In the 2007 SOE report, the following lake management actions were proposed:

1. Change in disposal of municipal and commercial wastes on the island; and,
2. Protection of potable water supply sources.

Since 2007, improvement of solid waste management to coastal rubbish dumps and transfer stations has occurred. This has included the construction of a waste facility for fish carcases draining to the coast.

Potable water supply has remained an issue on the island, with adverse effects to Lake Rangitai due to high demand for water over the last three years of droughts.

Alternative potable water supply sources are scarce, as discussed in section 11 and this remains a high priority issue for the Chatham Islands.

Recommendations for Watercourse Management

Small but increasing nitrate levels are widespread amongst Chatham Island watercourses. While increases are low, the cumulative increases are concerning, and improved land management practices are needed. This is particularly evident in catchments that drain to lakes and to Te Whanga Lagoon, as an increase in cumulative nutrient loading from tributaries could lead to nutrient levels that support increased algal blooms.

As reported in Meredith & Croucher (2007) culvert design for the passage of native fish and invertebrates is required. Since 2017, the NZ Fish Passage Guidelines (Franklin *et al*., 2017) has been released, highlighting the importance of providing passage from native species. It is recommended that an assessment of fish passage barriers on the island be conducted. Chatham Islands are in a unique position of having no predatory exotic fish present and efforts should be made to improve passage of native fish, where feasible. A formal fish survey is also recommended to provide a baseline of fish species distribution on the island.

In the 2007 SOE report (Meredith & Croucher 2007) it was recommended that fish and invertebrate surveys be conducted on a five-yearly basis. This was not completed in the intervening time due to difficulties sampling in drought conditions. Impacts of recent drought conditions will need to be considered and an island specific biological index created, to enable meaningful comparisons across sampling events, as the distinct island communities cannot be compared to mainland indices. A fish passage survey should be completed at this time, to map barriers to native fish movement and develop a plan to mitigate these barriers, where feasible.

Recommendations for Te Whanga Lagoon Management

The main management focus for Te Whanga Lagoon should be an effort to reduce nutrients (in particular nitrogen) and contaminants (sediment, microbial bacteria) from land-based activities in catchments that flow into the lagoon, as well as activities around the lagoon shoreline.

Flow reductions to Te Whanga, as discussed in the 2007 report (Meredith & Croucher 2007), could lead to an increase in salinity and nutrient conditions, which could lead to algal blooms in Te Whanga Lagoon. It is noted that there are no obvious increasing or decreasing trends in mean annual flow for Te Awainanga River, the main river flowing into the lagoon (refer to section 3.2).

Increased knowledge on manual lagoon openings and nutrient cycling within the lagoon is required, as discussed in Meredith & Croucher (2007) to determine how openings affect water quality spatially within the lagoon. An increase to monthly monitoring, as discussed at the start of this section, would enable a more meaningful understanding on the frequency and duration of algal blooms in the lagoon.

13.6 Te Whanga Nutrient Flux

Recommendations regarding watercourse management in relation to the nutrient flux from the watercourses flowing into Te Whanga have been included in section 13.5 above.

13.7 Review of Monitored Water Bodies Suitable for or Limiting Potable and Domestic Uses

Should any of the surface waterbodies be considered or currently used for potable water supply then a comprehensive suite of chemical analyses is required to determine the suitability of the water for potable and domestic use. This should include testing for heavy metals. The dark brown colour of most of the rivers and streams is caused by tannins and lignins leaching from the peat which can be removed by ultrafiltration. This process is likely to be only viable for large community schemes and/or large commercial operations and may therefore not be feasible for the Chatham Islands. Therefore, should surface water be considered as a potable water source, further investigations should focus on rivers and streams that are free of tannins and lignins leaching from the peat (i.e. avoid rivers with dark brown colours that are likely to drain peat basins).

Treatment will be required should any of these water bodies be used for drinking water. The exact treatment train required will depend on the results of the additional chemical analyses.

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Appendix A

Regressions

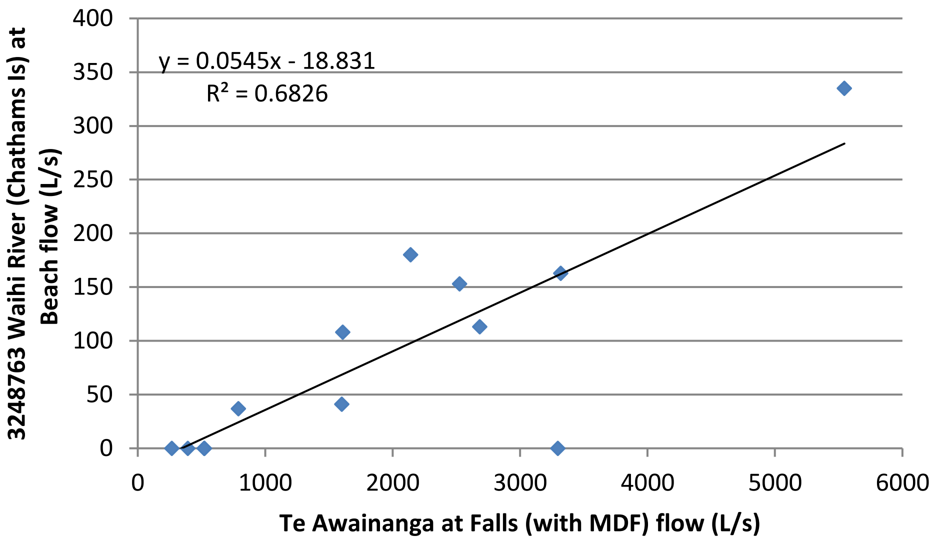

Figure A-1a: Correlation of Waihi River and Te Awainanga for all gaugings and supplemented by mean daily flow

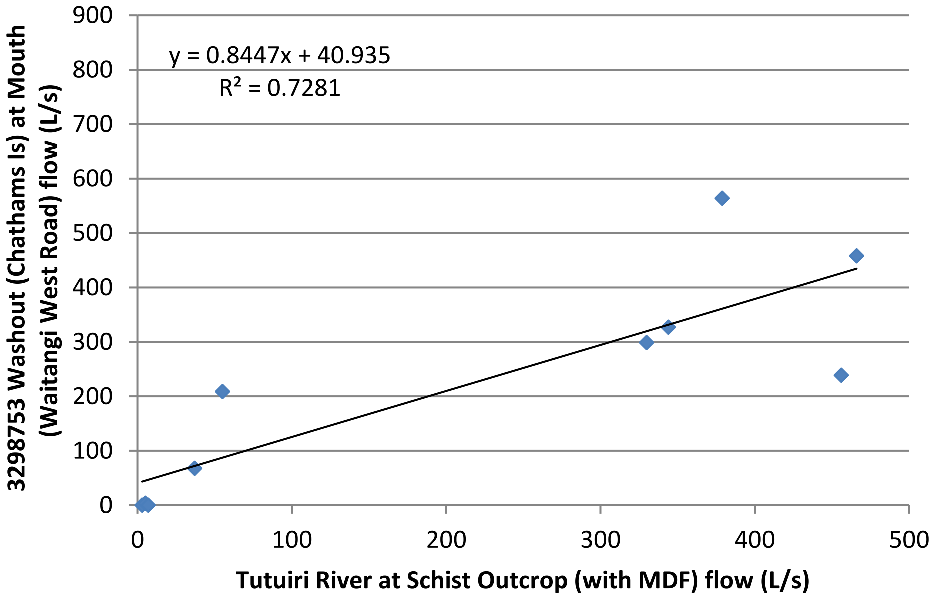

Figure A-2a: Correlation of Washout at Mouth and Tutuiri River for all gaugings and supplemented by mean daily flow

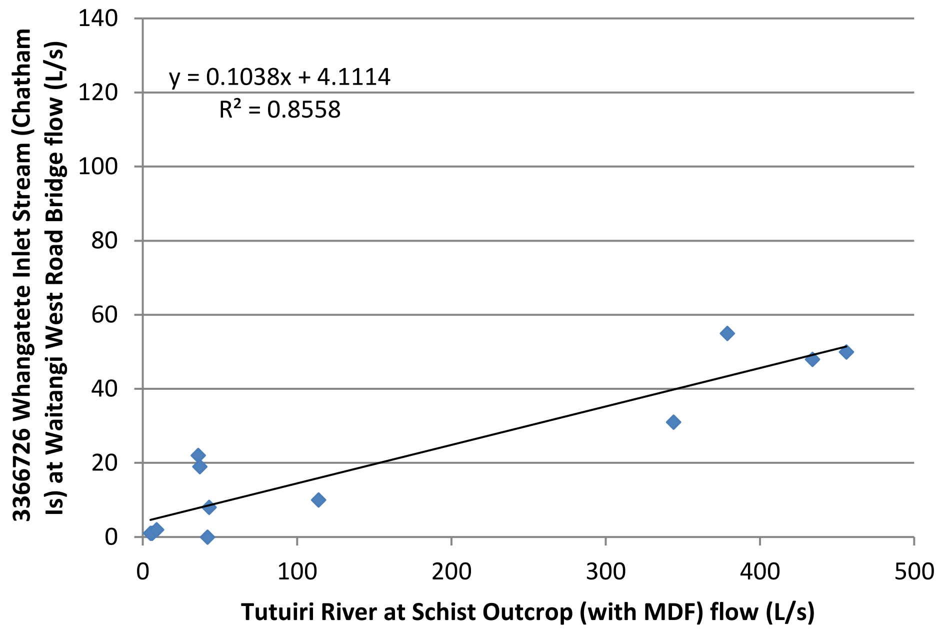

Figure A-3a: Correlation of Whangatete Stream and Tutuiri River for all gaugings and supplemented by mean daily flow

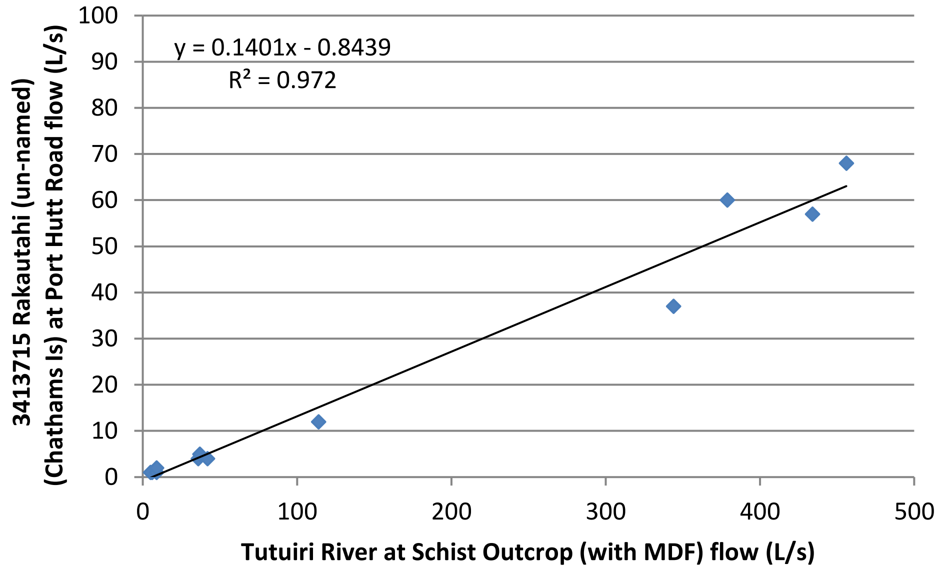

Figure A-4a: Correlation of Rakautahi and Tutuiri for all gaugings and supplemented by mean daily flow

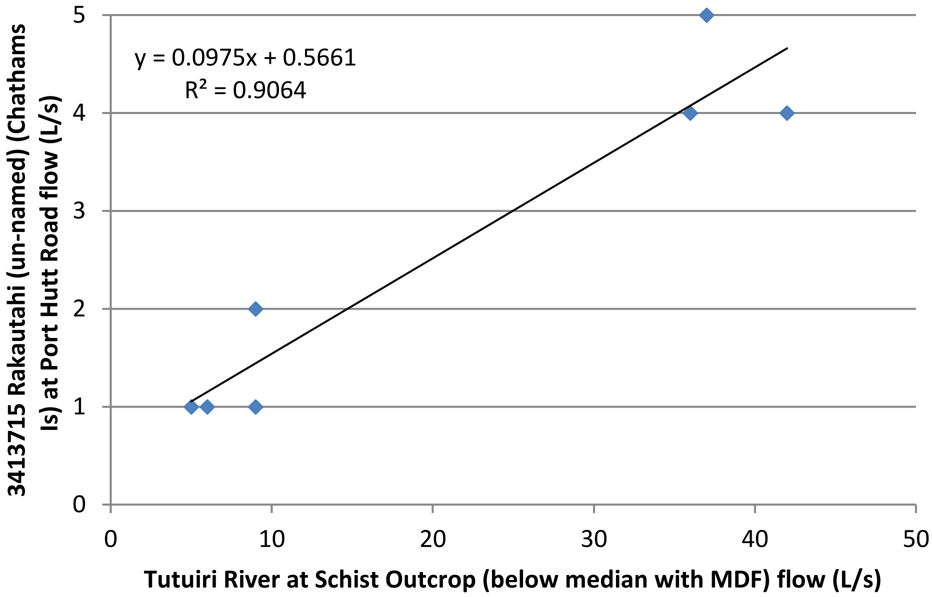

Figure A-4b: Correlation of Rakautahi and Tutuiri for all gaugings below the median flow and supplemented by mean daily flow

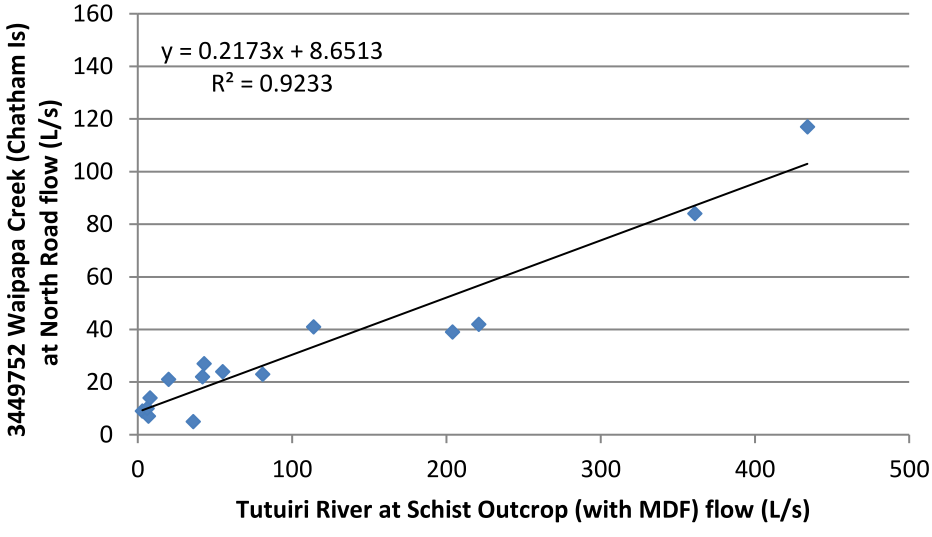

Figure A-5a: Correlation of Waipapa Creek and Tutuiri River for all gaugings and supplemented by mean daily flow

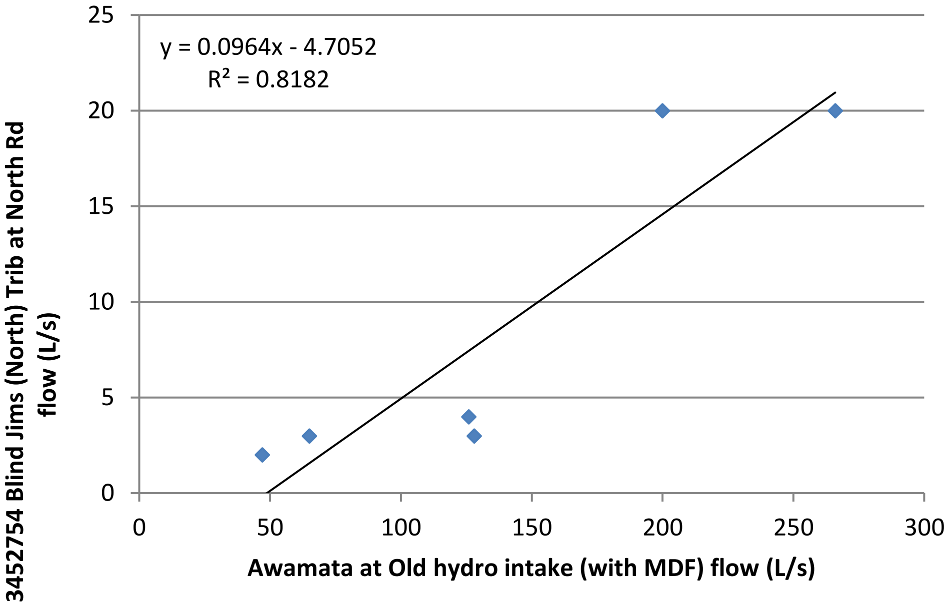

Figure A-6a: Correlation of Blind Jims (north) trib and Awamata for all gaugings and supplemented by mean daily flow

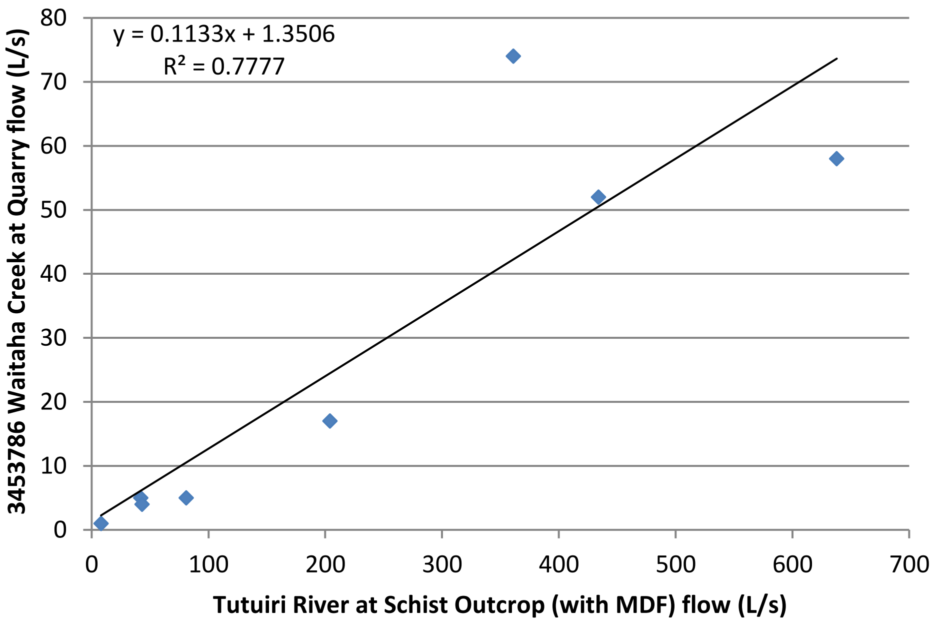

Figure A-7a: Correlation of Waitaha Creek and Tutuiri for all gaugings and supplemented by mean daily flow

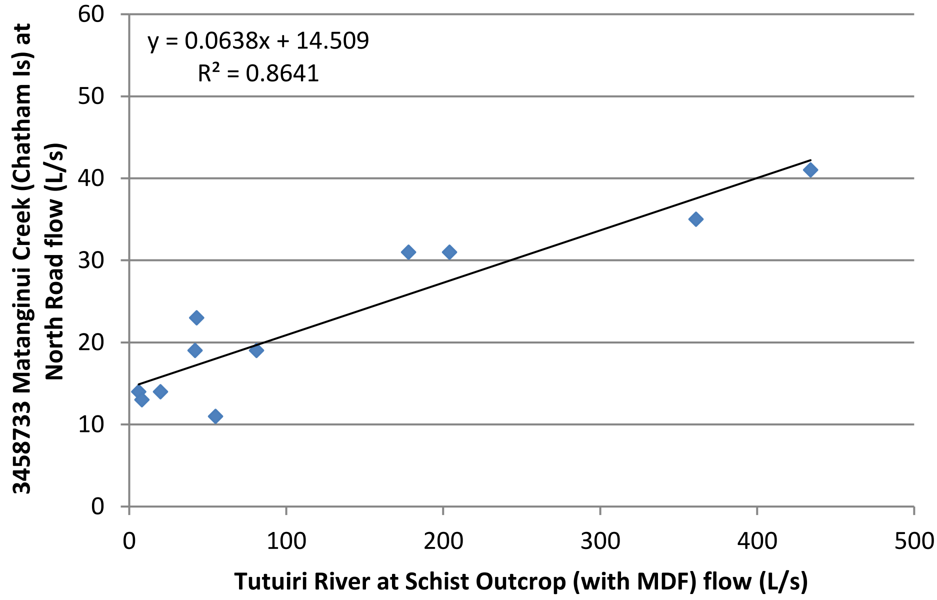

Figure A-8a: Correlation of Matanginui Creek and Tutuiri River for all gaugings and supplemented by mean daily flow

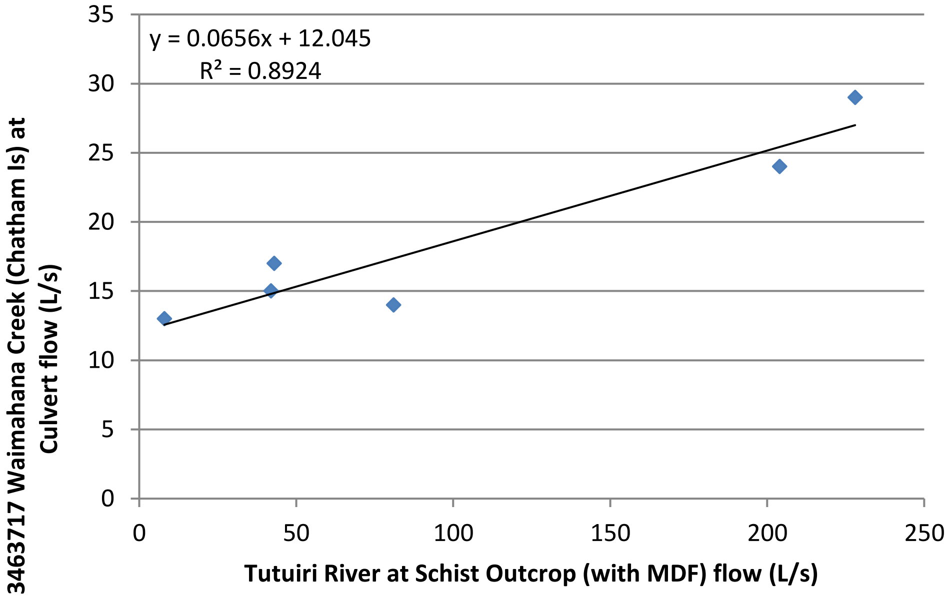

Figure A-9a: Correlation of Waimahana Creek and Tutuiri for all gaugings and supplemented by mean daily flow

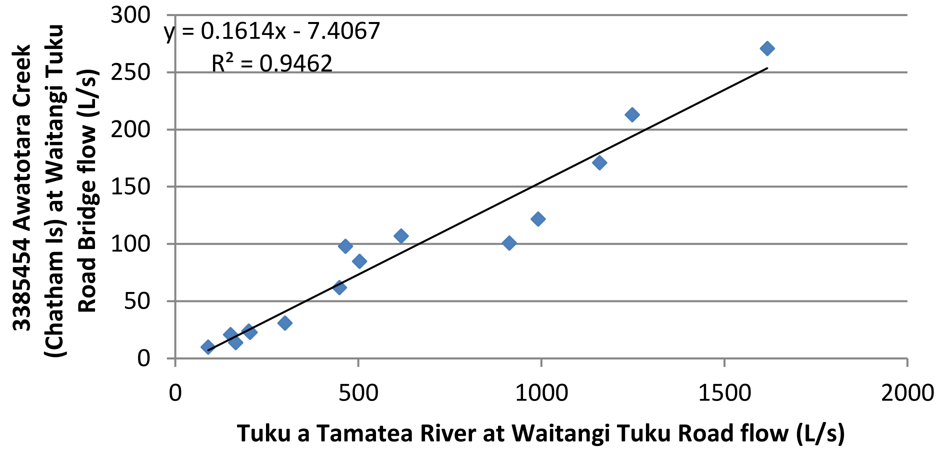

Figure A-10a: Correlation of Awatotara Creek and Tuku a Tamatea River for all gaugings – sufficient data to use concurrent gaugings only

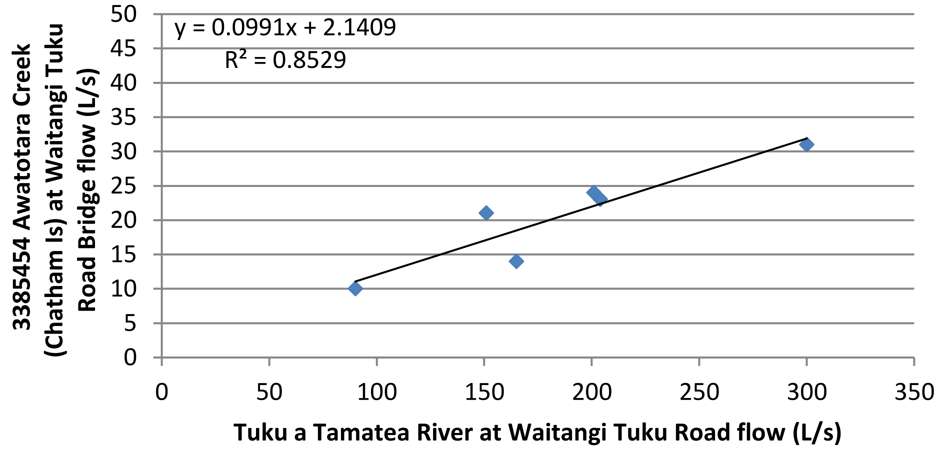

Figure A-10b: Correlation of Awatotara Creek and Tutiri River for all gaugings below median flow – sufficient data to use concurrent gaugings only

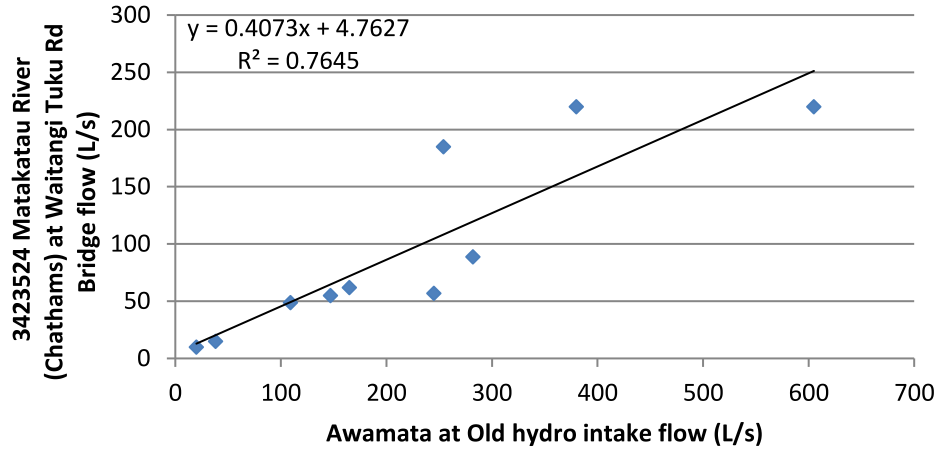

Figure A-11a: Correlation of Matakatau River and Awamata for all gaugings – sufficient data to use concurrent gaugings only

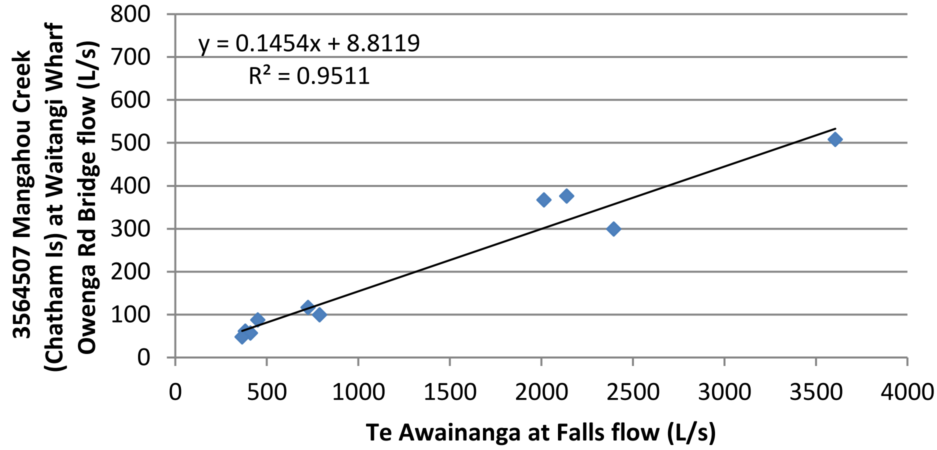

Figure A-12a: Correlation of Mangahou Creek and Te Awainanga for all gaugings – sufficient data to use concurrent gaugings only

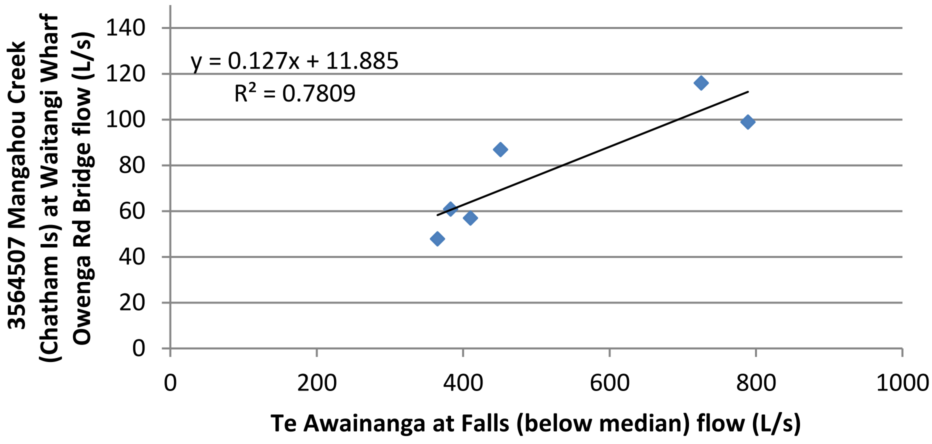

Figure A-12b: Correlation of Mangahou Creek and Te Awainanga for all gaugings below median flow – sufficient data to use concurrent gaugings only

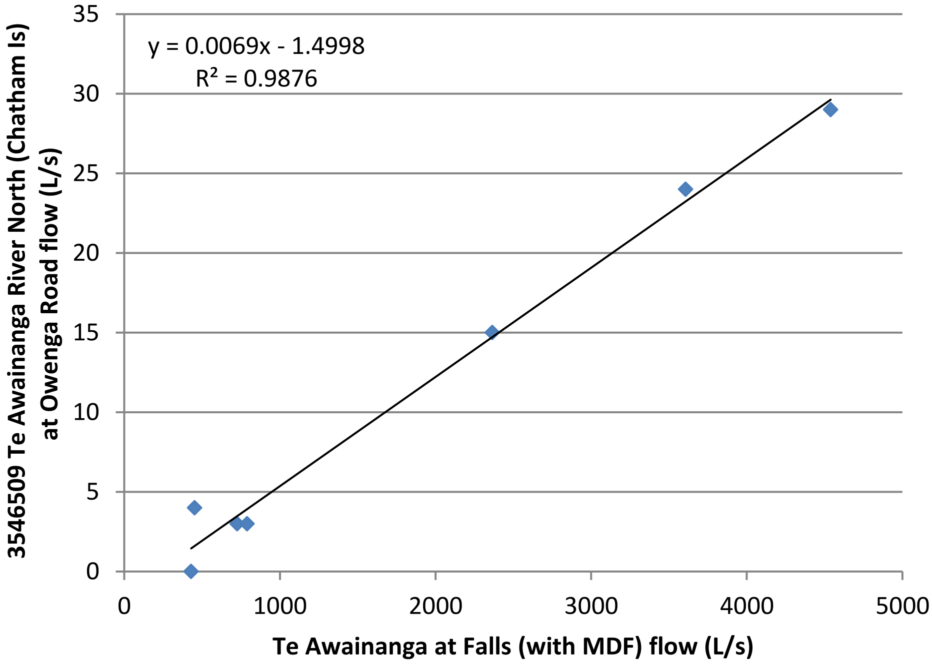

Figure A-13a: Correlation of Te Awainanga North and Te Awainanga for all gaugings and supplemented by mean daily flow

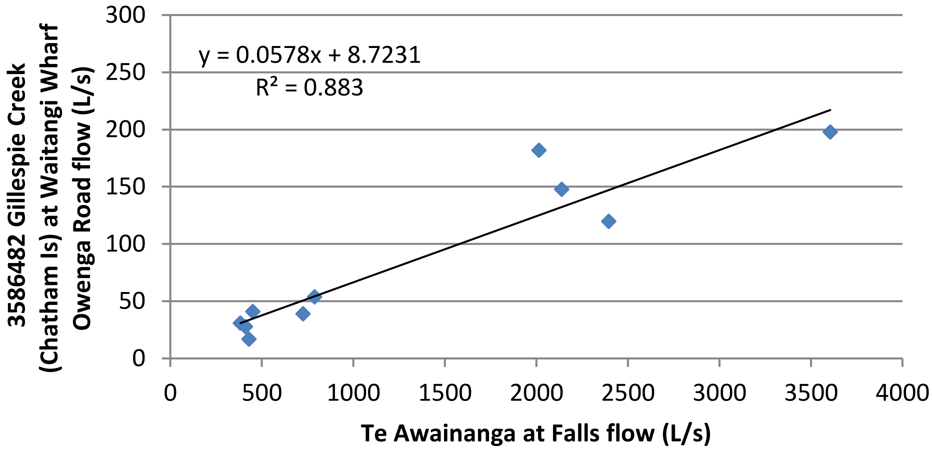

Figure A-14a: Correlation of Gillespie Creek and Te Awainanga for all gaugings – sufficient data to use concurrent gaugings only

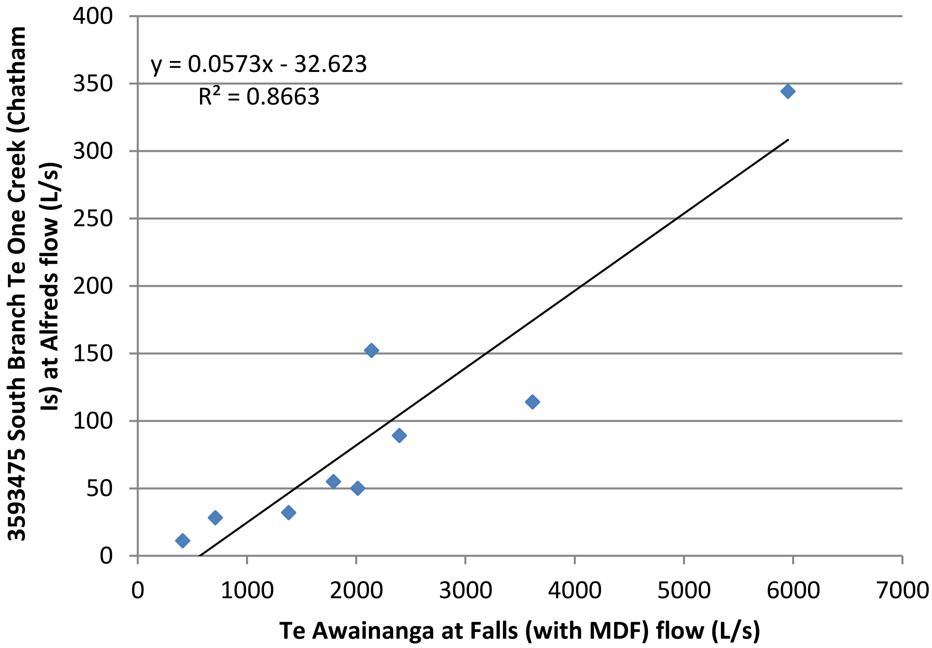

Figure A-15a: Correlation of South Branch Te One Creek and Te Awainanga for all gaugings and supplemented by mean daily flow

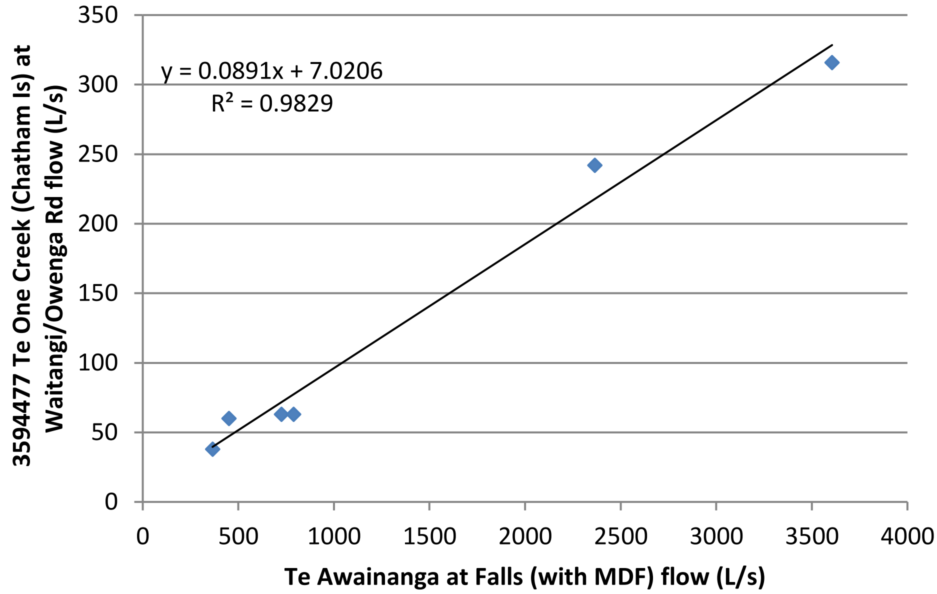

Figure A-16a: Correlation of Te One Creek and Te Awainanga for all gaugings and supplemented by mean daily flow

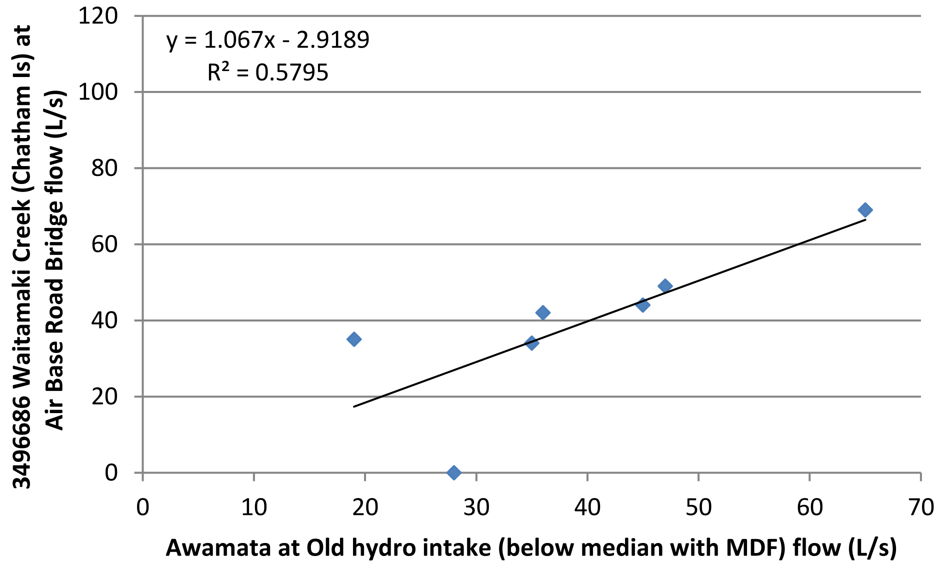

Figure A-17a: Correlation Waitamaki Creek and Awamata for all gaugings below median and supplemented by mean daily flow

Table 1: Concurrent gaugings (red = gauging value, black = mean daily recorder value)

Date	Te Awainanga at Falls	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop	3452533 Nairn (Chatham Is) at Daymonds (Recorder)	3379428 Tuku a Tamatea River (Chatham Is) at Waitangi Tuku Road Bridge	3248763 Waihi River (Chathams Is) at Beach	3254737 Unnamed Stream (Chathams Is) at Beach	3298753 Washout (Chathams Is) at Mouth (Waitangi West Road)	3509698 Oringi Creek (Chatham Is) at Air Base Road	3332713 Whangamoe Creek (Chatham Is) at Inlet	3366726 Whangatete Inlet Stream (Chatham Is) at Waitangi West Road Bridge	3413715 Rakautahi (un-named) (Chathams Is) at Port Hutt Road	3449752 Waipapa Creek (Chatham Is) at North Road	3451765 Nikau Creek (Chatham Is) at North Road	3452754 Blind Jims (North) Trib at North Rd	3453786 Waitaha Creek at Quarry	3454743 Blind Jims Creek (Chatham Is) at North Road	3458733 Matanginui Creek (Chatham Is) at North Road	3458789 Unnamed Wharekauri Stm (Chatham Is) at North Rd	3459791 Waitaha Creek North (Chatham Is) at North Road	3463717 Waimahana Creek (Chatham Is) at Culvert	3473724 Waimahana Creek (Chatham Is) at Chudleigh Reserve	3545509 South Branch Te Awainanga (Chatham Is) at Waitangi/Owenga Rd	3546509 Te Awainanga River North (Chatham Is) at Owenga Road	3385454 Awatotara Creek (Chatham Is) at Waitangi Tuku Road Bridge	3423524 Matakatau River (Chathams) at Waitangi Tuku Rd Bridge	3468549 Mangape Creek at Bridge	3564507 Mangahou Creek (Chatham Is) at Waitangi Wharf Owenga Rd Bridge	3586482 Gillespie Creek (Chatham Is) at Waitangi Wharf Owenga Road	3593475 South Branch Te One Creek (Chatham Is) at Alfreds	3594477 Te One Creek (Chatham Is) at Waitangi/Owenga Rd	3496686 Waitamaki Creek (Chatham Is) at Air Base Road Bridge
5/Apr/05	0.733	0.023			**0.204**																				**0.023**							
6/Apr/05	0.599	0.02									**0.005**		**0.012**				**0.011**															
7/Apr/05	0.522	0.019																										**0.137**	**0.06**			
8/Apr/05	0.477	0.019							**0.023**																							**0.035**
17/Jul/06	2.309	0.198	**0.27**														**0.022**															
18/Jul/06	1.907	0.161											**0.058**															**0.274**	**0.126**			
19/Jul/06	1.608	0.141				**0.108**	**0.091**	**0.144**	**0.038**		**0.021**	**0.026**																				**0.083**
20/Jul/06	1.387	0.123			**0.503**																				**0.085**							
14/Sep/06	**0.523**	0.053	0.036			**0**					**0.022**	**0.004**	**0.005**																			
15/Sep/06	0.446	0.053	0.031																									**0.082**	**0.035**			
17/Sep/06	0.413	**0.038**	0.025		**0.151**																				**0.021**	**0.015**						
21/Nov/06	0.463	0.049	0.005														**0.008**															
22/Nov/06	0.419	0.047	**0.003**						**0.031**				**0.009**																			**0.049**
23/Nov/06	0.42	0.048	0.003					**0**																								
25/Nov/06	**0.383**	0.044	0.003																									**0.061**	**0.031**			
28/Nov/06	1.001	0.074	0.05																						**0.009**	**0.002**						
15/Mar/07	5.415	0.255	0.055										**0.024**				**0.01**	**0.011**														
16/Mar/07	3.938	0.264	0.037					**0.068**	**0.032**		**0.019**	**0.005**																				**0.049**
17/Mar/07	2.958	**0.165**	0.021		**0.913**																				**0.101**	**0.062**						
18/Mar/07	**2.014**	0.374	0.021																									**0.367**	**0.182**	**0.05**		
20/Jun/07	1.227	0.11	0.078																									**0.177**	**0.07**			
23/Jun/07	5.953	**0.605**	1.85		**1.617**																				**0.271**	**0.22**				**0.344**		
25/Jun/07	5.967	0.438	1.179										**0.143**					**0.057**														
4/Sep/07	1.133	0.112	0.114						**0.04**		**0.01**	**0.012**	**0.041**				**0.018**															**0.094**

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Table 1: Concurrent gaugings (red = gauging value, black = mean daily recorder value)

Date	Te Awainanga at Falls	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop	3452533 Nairn (Chatham Is) at Daymonds (Recorder)	3379428 Tuku a Tamatea River (Chatham Is) at Waitangi Tuku Road Bridge	3248763 Waihi River (Chathams Is) at Beach	3254737 Unnamed Stream (Chathams Is) at Beach	3298753 Washout (Chathams Is) at Mouth (Waitangi West Road)	3509698 Oringi Creek (Chatham Is) at Air Base Road	3332713 Whangamoe Creek (Chatham Is) at Inlet	3366726 Whangatete Inlet Stream (Chatham Is) at Waitangi West Road	3413715 Rakautahi (un-named) (Chathams Is) at Port Hutt Road	3449752 Waipapa Creek (Chatham Is) at North Road	3451765 Nikau Creek (Chatham Is) at North Road	3452754 Blind Jims (North) Trib at North Rd	3453786 Waitaha Creek at Quarry	3454743 Blind Jims Creek (Chatham Is) at North Road	3458733 Matanginui Creek (Chatham Is) at North Road	3458789 Unnamed Wharekauri Stm (Chatham Is) at North Rd	3459791 Waitaha Creek North (Chatham Is) at North Road	3463717 Waimahana Creek (Chatham Is) at Culvert	3473724 Waimahana Creek (Chatham Is) at Chudleigh Reserve	3545509 South Branch Te Awainanga (Chatham Is) at Waitangi/Owenga Rd	3546509 Te Awainanga River North (Chatham Is) at Owenga Road	3385454 Awatotara Creek (Chatham Is) at Waitangi Tuku Road Bridge	3423524 Matakatau River (Chathams) at Waitangi Tuku Rd Bridge	3468549 Mangape Creek at Bridge	3564507 Mangahou Creek (Chatham Is) at Waitangi Wharf Owenga Rd Bridge	3586482 Gillespie Creek (Chatham Is) at Waitangi Wharf Owenga Road	3593475 South Branch Te One Creek (Chatham Is) at Alfreds	3594477 Te One Creek (Chatham Is) at Waitangi/Owenga Rd	3496686 Waitamaki Creek (Chatham Is) at Air Base Road Bridge
5/Sep/07	1.601	0.165	0.178			0.041												0.031														
6/Sep/07	2.139	0.146	0.132																							0.062		0.376	0.148	0.152		
8/Sep/07	1.268	0.08	0.075		0.448																				0.062							
21/Oct/07	0.73	0.071	0.02										0.021				0.011	0.014														
22/Oct/07	0.71	0.071	0.02																									0.117	0.064	0.028		
10/Apr/08	0.41	0.036	0.008																									0.057	0.028	0.011		
11/Apr/08	0.333	0.035	0.007						0.013				0.007																			0.034
13/Apr/08	0.298	0.034	0.006				0																									
14/Apr/08	0.287	0.02	0.006		0.09						0.001	0.001													0.01	0.01						
10/Jul/08	1.653	0.147	0.177		0.617																				0.107	0.055						
11/Jul/08	1.38	0.122	0.148		0.492																							0.219	0.1	0.032		0.027
12/Jul/08	1.518	0.194	0.221		0.487								0.042																			
13/Jul/08	12.536	1.004	1.109		1.853	0.367	0.191	0.84			0.129	0.255																				
12/Nov/08	0.581	0.045	0.006						0.024				0.01				0.011	0.014														0.044
13/Nov/08	0.521	0.043	0.005			0	0	0.004			0.001	0.001																				
14/Nov/08	0.472	0.031	0.005		0.165																				0.014							
17/Nov/08	0.455	0.038	0.003																							0.002						
19/Mar/09	1.821	0.086	0.081		0.358								0.023			0.01	0	0.019			0.014											
20/Mar/09	10.744	0.254	0.6		1.159																				0.171	0.185						
21/Mar/09	5.545	0.193	0.379			0.335	0.19	0.564	0		0.055	0.06																				
22/Mar/09	3.615	0.15	0.277																								0.06	0.702	0.284	0.114		
25/Jun/09	2.684	0.273	0.456		0.607	0.113	0.042	0.239			0.05	0.068															0.22					
26/Jun/09	2.395	0.199	0.361		0.472								0.084			0.07	0.025	0.035										0.299	0.12	0.089		
27/Jun/09	1.727	0.109	0.371		0.465																				0.098	0.049						
28/Jun/09	1.385	0.107	0.228																		0.029											
9/Dec/09	0.365	0.034	0.011		0.127																		0.004		0.01		0.13	0.048			0.038	

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Date	Te Awainanga at Falls	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop	3452533 Nairn (Chatham Is) at Daymonds (Recorder)	3379428 Tuku a Tamatea River (Chatham Is) at Waitangi Tuku Road Bridge	3248763 Waihi River (Chathams Is) at Beach	3254737 Unnamed Stream (Chathams Is) at Beach	3298753 Washout (Chathams Is) at Mouth (Waitangi West Road)	3509698 Oringi Creek (Chatham Is) at Air Base Road	3332713 Whangamoe Creek (Chatham Is) at Inlet	3366726 Whangatete Inlet Stream (Chatham Is) at Waitangi West Road Bridge	3413715 Rakautahi (un-named) (Chathams Is) at Port Hutt Road	3449752 Waipapa Creek (Chatham Is) at North Road	3451765 Nikau Creek (Chatham Is) at North Road	3452754 Blind Jims (North) Trib at North Rd	3453786 Waitaha Creek at Quarry	3454743 Blind Jims Creek (Chatham Is) at North Road	3458733 Matanginui Creek (Chatham Is) at North Road	3458789 Unnamed Wharekauri Stm (Chatham Is) at North Rd	3459791 Waitaha Creek North (Chatham Is) at North Road	3463717 Waimahana Creek (Chatham Is) at Culvert	3473724 Waimahana Creek (Chatham Is) at Chudleigh Reserve	3545509 South Branch Te Awainanga (Chatham Is) at Waitangi/Owenga Rd	3546509 Te Awainanga River North (Chatham Is) at Owenga Road	3385454 Awatotara Creek (Chatham Is) at Waitangi Tuku Road Bridge	3423524 Matakatau River (Chathams) at Waitangi Tuku Rd Bridge	3468549 Mangape Creek at Bridge	3564507 Mangahou Creek (Chatham Is) at Waitangi Wharf Owenga Rd Bridge	3586482 Gillespie Creek (Chatham Is) at Waitangi Wharf Owenga Road	3593475 South Branch Te One Creek (Chatham Is) at Alfreds	3594477 Te One Creek (Chatham Is) at Waitangi/Owenga Rd	3496686 Waitamaki Creek (Chatham Is) at Air Base Road Bridge
10/Dec/09	0.3	0.036	0.009		0.119				0.015		0.002	0.001																				0.042
12/Dec/09	0.286	0.036	0.008		0.121								0.014			0	0.009	0.013			0.013											
14/Dec/09	0.267	0.034	0.007		0.107	0	0	0																								
16/Dec/09	2.21	0.104	0.114		0.622																					0.025						
17/Dec/09	1.791	0.072	0.074		0.451																								0.116	0.055		
9/Dec/10	0.451	0.045			0.145																			0.004			0.19	0.087	0.041		0.06	
10/Dec/10	0.394	0.045			0.12							0.001																				
11/Dec/10	0.404	0.047			0.108								0.016		0.002	0	0.013	0.015		0.002												
24/Feb/11	0.408	0.046	0.009		0.132							0.002					0.008					0.073										
25/Feb/11	0.43	0.045	0.007		0.124																			0			0.06		0.017			
8/Jun/11	5.122	0.386	1.216		1.589					0.101	0.084	0.132																				
9/Jun/11	3.235	0.266	0.638		1.209										0.02	0.06						0.176										
10/Jun/11	2.365	0.245	0.419		0.935																	0.015		0.015	0.117	0.057	0.38	0.43			0.242	
9/Sep/11	0.659	0.065	0.042	0.234					0.037	0	0	0.004	0.022	0.002	0.003	0.01	0.013	0.019		0.001	0.015											0.069
10/Sep/11	0.725	0.052	0.038	0.218	0.201																			0.003	0.024			0.116	0.039		0.063	
14/Sep/11	3.296	0.173	0.466	0.934	0.741	0	0	0.458																								
23/Nov/11	0.789	0.047	0.017	0.133	0.3																			0.003	0.031		0.33	0.099	0.054		0.063	
24/Nov/11	2.294	0.128	0.043	0.53	0.479				0.06	0.011	0.008		0.027	0.001	0.003	0	0.017	0.023		0.001	0.017											0.085
27/Nov/11	2.142	0.192	0.055	0.652	0.366	0.18	0	0.209																								
14/Mar/12	4.539	0.282	0.851		1.248																			0.029	0.213	0.089	0.22					
15/Mar/12	2.524	0.17	0.344		0.554	0.153	0.212	0.327	0.048	0.037	0.031	0.037																				0.087
16/Mar/12	1.777	0.126	0.204		0.451								0.039	0.005	0.004	0.02	0.009	0.031		0.005	0.024											
13/Jun/12	7.745	0.38	0.695	0.873	0.991																				0.122	0.22						
15/Jun/12	3.485	0.2	0.434	0.818	0.767				0.058		0.048	0.057	0.117	0.011	0.02	0.05	0.021	0.041		0												0
16/Jun/12	3.606	0.306	0.405	1.017	0.82																			0.024			0.21	0.508	0.198		0.316	
17/Jun/12	3.32	0.312	0.33	1.194	0.833	0.163	0.102	0.299																								

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Date	Te Awainanga at Falls	Awamata at Old Hydro Intake	Tutuiri River at Schist Outcrop	3452533 Nairn (Chatham Is) at Daymonds (Recorder)	3379428 Tuku a Tamatea River (Chatham Is) at Waitangi Tuku Road Bridge	3248763 Waihi River (Chathams Is) at Beach	3254737 Unnamed Stream (Chathams Is) at Beach	3298753 Washout (Chathams Is) at Mouth (Waitangi West Road)	3509698 Oringi Creek (Chatham Is) at Air Base Road	3332713 Whangamoe Creek (Chatham Is) at Inlet	3366726 Whangatete Inlet Stream (Chatham Is) at Waitangi West Road Bridge	3413715 Rakautahi (un-named) (Chathams Is) at Port Hutt Road	3449752 Waipapa Creek (Chatham Is) at North Road	3451765 Nikau Creek (Chatham Is) at North Road	3452754 Blind Jims (North) Trib at North Rd	3453786 Waitaha Creek at Quarry	3454743 Blind Jims Creek (Chatham Is) at North Road	3458733 Matanginui Creek (Chatham Is) at North Road	3458789 Unnamed Wharekauri Stm (Chatham Is) at North Rd	3459791 Waitaha Creek North (Chatham Is) at North Road	3463717 Waimahana Creek (Chatham Is) at Culvert	3473724 Waimahana Creek (Chatham Is) at Chudleigh Reserve	3545509 South Branch Te Awainanga (Chatham Is) at Waitangi/Owenga Rd	3546509 Te Awainanga River North (Chatham Is) at Owenga Road	3385454 Awatotara Creek (Chatham Is) at Waitangi Tuku Road Bridge	3423524 Matakatau River (Chathams) at Waitangi Tuku Rd Bridge	3468549 Mangape Creek at Bridge	3564507 Mangahou Creek (Chatham Is) at Waitangi Wharf Owenga Rd Bridge	3586482 Gillespie Creek (Chatham Is) at Waitangi Wharf Owenga Road	3593475 South Branch Te One Creek (Chatham Is) at Alfreds	3594477 Te One Creek (Chatham Is) at Waitangi/Owenga Rd	3496686 Waitamaki Creek (Chatham Is) at Air Base Road Bridge
5/Sep/12	1.563	0.145	0.102	0.341	0.516																											**0.097**
6/Mar/13	**0.853**	**0.028**	0.026	0.192	**0.404**																											**0**
10/Mar/13	0.393	0.033	0.006	0.134	0.154	**0**	**0**																									
9/Jun/13	0.789	0.07	0.139	0.296	0.257	**0.037**	**0.053**																									
3/Dec/14	0.53	**0.026**	0.008	0.124	**0.148**																			**0.474**								

Table 2: Regression analyses with primary recorder sites

Gauging site number and location	Using all flows								Using only flows below the median								Comments
	Te Awainanga at Falls		Awamata at Old hydro intake		Tutuiri River at Schist Outcrop[5]		Regression equation	Primary Site	Te Awainanga at Falls		Awamata at Old hydro intake		Tutuiri River at Schist Outcrop[5]		Regression equation	Primary Site	
	# of concurrent gaugings	r^2	# of concurrent gaugings[3]	r^2	# of concurrent gaugings	r^2			# of concurrent gaugings	r^2	# of concurrent gaugings[3]	r^2	# of concurrent gaugings	r^2			
3248763 Waihi River at Beach	14	0.68	14	0.56	12	0.52	y = 0.0545x - 18.83	Te Awainanga	5	-	5	-	4	-			
3254737 Unnamed Stream at Beach[1]	13	0.45	13	0.32	12	0.43		No correlations	5	-	5	-	4	-			r^2 values all <0.6
3298753 Washout at Mouth (Waitangi West Road)	12	0.80	12	0.62	10	0.93	y = 0.8447x + 40.93	Tutuiri River	3	-	3	-	4	-			
3509698 Oringi Creek (Chatham Is) at Air Base Road[1]	13	0.00	13	0.10	11	0.03		No correlations	6	0.64	6	0.48	7	0.57		No correlations	r^2 values all <0.6
3366726 Whangatete Inlet Stream at Waitangi West Road Bridge	15	0.71	16	0.84	12	0.86	y = 0.1038x + 4.11	Tutuiri River	6	0.02	6	0.05	7	0.28		No correlations	
3413715 Rakautahi (un-named) at Port Hutt Road	15	0.63	16	0.92	12	0.97	y = 0.1401x - 0.84	Tutuiri River	7	0.58	7	0.60	7	0.91	y = 0.0975x + 0.57	Tutuiri River	
3449752 Waipapa Creek at North Road	19	0.54	19	0.72	15	0.92	y = 0.2173x + 8.65	Tutuiri River	9	0.25	9	0.29	8	0.34		No correlations	
3452754 Blind Jims (North) Trib at North Rd	6	0.74	6	0.82	5	-	y = 0.0964x - 4.71	Awamata	2	-	2	-	2	-			
3453786 Waitaha Creek at Quarry	9	0.57	9	0.79	8	0.78	y = 0.1133x + 1.35	Tutuiri River	3	-	3	-	3	-			
3454743 Blind Jims Creek at North Road[1]	16	0.09	16	0.30	14	0.49		No correlations	8	0.23	8	0.06	7	0.77		No correlations	r^2 values all <0.6
3458733 Matanginui Creek at North Road	13	0.35	13	0.61	11	0.86	y = 0.0638x + 14.51	Tutuiri River	5	-	5	-	5	-			
3463717 Waimahana Creek at Culvert	6	0.09	6	0.38	6	0.89	y = 0.0656x + 12.04	Tutuiri River	2	-	2	-	2	-			
3496686 Waitamaki Creek at Air Base Road Bridge[1]	13	0.13	13	0.18	11	0.19		No correlations	6	0.48	6	0.83	7	0.64		No correlations	r^2 values all <0.6
3385454 Awatotara Creek at Waitangi Tuku Road Bridge[3]	3		15	0.84	15	0.95	y = 0.1614x - 7.41	Tuku a Tamatea	3	-	6	0.70	6	0.85	y = 0.0991x + 2.14	Tuku a Tamatea	Tuku a Tamatea has been used in place of Tutuiri River at Schist. Used concurrent gauging data only
3423524 Matakatau River (Chathams) at Waitangi Tuku Rd Bridge[3]	2		10	0.76	10	0.66	y = 0.4073x + 4.76	Awamata	4	-	4	-	4	-			Used concurrent gauging data only
3546509 Te Awainanga River North at Owenga Road[4]	7	0.99	7	0.92	6	0.90	y = 0.0069x - 1.50	Te Awainanga	5	-	5	-	4	-			
3468549 Mangape Creek at Bridge[1]	9	0.01	9	0.11	8	0.07		No correlations	4	-	4	-	3	-			r^2 values all <0.6
3564507 Mangahou Creek at Waitangi Wharf Owenga Rd Bridge[3]	10	0.95	4	-	0	-	y = 0.1454x + 8.81	Te Awainanga	6	0.78	3	-	0	-	y = 0.127x + 11.88	Te Awainanga	Used concurrent gauging data only
3586482 Gillespie Creek at Waitangi Wharf Owenga Road[3]	10	0.88	2	-	0	-	y = 0.0578x + 8.72	Te Awainanga	6	0.57	2	-	0	-			Used concurrent gauging data only
3593475 South Branch Te One Creek at Alfreds	9	0.87	9	0.66	9	0.87	y = 0.0573x - 32.62	Te Awainanga	2	-	3	-	3	-			
3594477 Te One Creek at Waitangi/Owenga Rd	6	0.98	6	1.00	5	-	y = 0.0891x + 7.02	Te Awainanga	4	-	4	-	3	-			

Notes: Insufficient data (less than six concurrent gaugings) for analysis at sites: 3332713 Whangamoe Creek (Chatham Is) at Inlet, 3451765 Nikau Creek (Chatham Is) at North Road, 3458789 Unnamed Wharekauri Stm (Chatham Is) at North Rd, 3459791 Waitaha Creek North (Chatham Is) at North Road, 3473724 Waimahana Creek (Chatham Is) at Chudleigh Reserve.
Green background is the best regression to use for estimating all flow statistics for that site. Yellow background is the best regression to use when estimating 7DMALF statistics for that site and blue background is the best regression to use when estimating all other flow statistics (except 7DMALF).
1. r^2 values are considered too low (<0.6) for an accurate regression analysis.
3. Concurrent gaugings only were used for this site (no mean daily flow data was used).
4. Removed potential erroneous gauging on 03/Dec/2014. Tuku and Awamata record flows in lower quartile for this day while gauging at this site is an order of magnitude greater than any other recorded flow.
5. Tuku a Tamatea River has been used in place of Tutuiri River for Awatotara as a better correlation is expected.

Appendix B

Site Photos

Lakes

Photo 1: Lake Huro

Photo 2: Lake Rangitai

Photo 3: Lake Te Wapu…………………………………

Photo 4: Tennants Lake

Watercourses

Photo 5: Awamata Stream

Photo 6: Mangape Creek

Photo 7: Te Awaninga River

Photo 8: Te One Stream

Photo 9: Waimahana Creek

Photo 10: Blind Jims Creek

Photo 11: Whangamoe Inlet Stream

Photo 12: Washout Creek

Te Whanga Lagoon – representative photos

Photo 13: Te Whanga at Airbase Road

Photo 14: Te Whanga at Te Matarae Point

Photo 15: Te Whanga at North Road

Photo 16: Te Whanga at Blind Jims

Appendix C

Water Quality Parameters

Table 1: Water quality parameters and analyses used in Chatham Island surface water quality monitoring programme

Parameter	Type of Measurement	Sample Method	Laboratory Detection Limit	Unit
Dissolved Oxygen (DO)	Field measurement	NI-YSI 55 DO Meter – EMQ D7	0.5	mg/L
DO % Saturation	Field measurement	NI-YSI 55 DO Meter – EMQ D7		%
Temperature	Field measurement	NI-YSI 55 DO Meter – EMQ D7		°C
pH	Field measurement	NI-YSI pH 100 Meter – EMQ P2		pH
Salinity	Laboratory analysis (ECan)	NI-YSI/30 SCT Meter – EMQ S7		pH
Conductivity	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 (20th 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 (20th ED)	0.010	mg/L
Total ammonia-nitrogen (NH3N)	Laboratory analysis (ECan)	APHA 4500 NH_3-F modified (20th 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	0.003	mg/L
Dissolved reactive phosphorus (DRP)		APHA 4500-P B F (20th Ed)		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
E. coli	XX			MPN

Appendix D

Surface Water Quality and Ecology Summary Data

Table D1: Surface Water Quality Summary Data

Sites		Alkalinity to pH4.5as HCO_3 (mg/L)	Alkalinity Total (mg/L)	Ammoniacal Nitrogen (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Clarity Tube (cm)	Conductivity (mS/m)	Dissolved Inorganic Nitrogen (mg/L)	Dissolved Non Purgeable Organic Carbon (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Saturation)	Dissolved Reactive Phosphorus (mg/L)	Kjeldahl Nitrogen Total (mg/L)	Nitrate Nitrogen (mg/L)	Nitrate-N & Nitrite-N (mg/L)	Nitrite Nitrogen (mg/L)	Organic Nitrogen (mg/L)	pH	Salinity (ppt)	Salinity Field (ppt)	Sulphate (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature (Field) (°C)
LAKE HURO (CHATHAMS) LAKE EDGE OPP DOC HQ	Maximum	128	-	0.22	0.28	110	100	114.7	0.64	-	27	13.8	134	0.032	2.7	-	0.59	-	2.06	10	-	8.71	26	4.9	0.8	23.7
	Median	103.5	-	0.05	0.28	110	18	69.6	0.056	-	15.4	10.18	100.5	0.004	2.7	-	0.016	-	1.011	8.5	-	0.4	21.5	1.32	0.0895	14.9
	Minimum	74	-	0.005	0.28	110	3	35.8	0.0115	-	10.6	4.91	53.6	0.0005	2.7	-	0.001	-	0.5785	6.8	-	0.1	18	0.59	0.011	4.1
	n	6	-	41	1	1	51	49	41	-	55	49	49	41	1	-	42	-	41	51	-	46	4	56	56	52
LAKE MARAKAPIA (CHATHAMS) SOUTHWEST SHORE BY TREES	Maximum	156	-	0.7	-	-	100	110.9	0.8	-	40	13.79	135.2	-	0.75	-	0.2	-	2.313	9.72	-	0.56	12	2.5	0.095	25.1
	Median	133	-	0.05	-	-	100	65.3	0.15	-	15.55	10.555	101	-	0.75	-	0.1	-	0.596	8.55	-	0.325	11.5	0.74	0.0145	13.75
	Minimum	118	-	0.005	-	-	42	11.2	0.015	-	9.3	4.92	53.3	-	0.75	-	0.003	-	0.292	6.4	-	0.2	11	0.37	0.004	6
	n	3	-	40	-	-	48	48	40	-	54	48	48	-	1	-	41	-	40	50	-	46	2	54	54	50
LAKE RANGITAI (CHATHAMS) EASTERN SHORE OFF TAIA-HAPUPU RD	Maximum	151	-	0.35	0.69	220	100	187.1	0.368	-	13.2	12.54	163.3	-	0.54	-	0.1	-	2.243	9.1	-	0.96	31	2.3	0.21	23.8
	Median	127.5	-	0.05	0.69	220	100	102.55	0.108	-	7.8	9.77	100	-	0.54	-	0.1	-	0.351	8.3	-	0.5	28	0.43	0.008	14.2
	Minimum	92	-	0.006	0.69	220	38	37.8	0.014	-	4.7	4.62	53.7	-	0.54	-	0.002	-	0.08	7	-	0.2	24	0.19	0.002	7.4
	n	6	-	43	1	1	52	52	55	-	56	53	53	-	1	-	44	-	55	54	-	50	4	57	57	55
LAKE TE WAPU (CHATHAMS) NORTH END AT KAIANGAROA	Maximum	189	-	0.055	-	-	100	3427	0.37	-	71	12.8	136.8	-	1.4	-	0.32	0.002	4.345	8.9	-	21.55	260	4.6	0.5	22
	Median	151	-	0.0315	-	-	38	568.85	0.1315	-	38	9.68	97.3	-	1.4	-	0.1	0.002	1.403	8.3	-	3.86	240	1.56	0.0485	13.95
	Minimum	49	-	0.005	-	-	4	10	0.01	-	6.4	4.66	54.3	-	1.4	-	0.003	0.002	0.4	6.5	-	0.5	73	0.55	0.011	6.1
	n	5	-	42	-	-	51	50	42	-	56	51	51	-	1	-	43	1	42	53	-	50	3	56	56	54
TENNANTS LAKE (CHATHAMS) SHORELINE	Maximum	152	-	0.13	0.23	85	100	98.1	0.276	-	26	13.06	125.2	-	0.75	-	0.2	-	1.2	9.03	-	2.6	8.4	1.35	0.14	24.3
	Median	107.5	-	0.05	0.23	85	100	56.9	0.15	-	11.8	10.2	100.5	-	0.75	-	0.1	-	0.468	8.3	-	0.3	7.6	0.49	0.013	13.7

Table D1: Surface Water Quality Summary Data

Sites		Alkalinity to pH4.5as HCO_3 (mg/L)	Alkalinity Total (mg/L)	Ammoniacal Nitrogen (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Clarity Tube (cm)	Conductivity (mS/m)	Dissolved Inorganic Nitrogen (mg/L)	Dissolved Non Purgeable Organic Carbon (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Saturation)	Dissolved Reactive Phosphorus (mg/L)	Kjeldahl Nitrogen Total (mg/L)	Nitrate Nitrogen (mg/L)	Nitrate-N & Nitrite-N (mg/L)	Nitrite Nitrogen (mg/L)	Organic Nitrogen (mg/L)	pH	Salinity (ppt)	Salinity Field (ppt)	Sulphate (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature (Field) (°C)
	Minimum	65	-	0.005	0.23	85	62	4	0.014	-	8.6	5.1	54.7	-	0.75	-	0.002	-	0.08	6.4	-	0	7	0.23	0.002	6.2
	n	6	-	43	1	1	52	53	43	-	50	53	53	-	1	-	44	-	43	54	-	50	4	57	57	55
WATERCOURSES																										
AWAMATA STREAM (CHATHAMS) WAITANGI-TUKU RD	Maximum	37	20	0.05	0.13	66	88	36.75	0.09	-	51	13.93	135	0.04	0.68	-	0.061	0.008	1.141	8	-	0.2	15	1.23	0.16	20.7
	Median	24	20	0.05	0.13	66	46.5	27	0.0525	-	24	11.02	102	0.019	0.68	-	0.008	0.008	0.32	6.95	-	0.11	6.6	0.38	0.049	11.7
	Minimum	4	20	0.005	0.13	66	15	13.4	0.0085	-	7.5	4.8	51.9	0.009	0.68	-	0.001	0.008	0.0975	4.3	-	0	2.6	0.14	0.029	6
	n	20	1	57	1	1	54	51	57	-	57	53	53	57	1	-	57	1	57	54	-	50	23	57	57	55
AWATOTARA CREEK (CHATHAMS) WAITANGI-TUKU ROAD	Maximum	-	3.2	-	0.09	50	78	33.28	-	-	72	12.8	121.2	0.049	0.85	0.009	0.1	-	-	7.99	-	1.11	11	1.14	0.083	15.2
	Median	-	3.2	-	0.09	50	45	20.95	-	-	35	10.51	95.6	0.023	0.85	0.009	0.021	-	-	5.095	-	0.1	4	0.43	0.039	10.2
	Minimum	-	3.2	-	0.09	50	18	7.2	-	-	19	4.88	53.4	0.0005	0.85	0.009	0.002	-	-	3.6	-	0	2.4	0.14	0.022	6.3
	n	-	1	-	1	1	54	52	-	-	57	53	53	57	1	1	57	-	-	54	-	50	23	57	57	55
BLIND JIMS CREEK (CHATHAM) BELOW CULVERT NORTH RD	Maximum	313	155	0.077	0.11	66	100	1822	0.15	-	17	12.62	121.1	0.058	0.3	-	0.1	-	5.691	8.8	-	24.48	1000	5.8	0.51	24.4
	Median	200	155	0.05	0.11	66	100	64.55	0.112	-	7.2	8.82	88.9	0.007	0.3	-	0.1	-	0.118	7.9	-	0.3	17	0.21	0.033	15.1
	Minimum	107	155	0.006	0.11	66	44	25.1	0.014	-	0.7	1.76	16.3	0.002	0.3	-	0.002	-	-0.11	6.7	-	0.1	6.8	0.04	0.002	6.6
	n	24	1	57	1	1	50	52	57	-	57	53	53	57	1	-	57	-	57	54	-	49	23	57	57	55
MANGAHOU STREAM (CHATHAMS) 50M BELOW BRIDGE ON WAITANHI WHARF OWENGA RD	Maximum	475	7.4	0.05	0.06	35	89	28	0.067	-	46	12.37	117.4	0.032	0.57	0.004	0.025	-	0.765	9	-	0.8	6.5	0.83	0.11	16.4
	Median	11	7.4	0.05	0.06	35	43	15.3	0.0525	-	24	10.46	94.9	0.018	0.57	0.004	0.005	-	0.2205	6.495	-	0.1	3.4	0.27	0.037	11
	Minimum	4	7.4	0.006	0.06	35	23	6.16	0.0085	-	11	4.94	11.3	0.006	0.57	0.004	0.001	-	0.033	4.2	-	0	2	0.1	0.015	6.9
	n	13	1	57	1	1	52	51	57	-	57	53	53	57	1	1	57	-	57	54	-	50	23	57	57	55

Table D1: Surface Water Quality Summary Data

Sites		Alkalinity to pH4.5as HCO_3 (mg/L)	Alkalinity Total (mg/L)	Ammoniacal Nitrogen (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Clarity Tube (cm)	Conductivity (mS/m)	Dissolved Inorganic Nitrogen (mg/L)	Dissolved Non Purgeable Organic Carbon (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Saturation)	Dissolved Reactive Phosphorus (mg/L)	Kjeldahl Nitrogen Total (mg/L)	Nitrate Nitrogen (mg/L)	Nitrate-N & Nitrite-N (mg/L)	Nitrite Nitrogen (mg/L)	Organic Nitrogen (mg/L)	pH	Salinity (ppt)	Salinity Field (ppt)	Sulphate (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature (Field) (°C)
MANGAPE CREEK (CHATHAMS) WAITANGI-OWENGA RD	Maximum	479	106	0.37	0.27	99	84	102.6	0.9	-	32	11.7	101.4	0.087	3.1	0.008	0.61	0.002	3.678	8.9	-	0.54	84	4	0.49	22
	Median	123.5	106	0.039	0.27	99	16	72.6	0.074	-	14.5	7.9	75.8	0.021	3.1	0.008	0.044	0.002	1.1495	7.925	-	0.4	40	1.3	0.134	13.3
	Minimum	83	106	0.0025	0.27	99	6	42.6	0.005	-	5	0.09	1.1	0.0005	3.1	0.008	0.001	0.002	0.549	6	-	0.1	18	0.61	0.012	6.5
	n	24	1	57	1	1	54	51	60	-	57	53	53	57	1	1	57	1	60	54	-	50	23	57	57	54
TE AWAINANGA RIVER (CHATHAMS) WAITANGI-OWENGA RD	Maximum	40	15.2	0.05	0.08	32	78	21.24	0.103	-	41	12.4	119	0.038	0.53	0.013	0.06	0.005	0.903	7.8	0.1	0.1	7.2	0.97	0.2	18.1
	Median	13	15.2	0.05	0.08	32	47.5	15	0.057	-	20	10.85	99.1	0.023	0.53	0.013	0.014	0.005	0.212	6.9	0.1	0.1	3.5	0.27	0.05	11.9
	Minimum	4	15.2	0.006	0.08	32	20	9.2	0.0085	-	8.6	4.96	53	0.01	0.53	0.013	0.001	0.005	0.08	4.9	0.1	0	2.4	0.1	0.026	6.6
	n	18	1	57	1	1	52	50	57	-	57	53	53	57	1	1	57	1	57	54	1	50	23	57	57	55
TE ONE CREEK (CHATHAMS) ABOVE BRIDGE OWENGA RD	Maximum	463	23	0.15	0.12	51	100	32.2	0.158	-	62	12.92	122.2	0.061	0.74	0.006	0.07	-	1.218	9.2	-	0.2	14	1.31	0.121	18.8
	Median	14	23	0.05	0.12	51	46.5	24.6	0.053	-	24	10.9	101.6	0.026	0.74	0.006	0.007	-	0.326	7	-	0.1	8.8	0.39	0.06	11.7
	Minimum	5	23	0.005	0.12	51	23	0.1	0.0075	-	10	4.84	52.1	0.008	0.74	0.006	0.001	-	0.0965	4.5	-	0	3.8	0.12	0.034	6.4
	n	18	1	57	1	1	54	51	57	-	57	53	53	57	1	1	57	-	57	53	-	50	23	57	57	55
UNNAMED NORTHERN TRIB DRAINING RAKAUTAHI UPSTREAM OF CULVERT PORT HUTT	Maximum	225	11.3	0.05	0.2	89	78	70.6	0.223	-	82	13.8	112.8	0.039	1.1	0.008	0.21	0.008	6.5475	8.3	-	0.3	24	6.6	0.16	23.8
	Median	36.5	11.3	0.033	0.2	89	29	38.935	0.052	-	40	9.2	91.5	0.017	1.1	0.008	0.006	0.008	0.5905	6.65	-	0.2	9.5	0.62	0.038	14.3
	Minimum	4	11.3	0.005	0.2	89	16	16.9	0.0075	-	19	3.06	32.3	0.002	1.1	0.008	0.002	0.008	0.1645	4	-	0.1	2.8	0.2	0.013	7
	n	18	1	57	1	1	53	52	57	-	57	53	53	57	1	1	57	1	57	54	-	49	23	57	57	55
WAIMAHANA CREEK (CHATHAMS) ABOVE BRIDGE ON	Maximum	268	126	0.046	0.15	55	100	73.6	0.068	-	32	11.7	109.4	0.27	0.17	0.015	0.045	-	0.75	8.8	-	6.3	14	0.8	0.48	16.3
	Median	196.5	126	0.012	0.15	55	89.5	57.6	0.025	-	4.1	9.04	85	0.13	0.17	0.015	0.011	-	0.097	7.9	-	0.3	9.5	0.12	0.21	12.55
	Minimum	80	126	0.0025	0.15	55	21	21.6	0.005	-	0.25	4.59	52.6	0.018	0.17	0.015	0.0025	-	-0.028	7.1	-	0.1	6.8	0.04	0.092	8.5

Table D1: Surface Water Quality Summary Data

Sites		Alkalinity to pH4.5as HCO_3 (mg/L)	Alkalinity Total (mg/L)	Ammoniacal Nitrogen (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Clarity Tube (cm)	Conductivity (mS/m)	Dissolved Inorganic Nitrogen (mg/L)	Dissolved Non Purgeable Organic Carbon (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Saturation)	Dissolved Reactive Phosphorus (mg/L)	Kjeldahl Nitrogen Total (mg/L)	Nitrate Nitrogen (mg/L)	Nitrate-N & Nitrite-N (mg/L)	Nitrite Nitrogen (mg/L)	Organic Nitrogen (mg/L)	pH	Salinity (ppt)	Salinity Field (ppt)	Sulphate (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature (Field) (°C)
	n	24	1	57	1	1	52	51	57	-	57	51	51	57	1	1	57	-	57	53	-	48	23	57	57	54
WAITAHA CREEK AT CHATHAM ISLAND	Maximum	327	154	0.17	0.24	86	100	115.2	0.434	-	83	13.9	150.5	0.032	0.76	0.002	0.42	0.004	2.1275	10.2	-	0.58	42	2.3	2.2	24.5
	Median	154	154	0.0105	0.24	86	24	57.5	0.0265	-	32	9.86	94.5	0.011	0.76	0.002	0.014	0.004	0.518	8	-	0.3	20	0.56	0.04	13.35
	Minimum	9	154	0.0025	0.24	86	5	4.5	0.005	-	12.7	0.34	3.6	0.001	0.76	0.002	0.001	0.004	0.198	5.2	-	0	9.5	0.27	0.012	6.7
	n	21	1	56	1	1	51	51	56	-	56	52	52	56	1	1	56	1	55	53	-	48	23	55	53	54
WAITAMAKI CREEK (CHATHAMS) BELOW BRIDGE ON AIR BASE RD	Maximum	350	130	0.089	0.15	66	100	4691.7	0.151	-	28	12.91	145.3	0.068	0.26	-	0.062	-	0.8445	9.5	-	30.5	48	0.86	0.22	20.9
	Median	207	130	0.014	0.15	66	59.5	74	0.023	-	8	8.5	80.8	0.028	0.26	-	0.006	-	0.258	7.825	-	0.395	14	0.3	0.088	13.6
	Minimum	109	130	0.0025	0.15	66	20	33.8	0.005	-	2.5	0.22	2.1	0.01	0.26	-	0.001	-	0.021	5.4	-	0.2	8.3	0.04	0.022	6.1
	n	24	1	57	1	1	52	51	57	-	57	53	53	57	1	-	57	-	57	54	-	48	23	57	57	55
WASHOUT CREEK (CHATHAMS) BELOW BRIDGE, WAITANGI WEST RD	Maximum	130	32	0.41	0.53	150	62	1636.7	0.42	-	69	10.44	95	0.164	1.1	0.042	0.109	0.003	3.735	8.4	-	9.63	30	3.8	0.47	21.1
	Median	59.5	32	0.055	0.53	150	32	44.15	0.097	-	35	4.97	52.2	0.073	1.1	0.042	0.019	0.003	0.604	6.8	-	0.2	9.9	0.81	0.13	13.4
	Minimum	5	32	0.005	0.53	150	12	14.2	0.0145	-	21	0.81	7.3	0.017	1.1	0.042	0.001	0.003	0.139	4.2	-	0.1	4	0.22	0.03	6.6
	n	18	1	55	1	1	53	52	55	-	57	53	53	57	1	1	57	1	55	54	-	49	23	57	57	55
WHANGAMOE INLET STREAM (CHATHAMS) 30M BELOW ROADBRIDGE WAITANGI	Maximum	66	22	0.24	-	-	80	4680.1	0.246	-	62	11.2	94.6	0.09	0.84	0.006	0.041	-	1.216	7.9	0.2	30.4	580	1.28	0.13	22
	Median	28	22	0.0135	-	-	30.5	49.245	0.0235	-	26	6.765	70.8	0.046	0.84	0.006	0.006	-	0.50525	6.44	0.2	0.33	21	0.52	0.0815	12.85
	Minimum	5	22	0.0025	-	-	12	13.2	0.005	-	7.1	0.06	0.8	0.014	0.84	0.006	0.001	-	0.1725	4.1	0.2	0.1	4.2	0.19	0.037	7.2
	n	15	1	54	-	-	50	48	54	-	54	50	50	54	1	1	54	-	54	52	1	47	21	54	54	52
NAIRN RIVER (CHATHAMS) ROPE	Maximum	-	-	-	-	-	93	4062	-	-	-	11.94	116.1	-	-	-	-	-	-	8.2	-	25.8	-	-	-	21.5
	Median	-	-	-	-	-	50	330.4	-	-	-	9.16	92.55	-	-	-	-	-	-	7.6	-	1.74	-	-	-	14.4

Table D1: Surface Water Quality Summary Data

Sites		Alkalinity to pH4.5as HCO_3 (mg/L)	Alkalinity Total (mg/L)	Ammoniacal Nitrogen (mg/L)	Bromide (mg/L)	Chloride (mg/L)	Clarity Tube (cm)	Conductivity (mS/m)	Dissolved Inorganic Nitrogen (mg/L)	Dissolved Non Purgeable Organic Carbon (mg/L)	Dissolved Organic Carbon (mg/L)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% Saturation)	Dissolved Reactive Phosphorus (mg/L)	Kjeldahl Nitrogen Total (mg/L)	Nitrate Nitrogen (mg/L)	Nitrate-N & Nitrite-N (mg/L)	Nitrite Nitrogen (mg/L)	Organic Nitrogen (mg/L)	pH	Salinity (ppt)	Salinity Field (ppt)	Sulphate (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Water Temperature (Field) (°C)
	Minimum	-	-	-	-	-	17	31.01	-	-	-	4.61	50.3	-	-	-	-	-	-	6.8	-	0.15	-	-	-	6.7
	n	-	-	-	-	-	21	21	-	-	-	22	22	-	-	-	-	-	-	23	-	21	-	-	-	23
TE WHANGA LAGOON																										
TE WHAANGA LAGOON SOUTHERN BASIN (WEST)	Maximum	-	-	0.05	-	-	100	4992.3	0.468	9.1	17	12.4	133.2	0.012	0.2	-	0.44	-	0.657	8.4	29	32.74	-	0.71	0.12	23
	Median	-	-	0.05	-	-	100	3972	0.115	5.8	5.15	9.49	104.5	0.004	0.2	-	0.1	-	0.306	8.1	19.5	26.13	-	0.42	0.023	12.85
	Minimum	-	-	0.009	-	-	6	2180	0.021	4	1.6	4.97	53.9	0.002	0.2	-	0.001	-	-0.048	6	14.9	2.6	-	0.15	0.002	7
	n	-	-	38	-	-	45	45	39	27	24	45	45	15	1	-	39	-	39	47	10	47	-	51	51	48
TE WHANGA LAGOON (CHATHAMS) BEACH 300M NORTH OF BLIND JIMS CREEK	Maximum	186	-	0.45	-	-	100	5065.4	0.576	8.7	12	17.2	200	0.024	1.2	-	0.48	-	1.981	9.1	25.7	33.28	2100	41	8.1	25.3
	Median	167	-	0.05	-	-	75	3790	0.055	7.3	5.7	9.985	111.9	0.0045	1.2	-	0.007	-	0.63	8.2	19.7	25.905	1600	0.825	0.045	14
	Minimum	143	-	0.006	-	-	0	410.49	0.0145	5.4	1.6	4.7	52	0.0005	1.2	-	0.0005	-	0.261	6.7	12.1	11.7	1400	0.32	0.01	7.1
	n	5	-	44	-	-	50	47	47	27	33	50	51	44	1	-	45	-	47	53	7	48	3	60	60	54
TE WHANGA LAGOON (CHATHAMS) LAKE SHORE AT WAITAMAKI CK BEACH (AIR BASE RD)	Maximum	177	-	0.057	-	-	100	6400	0.15	8	13	15.7	163	0.023	0.4	-	0.1	0.002	0.802	8.7	24.2	33.45	2100	4.2	1	20.8
	Median	153	-	0.05	-	-	100	4052.2	0.088	5.3	4.2	9.295	105	0.005	0.4	-	0.0345	0.002	0.354	8.1	18.6	27.41	1700	0.4	0.0285	14
	Minimum	148	-	0.009	-	-	24	78	0.012	3.2	0.8	4.94	53.2	0.0005	0.4	-	0.001	0.002	0.01	6.1	15.5	0.4	1500	0.04	0.004	6.5
	n	5	-	43	-	-	52	47	46	27	30	50	50	43	1	-	44	1	46	52	6	49	3	58	58	53

Table D2: Surface Water Ecology Summary Data

Sites		Chlorophyll *a* planktonic ((ug/L)	*E. coli* (MPN/100ml)	Enterococci (MPN/100ml)	Macrophytes emergent	Macrophytes submerged	Macrophytes total	Periphyton long filament	Periphyton mats	Periphyton total cover	Sedimentation (%)
LAKES											
LAKE HURO (CHATHAMS) LAKE EDGE OPP DOC HQ	Maximum	133.5	-	-	-	-	-	-	-	-	-
	Median	17.85	-	-	-	-	-	-	-	-	-
	Minimum	0.4	-	-	-	-	-	-	-	-	-
	n	56	-	-	-	-	-	-	-	-	-
LAKE MARAKAPIA (CHATHAMS) SOUTHWEST SHORE BY TREES	Maximum	4	-	-	-	-	-	-	-	-	-
	Median	0.95	-	-	-	-	-	-	-	-	-
	Minimum	0.1	-	-	-	-	-	-	-	-	-
	n	54	-	-	-	-	-	-	-	-	-
LAKE RANGITAI (CHATHAMS) EASTERN SHORE OFF TAIA-HAPUPU RD	Maximum	6.8	2420	6	-	-	-	-	-	-	-
	Median	0.8	11	6	-	-	-	-	-	-	-
	Minimum	0.1	0.5	6	-	-	-	-	-	-	-
	n	55	47	1	-	-	-	-	-	-	-
LAKE TE WAPU (CHATHAMS) NORTH END AT KAIANGAROA	Maximum	51.7	-	-	-	-	-	-	-	-	-
	Median	5.95	-	-	-	-	-	-	-	-	-
	Minimum	0.3	-	-	-	-	-	-	-	-	-
	n	56	-	-	-	-	-	-	-	-	-
TENNANTS LAKE (CHATHAMS) SHORELINE OFF PORT HUTT RD	Maximum	13	31	-	-	-	-	-	-	-	-
	Median	0.75	31	-	-	-	-	-	-	-	-
	Minimum	0.1	31	-	-	-	-	-	-	-	-
	n	54	1	-	-	-	-	-	-	-	-
WATERCOURSES											
AWAMATA STREAM (CHATHAMS) WAITANGI-TUKU RD	Maximum	-	-	-	10	30	40	60	5	100	0
	Median	-	-	-	5	30	35	30	0	50	0
	Minimum	-	-	-	0	30	30	0	0	0	0
	n	-	-	-	2	2	2	2	3	2	3

Table D2: Surface Water Ecology Summary Data

Sites		Chlorophyll *a* planktonic ((ug/L)	*E. coli* (MPN/100ml)	Enterococci (MPN/100ml)	Macrophytes emergent	Macrophytes submerged	Macrophytes total	Periphyton long filament	Periphyton mats	Periphyton total cover	Sedimentation (%)
AWATOTARA CREEK (CHATHAMS) WAITANGI-TUKU ROAD	Maximum	-	-	-	100	30	100	0	0	100	10
	Median	-	-	-	50	15	65	0	0	50	0
	Minimum	-	-	-	0	0	30	0	0	0	0
	n	-	-	-	2	2	2	2	2	2	3
BLIND JIMS CREEK (CHATHAM) BELOW CULVERT NORTH RD	Maximum	-	72	-	30	60	90	-	-	10	0
	Median	-	72	-	30	60	90	-	-	10	0
	Minimum	-	72	-	30	60	90	-	-	10	0
	n	-	1	-	1	1	1	-	-	1	1
MANGAHOU STREAM (CHATHAMS) 50M BELOW BRIDGE ON WAITANHI WHARF OWENGA RD	Maximum	-	-	-	-	-	-	0	0	100	-
	Median	-	-	-	-	-	-	0	0	100	-
	Minimum	-	-	-	-	-	-	0	0	100	-
	n	-	-	-	-	-	-	1	1	1	-
MANGAPE CREEK (CHATHAMS) WAITANGI-OWENGA RD	Maximum	-	2420	-	-	5	-	-	-	-	95
	Median	-	141.5	-	-	5	-	-	-	-	95
	Minimum	-	11	-	-	5	-	-	-	-	95
	n	-	46	-	-	1	-	-	-	-	1
TE AWAINANGA RIVER (CHATHAMS) WAITANGI-OWENGA RD	Maximum	8.5	580	-	50	-	-	0	-	30	0
	Median	8.5	420	-	50	-	-	0	-	30	0
	Minimum	8.5	260	-	50	-	-	0	-	30	0
	n	1	2	-	1	-	-	1	-	1	1
TE ONE CREEK (CHATHAMS) ABOVE BRIDGE OWENGA RD	Maximum	-	-	-	10	0	10	0	0	90	0
	Median	-	-	-	10	0	10	0	0	45	0
	Minimum	-	-	-	10	0	10	0	0	0	0
	n	-	-	-	1	1	1	1	2	1	2
RAKAUTAHI UPSTREAM OF CULVERT PORT HUTT RD	Maximum	-	-	-	10	30	40	0	0	0	0
	Median	-	-	-	10	30	40	0	0	0	0

Table D2: Surface Water Ecology Summary Data

Sites		Chlorophyll *a* planktonic ((ug/L)	*E. coli* (MPN/100ml)	Enterococci (MPN/100ml)	Macrophytes emergent	Macrophytes submerged	Macrophytes total	Periphyton long filament	Periphyton mats	Periphyton total cover	Sedimentation (%)
	Minimum	-	-	-	10	30	40	0	0	0	0
	n	-	-	-	1	1	1	1	1	1	1
WAIMAHANA CREEK (CHATHAMS) ABOVE BRIDGE ON NORTH RD	Maximum	-	-	-	60	100	145	0	0	0	0
	Median	-	-	-	47.5	92.5	140	0	0	0	0
	Minimum	-	-	-	35	85	135	0	0	0	0
	n	-	-	-	2	2	2	1	1	1	1
WAITAHA CREEK AT CHATHAM ISLAND	Maximum	-	220	-	10	0	0	0	0	65	10
	Median	-	220	-	5	0	0	0	0	32.5	5
	Minimum	-	220	-	0	0	0	0	0	0	0
	n	-	1	-	2	1	1	1	1	2	2
WAITAMAKI CREEK (CHATHAMS) BELOW BRIDGE ON AIR BASE RD	Maximum	-	-	-	-	20	-	60	-	-	0
	Median	-	-	-	-	20	-	60	-	-	0
	Minimum	-	-	-	-	20	-	60	-	-	0
	n	-	-	-	-	1	-	1	-	-	1
WASHOUT CREEK (CHATHAMS) BELOW BRIDGE, WAITANGI WEST RD	Maximum	-	-	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-	-	-
	Minimum	-	-	-	-	-	-	-	-	-	-
	n	-	-	-	-	-	-	-	-	-	-
WHANGAMOE INLET STREAM (CHATHAMS) 30M BELOW ROADBRIDGE WAITANGI WEST RD	Maximum	1.5	-	-	-	-	-	-	-	-	-
	Median	1.5	-	-	-	-	-	-	-	-	-
	Minimum	1.5	-	-	-	-	-	-	-	-	-
	n	1	-	-	-	-	-	-	-	-	-
NAIRN RIVER (CHATHAMS) ROPE	Maximum	-	2420	548	-	-	-	-	-	-	-
	Median	-	299	35.5	-	-	-	-	-	-	-
	Minimum	-	9	1	-	-	-	-	-	-	-
	n	-	47	46	-	-	-	-	-	-	-

Table D2: Surface Water Ecology Summary Data

Sites		Chlorophyll *a* planktonic ((ug/L)	*E. coli* (MPN/100ml)	Enterococci (MPN/100ml)	Macrophytes emergent	Macrophytes submerged	Macrophytes total	Periphyton long filament	Periphyton mats	Periphyton total cover	Sedimentation (%)
TE WHANGA LAGOON											
TE WHAANGA LAGOON SOUTHERN BASIN (WEST)	Maximum	8.3	2480	-	-	-	-	-	-	-	-
	Median	1.6	10	-	-	-	-	-	-	-	-
	Minimum	0.2	5	-	-	-	-	-	-	-	-
	n	43	37	-	-	-	-	-	-	-	-
TE WHANGA LAGOON (CHATHAMS) BEACH 300M NORTH OF BLIND JIMS CREEK	Maximum	298.7	16000	1000	-	90	-	60	-	-	9
	Median	3.2	15	5	-	90	-	60	-	-	9
	Minimum	0.5	5	2	-	90	-	60	-	-	9
	n	57	48	47	-	1	-	1	-	-	1
TE WHANGA LAGOON (CHATHAMS) LAKE SHORE AT WAITAMAKI CK BEACH (AIR BASE RD)	Maximum	306.4	7700	96	-	-	-	-	-	90	-
	Median	1.2	5	5	-	-	-	-	-	90	-
	Minimum	0.1	5	1	-	-	-	-	-	90	-
	n	57	47	47	-	-	-	-	-	1	-

Appendix E

Additional Data Plots

Table E1: Summary of additional Chatham Island water quality monitoring sites.	
Reference ID	**Site description**
	Additional short-term sites
BJ	Blind Jim's Stream (north)
MC	Mananginui Creek
TA	Te Awainanga River - south branch
NR	Unnamed Nikau Reserve Stream
UW	Unnamed Wharekauri Stream
WS	Waimahana Stream
	Additional Te Whanga sites
AR1KM	Te Whanga Airbase Rd, 1 km offshore
AR250	Te Whanga Airbase Rd, 250 m offshore
AR500	Te Whanga Airbase Rd, 500 m offshore
AR750	Te Whanga Airbase Rd, 750m offshore
CNB	Te Whanga central northern basin
CSB	Te Whanga central southern basin
PT	Te Whanga at plum tree
PT250	Te Whanga at plum tree, 250 m offshore
PT1KM	Te Whanga at plum tree, 1 km offshore
PT500	Te Whanga at plum tree, 500 m offshore
PT750	Te Whanga at plum tree, 750m offshore
	Additional miscellaneous sites
CCB	Te Whanga- central basin
CCB1	Te Whanga - central basin
CSB	Te Whanga - south basin
LK	Lake Kaingarahu, north east lake margin off Taia-hapupu Rd
LKA	Lake Kairae mid lake
LT	Lake Taia mid lake
LW	Lake Wharemanu northern shore alongside fenceline from North Rd
TC	Tahatika Creek upstream from beach

Table E1: Summary of additional Chatham Island water quality monitoring sites.	
TSB	Te Whanga Lagoon, south basin recorder site
TR	Tuku River 50 m downstream of bridge on Waitangi-Tuku Rd
TUC	Tutuiri Creek upstream from beach
CPS	Unnamed stream by cattle point

Additional short-term sites

[BJ] "BLIND JIMS CATCHMENT (CHATHAMS) BLIND JIMS STREAM (NORTH) CHATHAM ISLAND"

[MC] "MANANGINUI CREEK (CHATHAMS) MANANGINUI CREEK, CHATHAM ISLAND"

[TA] "TE AWAINANGA RIVER - SOUTH BRANCH SOUTH BRANCH TE AWAINANGA RIVER"

[NR] "UNNAMED NIKAU RESERVE STREAM (CHATHAMS) NIKAU STREAM CHATHAM ISLAND"

[UW] "UNNAMED WHAREKAURI STREAM (CHATHAMS) WHAREKAURI STREAM CHATHAM ISLAND"

[WS] "WAIMAHANA STREAM (CHATHAMS) CHUDLEIGH RESERVE STREAM"

Additional Te Whanga sites

[AR1KM] "TE WHANGA AIRBASE RD 1KM OFFSHORE"

[AR250] "TE WHANGA AIRBASE RD 250 M OFFSHORE"

[AR500] "TE WHANGA AIRBASE RD 500 M OFFSHORE"

[AR750] "TE WHANGA AIRBASE RD 750M OFFSHORE"

[CNB] "TE WHANGA CENTRAL NORTHERN BASIN"

[CSB] "TE WHANGA CENTRAL SOUTHERN BASIN"

[PT250] "TE WHANGA LAGOON PLUM TREE 250 M OFFSHORE"

[PT] "TE WHANGA PLUM TREE"

[PT1KM] "TE WHANGA PLUM TREE 1 KM OFFSHORE"

[PT500] "TE WHANGA PLUM TREE 500 M OFFSHORE"

[PT750] "TE WHANGA PLUM TREE 750M OFFSHORE"

Additional mics. Sites

[CCB] "CHATHAM ISLAND TE WHANGA- CENTRAL BASIN"

[CCB1] "CHATHAM ISLAND TE WHANGA - CENTRAL BASIN"

[CSB] "CHATHAM ISLAND TE WHANGA - SOUTH BASIN"

[LK] "LAKE KAINGARAHU (CHATHAMS) NORTH EAST LAKE MARGIN OFF TAIA-HAPUPU RD"

[LKA] "LAKE KAIRAE MID LAKE"

[LT] "LAKE TAIA (CHATHAMS) MID LAKE"

[LW] "LAKE WHAREMANU (CHATHAMS) NORTHERN SHORE ALONGSIDE FENCELINE FROM NORTH RD"

[TC] "TAHATIKA CREEK (CHATHAMS) UPSTREAM FROM BEACH"

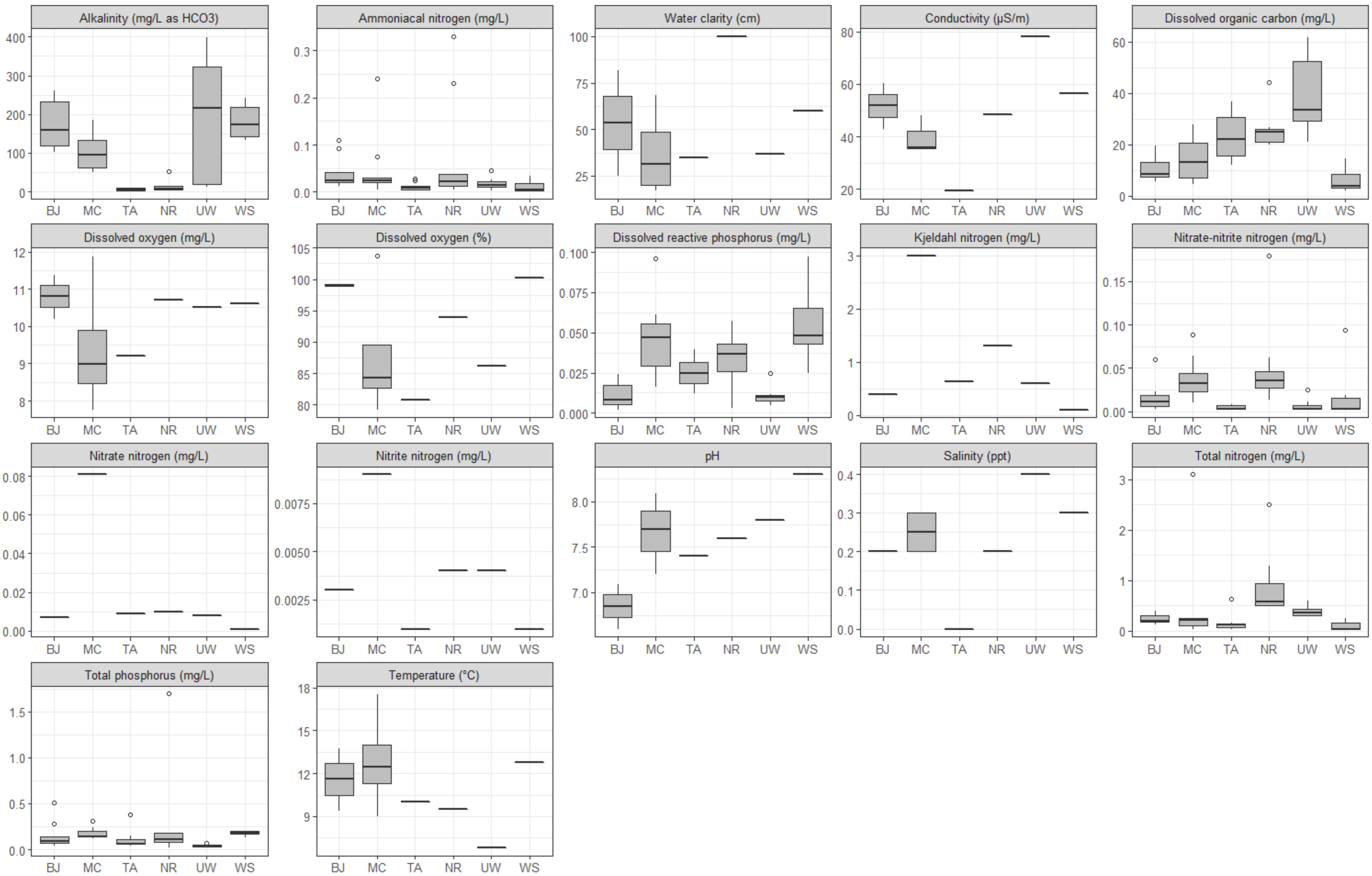
[TSB] "TE WHANGA LAGOON, SOUTH BASIN, CHATHAM ISLAND SOUTH BASIN RECORDER SITE"

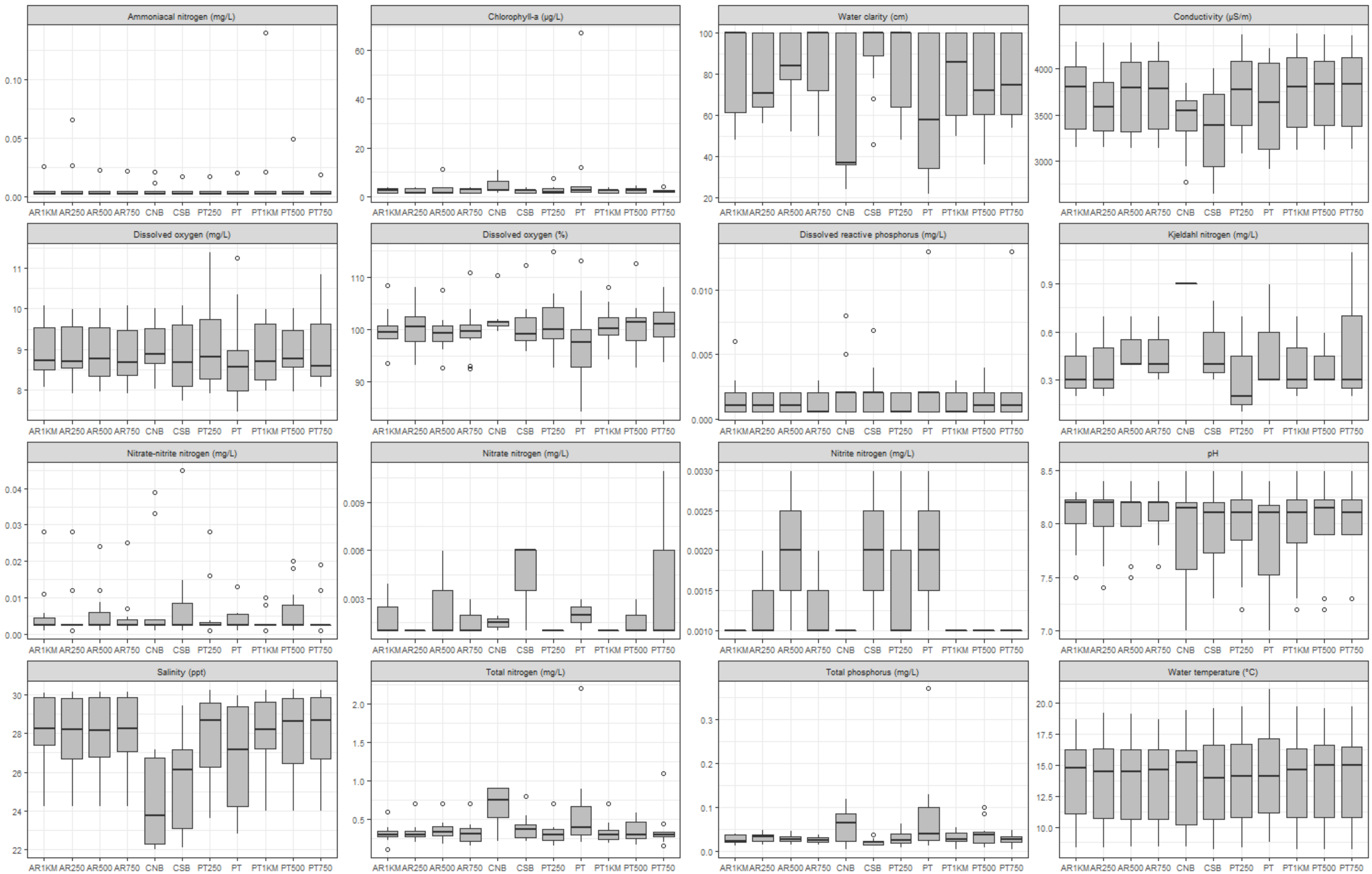
[TR] "TUKU RIVER 50M DS OF BRIDGE ON WAITANGI-TUKU RD"

[TUC] "TUTUIRI CREEK (CHATHAMS) UPSTREAM FROM BEACH"

[CPS] "UNNAMED STREAM BY CATTLE POINT (CHATHAMS) CATTLE POINT STREAM"


Alkalinity (mg/L as HCO3)
Ammoniacal nitogen (mg/L)
Bromide (mg/L)
Chloride (mg/L)
Chlorophyll-a (µg/L)
Water clarity (cm)
Conductivity (µS/m)
Field conuctivity (µS/m)
Dissolved organic carbon (mg/L)
Dissolved oxygen (mg/L)
Dissolved oxygen (%)
Dissolved reactive phosphorus (mg/L)
Fluoride (mg/L)
Emergent macrophyte cover (%)
Submerged macrophyte cover (%)
Total macrophyte cover (%)
Nitrate-Nitrite nitrogen (mg/L)
Periphyton cover (%)
pH
Field pH
Salinity (ppt)
Field salinity (ppt)
Sedimentation (%)
Sulphate (mg/L)
Total nitrogen (mg/L)
Total phosphorus (mg/L)
Water temperature (°C)
CCB CCB1 CSB LK LKA LT LW TC TSB TR TUC CPS


Alkalinity (mg/L as HCO3)
Ammoniacal nitrogen (mg/L)
Water clarity (cm)
Conductivity (µS/m)
Dissolved organic carbon (mg/L)
Dissolved oxygen (mg/L)
Dissolved oxygen (%)
Dissolved reactive phosphorus (mg/L)
Kjeldahl nitrogen (mg/L)
Nitrate-nitrite nitrogen (mg/L)
Nitrate nitrogen (mg/L)
Nitrite nitrogen (mg/L)
pH
Salinity (ppt)
Total nitrogen (mg/L)
Total phosphorus (mg/L)
Temperature (°C)
BJ
MC
TA
NR
UW
WS



Ammoniacal nitrogen (mg/L)
Chlorophyll-a (µg/L)
Water clarity (cm)
Conductivity (µS/m)
Dissolved oxygen (mg/L)
Dissolved oxygen (%)
Dissolved reactive phosphorus (mg/L)
Kjeldahl nitrogen (mg/L)
Nitrate-nitrite nitrogen (mg/L)
Nitrate nitrogen (mg/L)
Nitrite nitrogen (mg/L)
pH
Salinity (ppt)
Total nitrogen (mg/L)
Total phosphorus (mg/L)
Water temperature (°C)
AR1KM AR250 AR500 AR750 CNB CSB PT250 PT PT1KM PT500 PT750

Appendix F

Temporal Trend Plots

Lakes

Physicochemical parameters

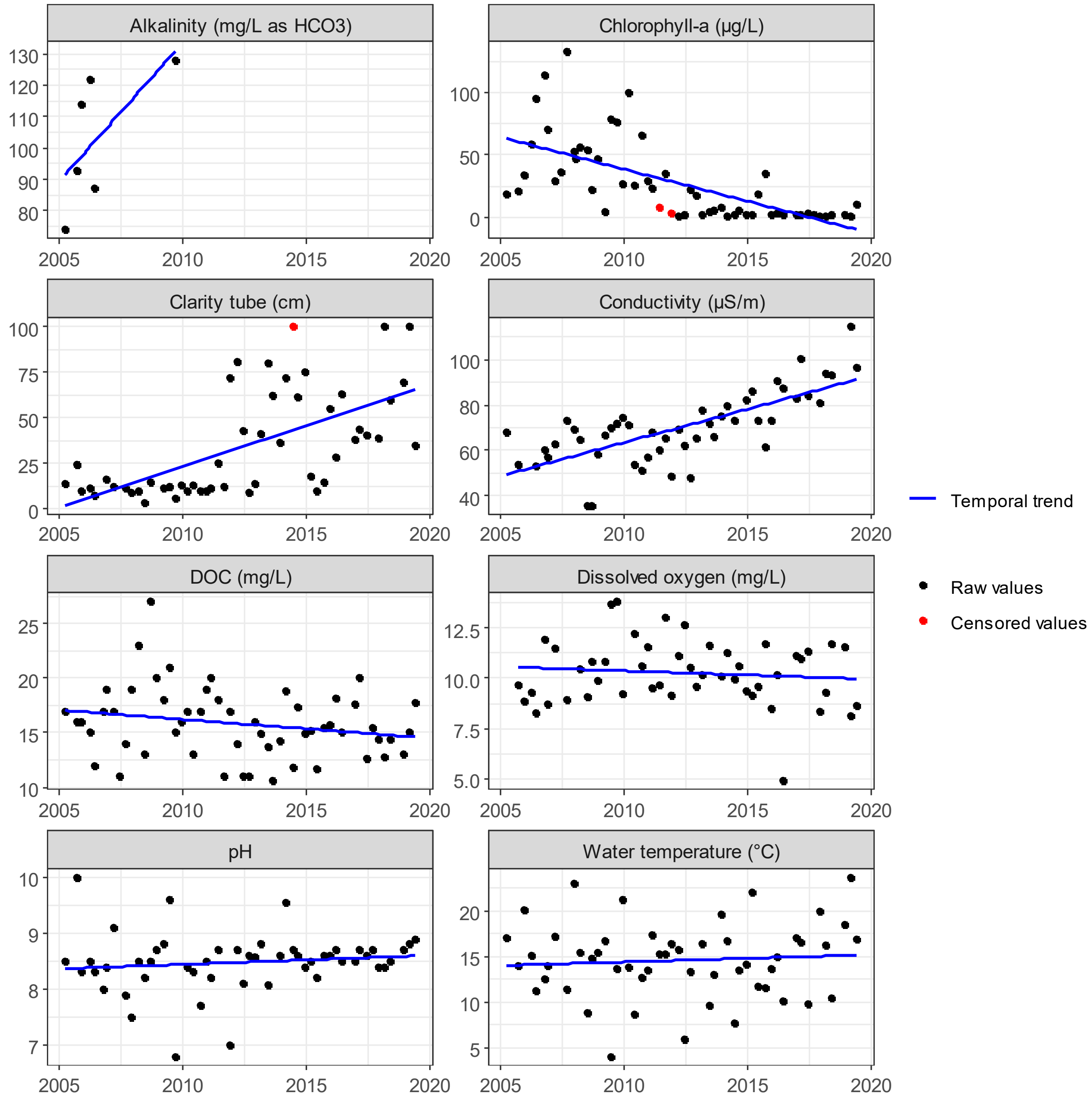


Figure 1. Lake Huro

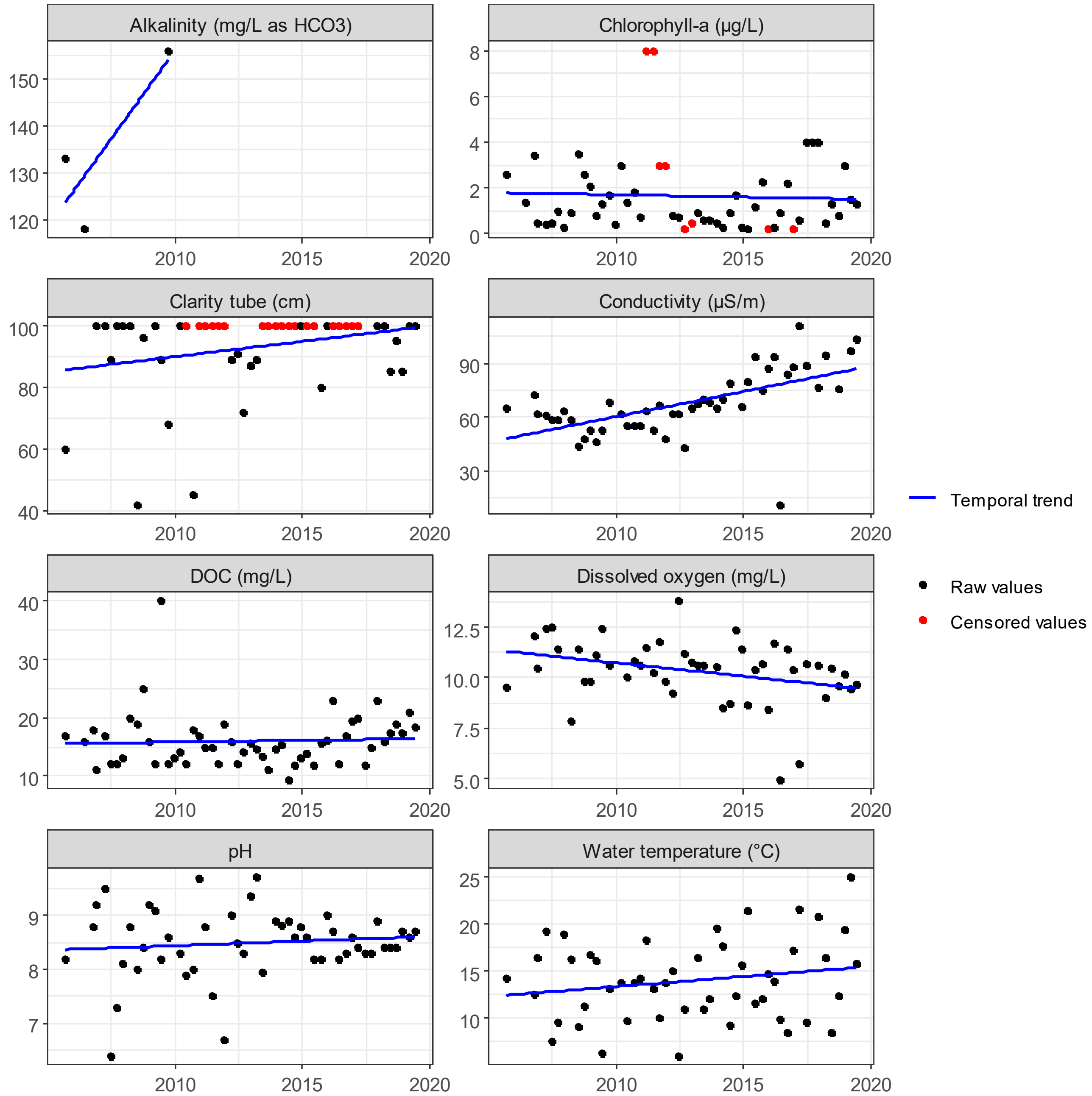


Figure 2. Lake Marakapia

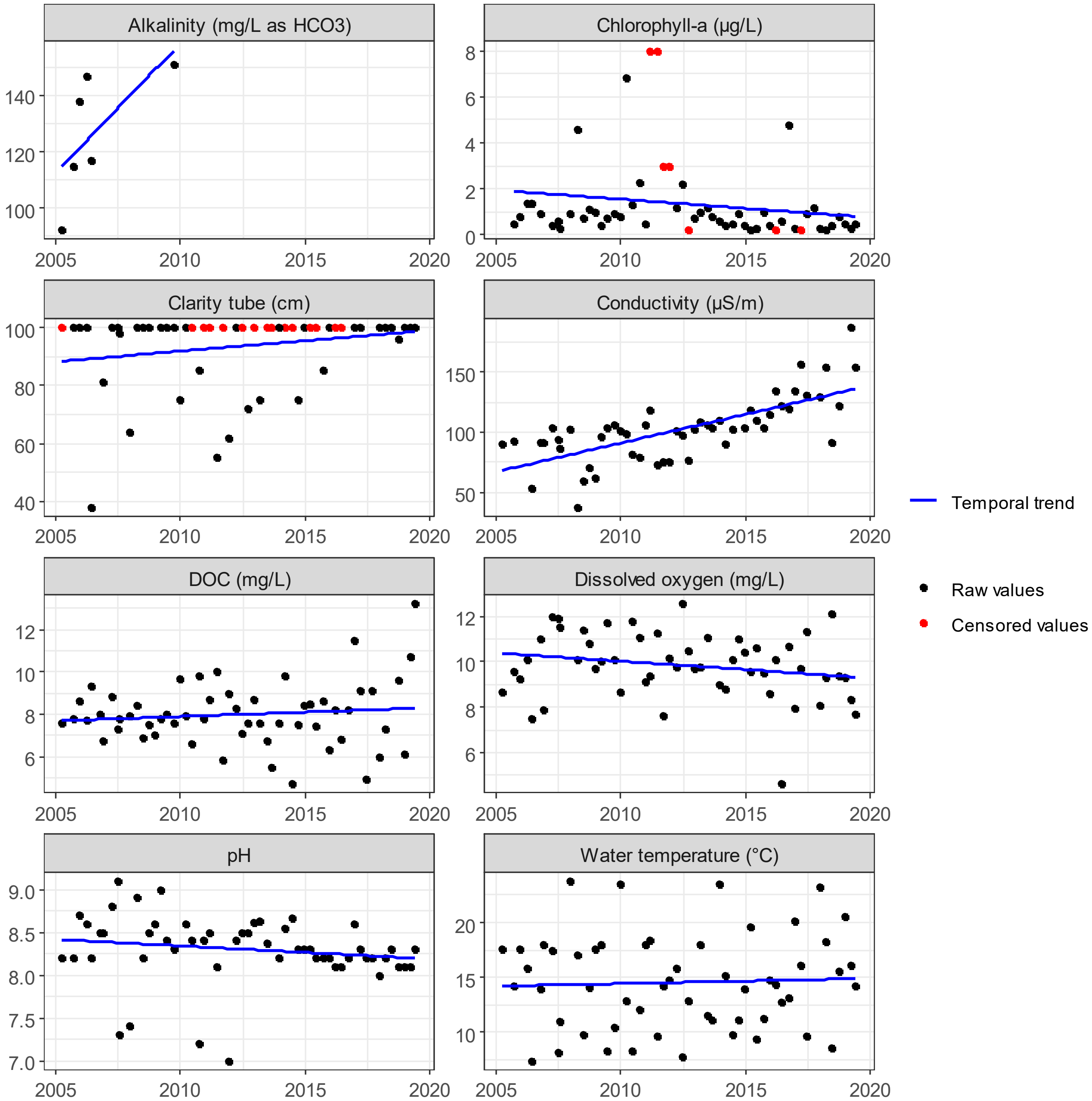


Figure 3. Lake Rangitai

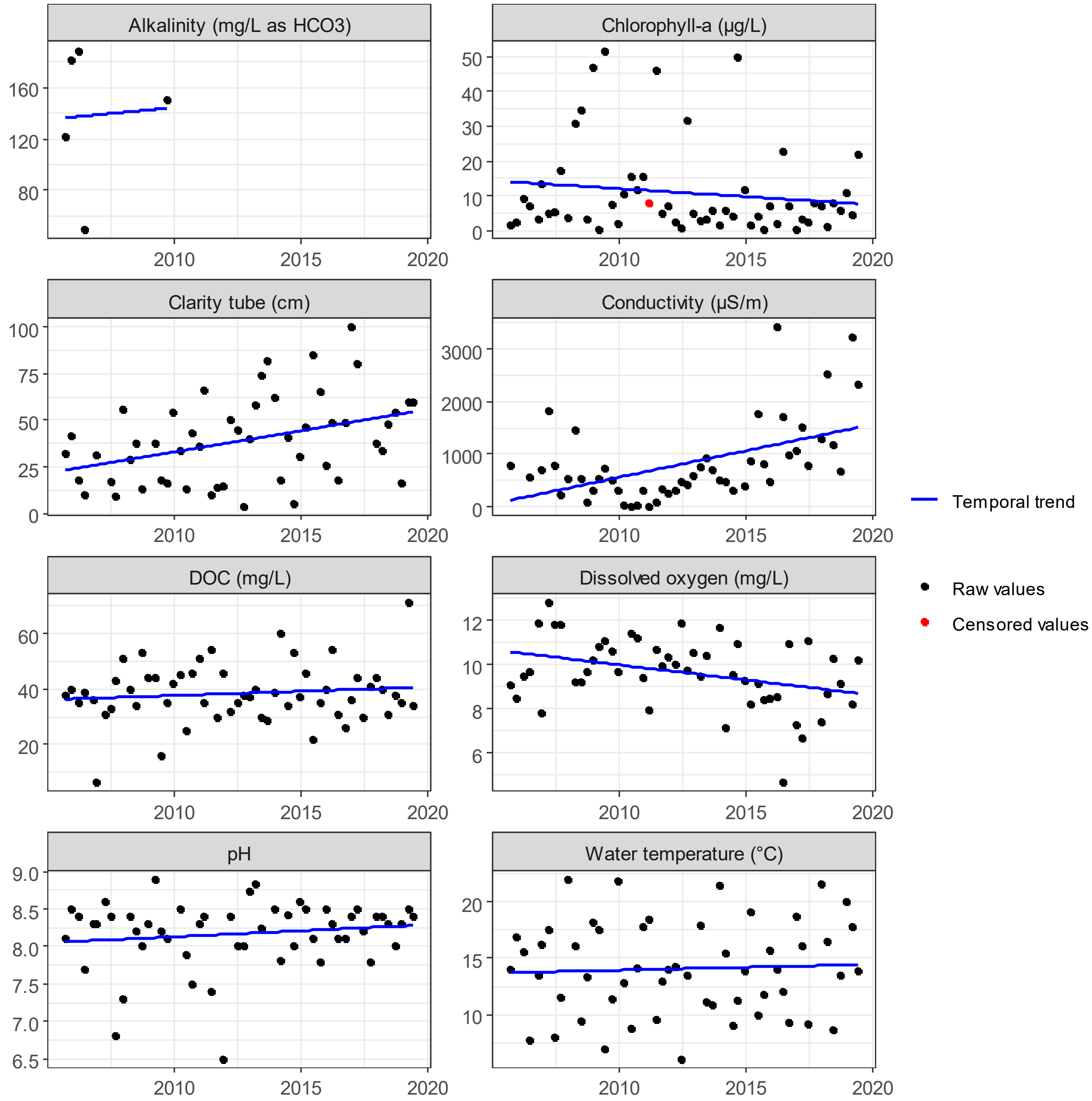


Figure 4. Lake Te Wapu

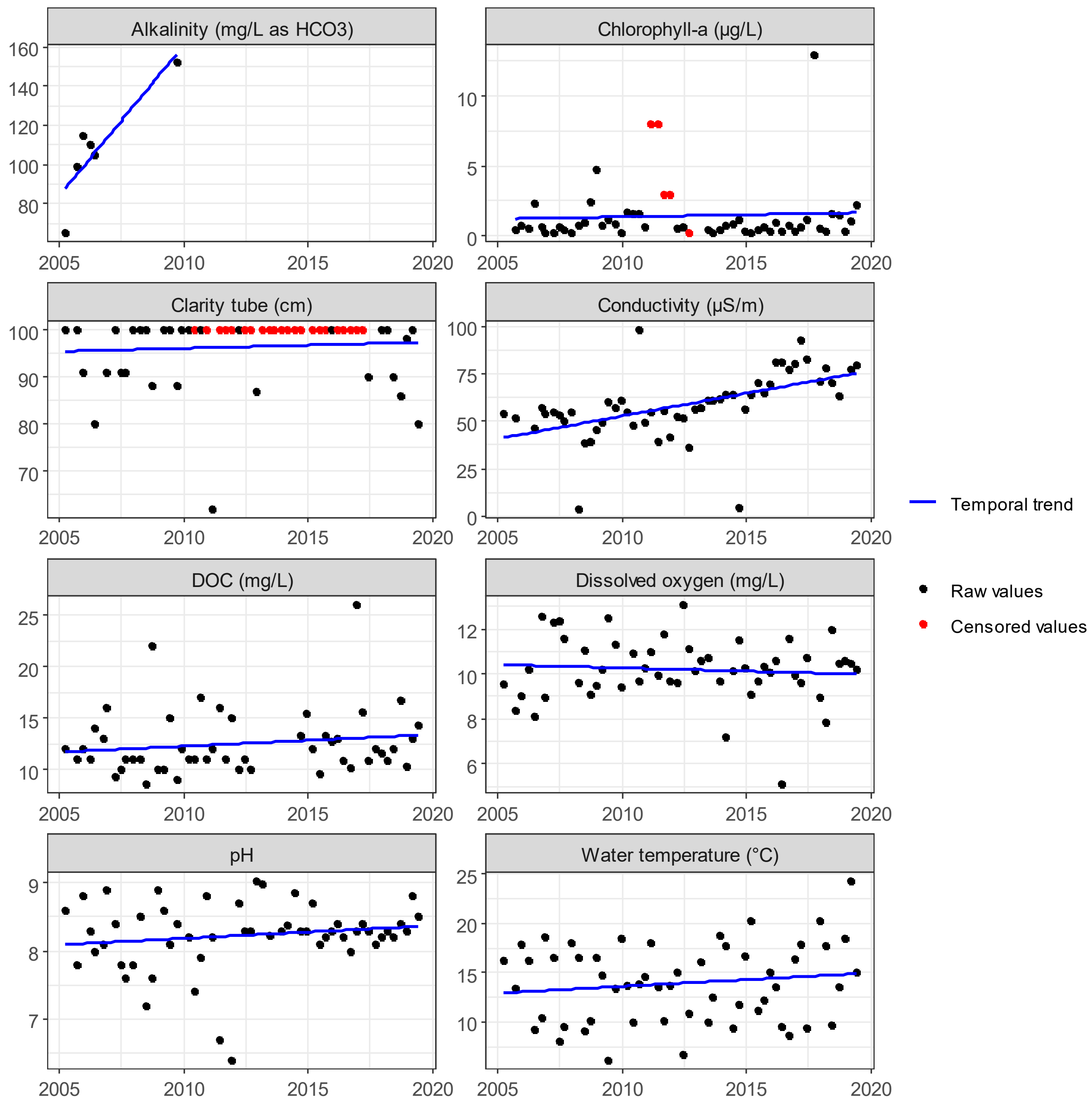


Figure 5. Tennants Lake

Nutrient parameters

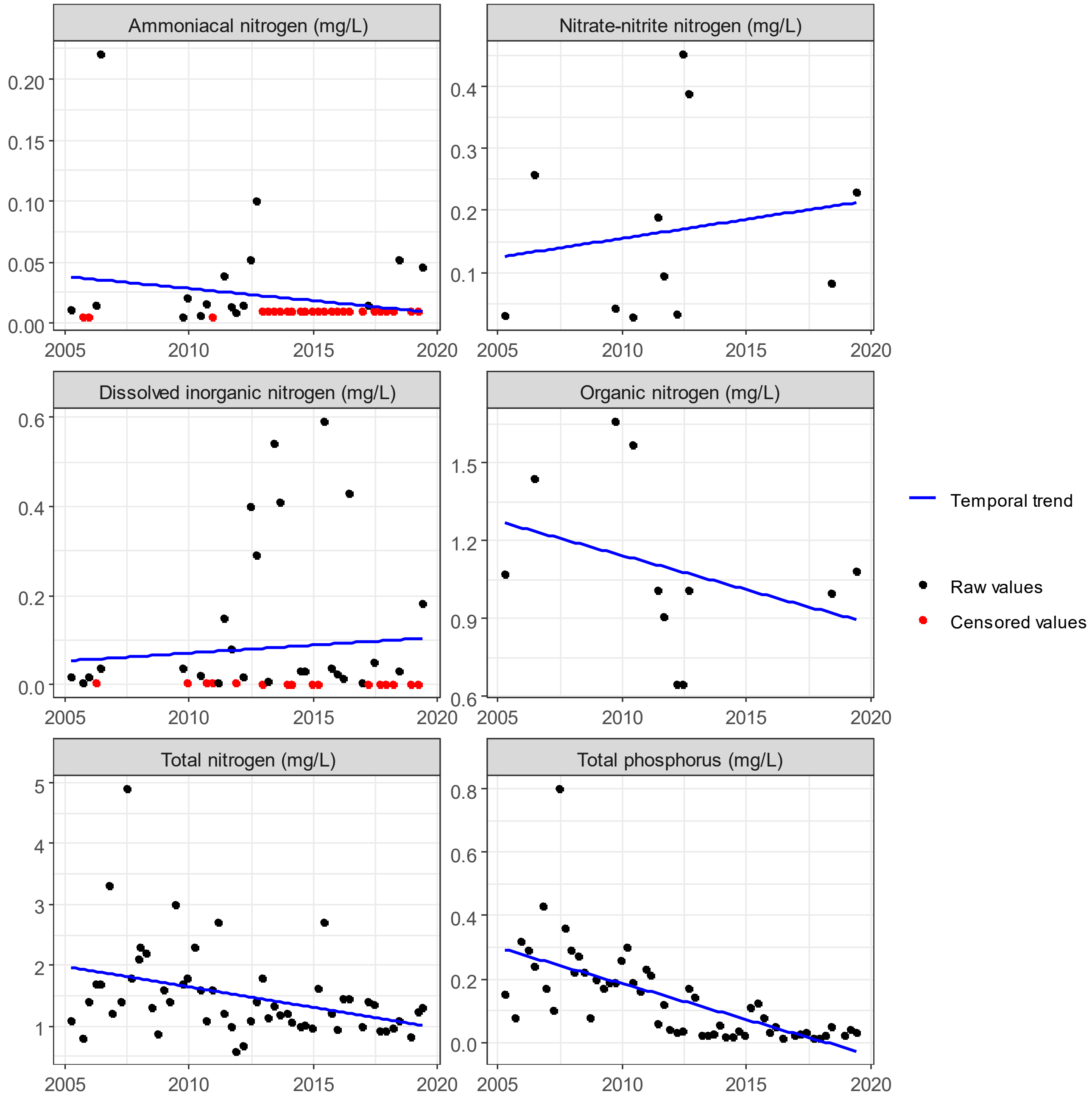


Figure 6. Lake Huro

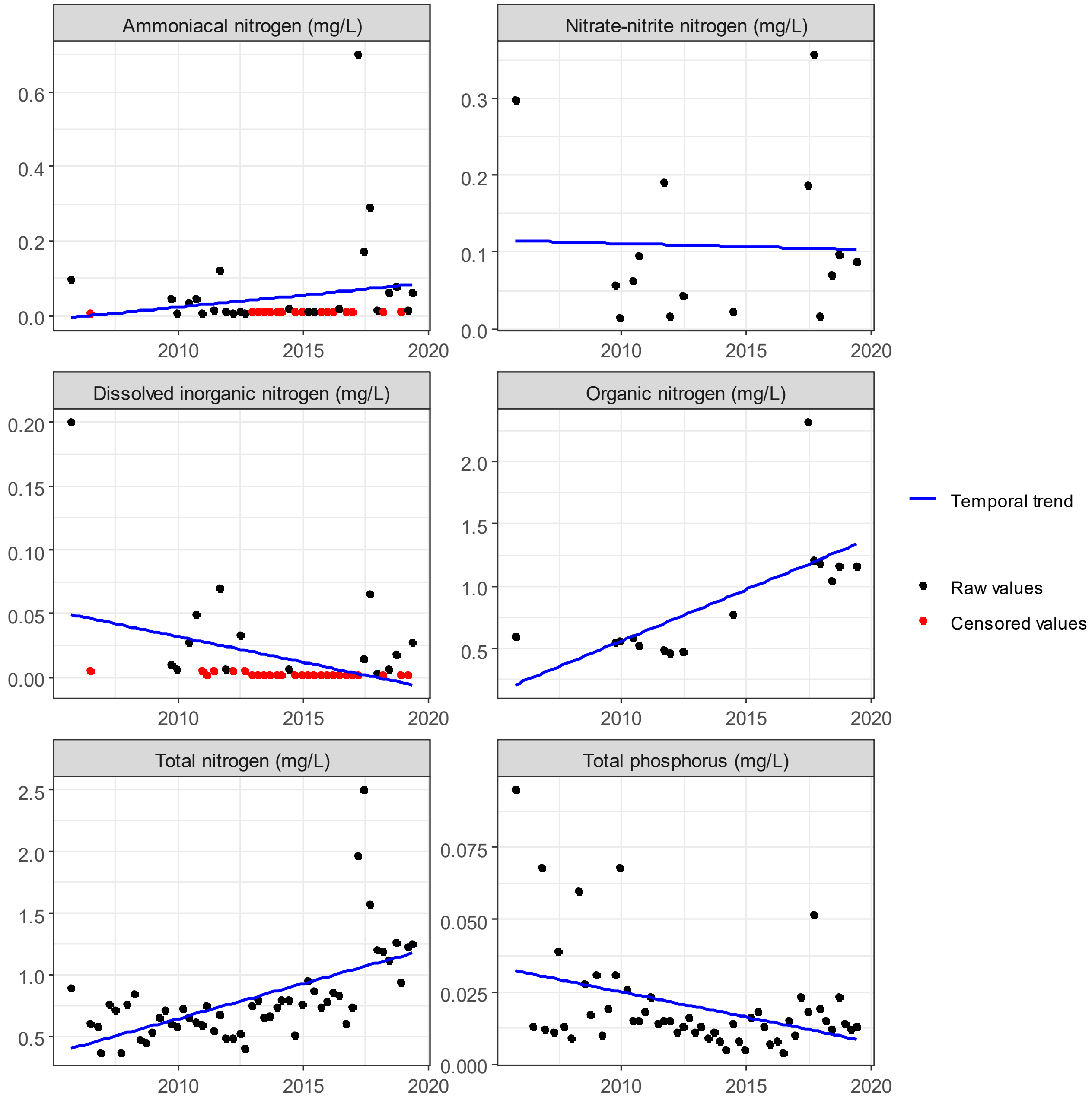


Figure 7. Lake Marakapia

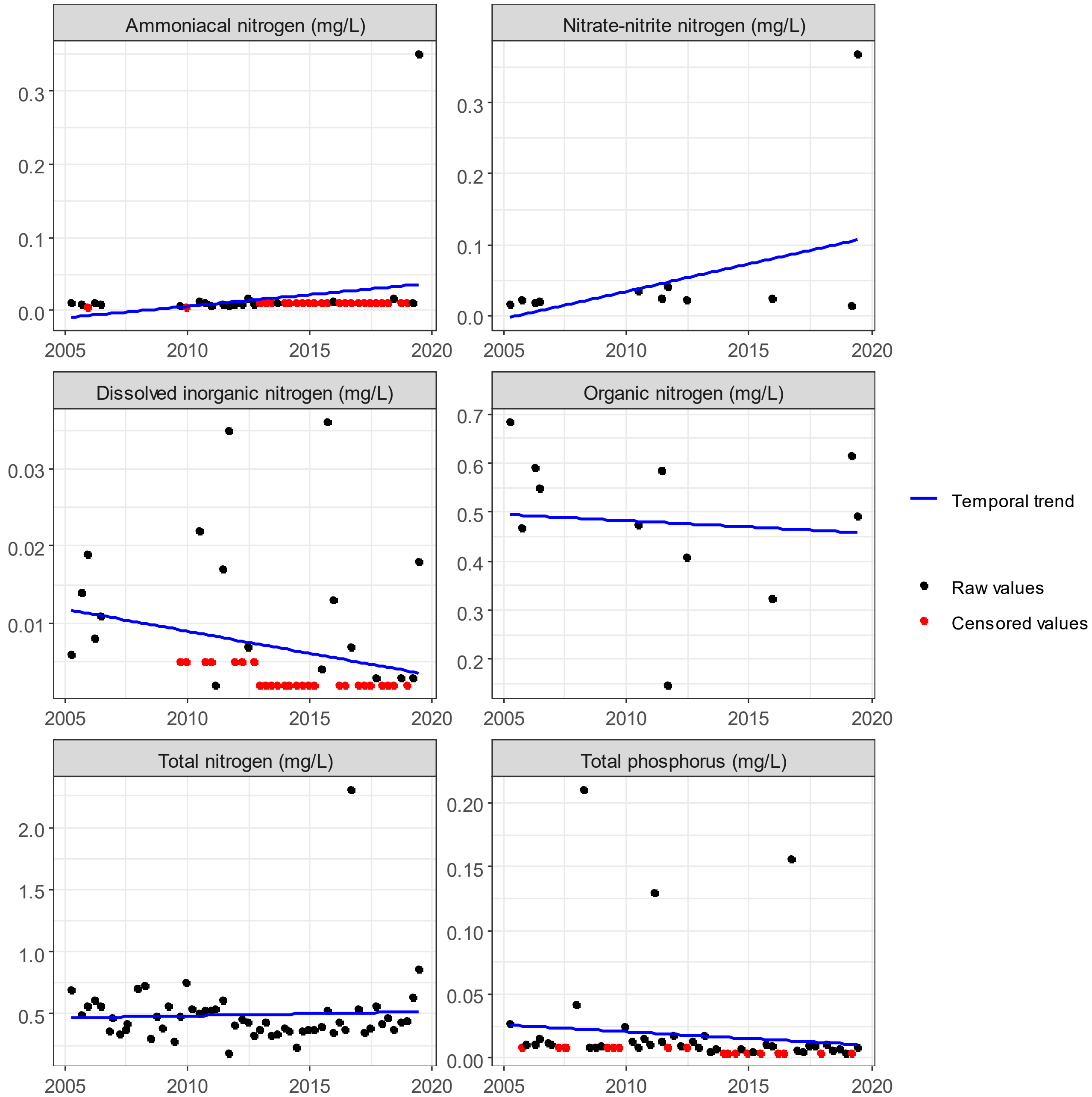


Figure 8. Lake Rangitai

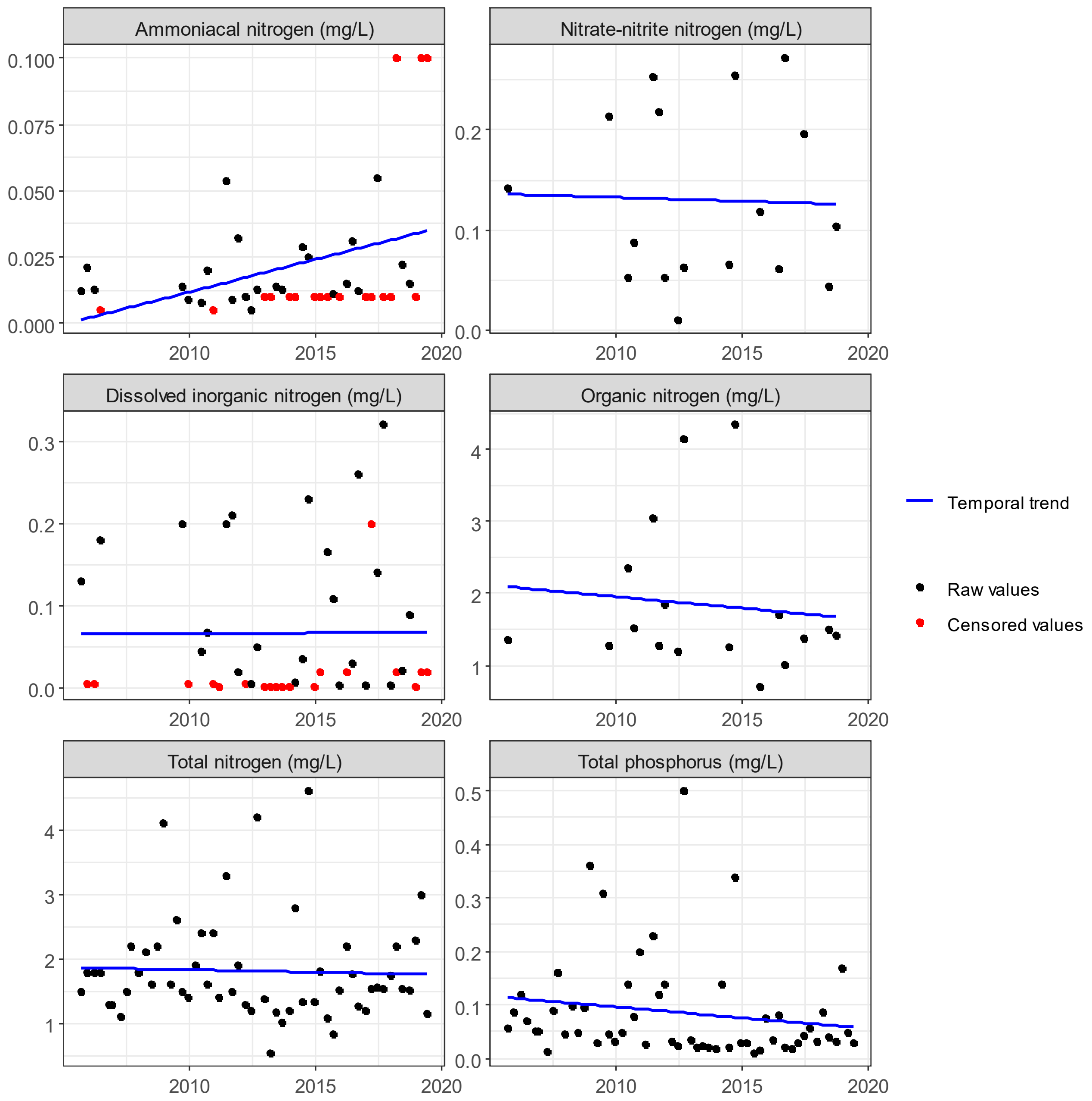


Figure 9. Lake Te Wapu

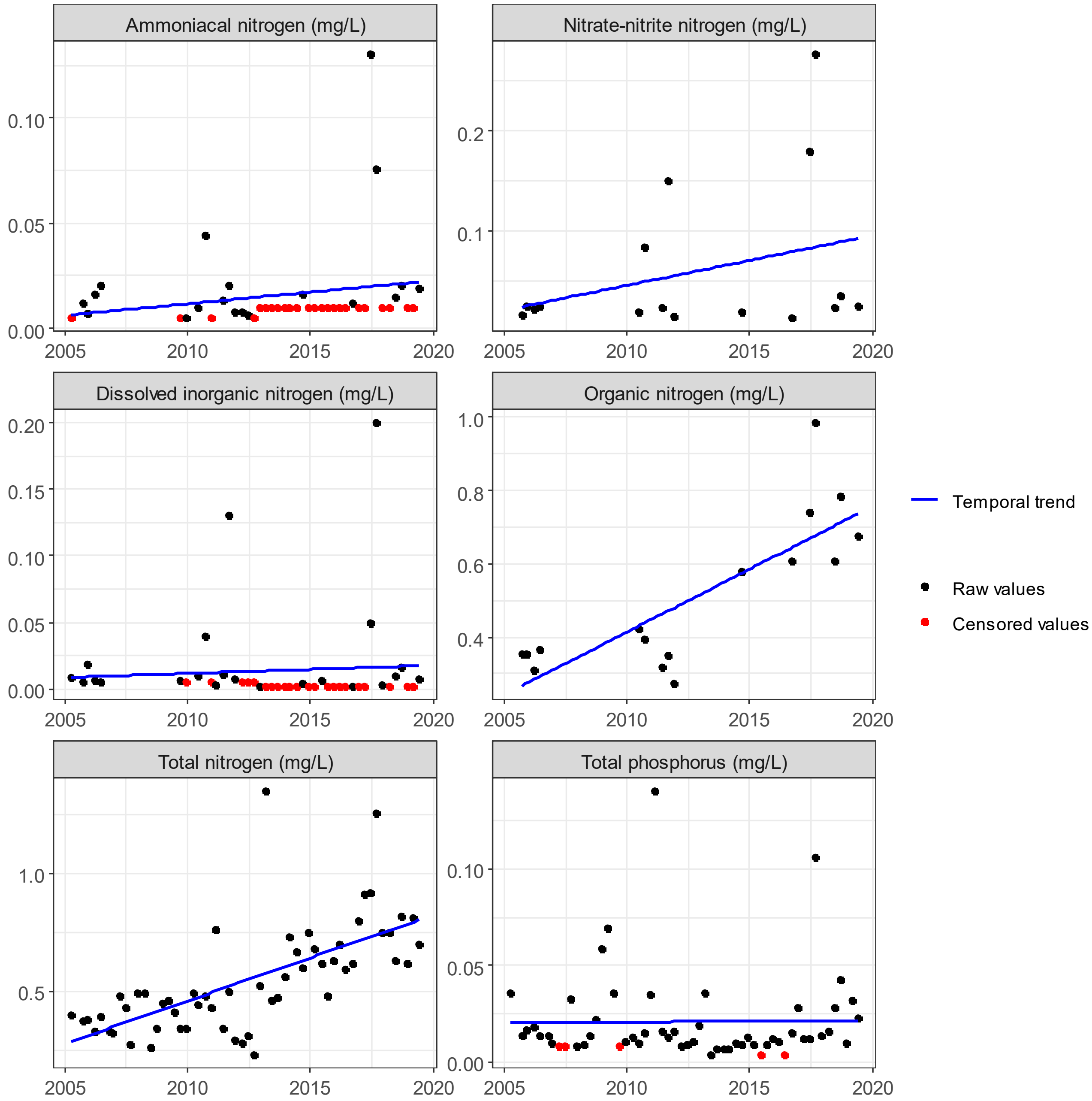


Figure 1. Tennants Lake

Streams

Physicochemical parameters

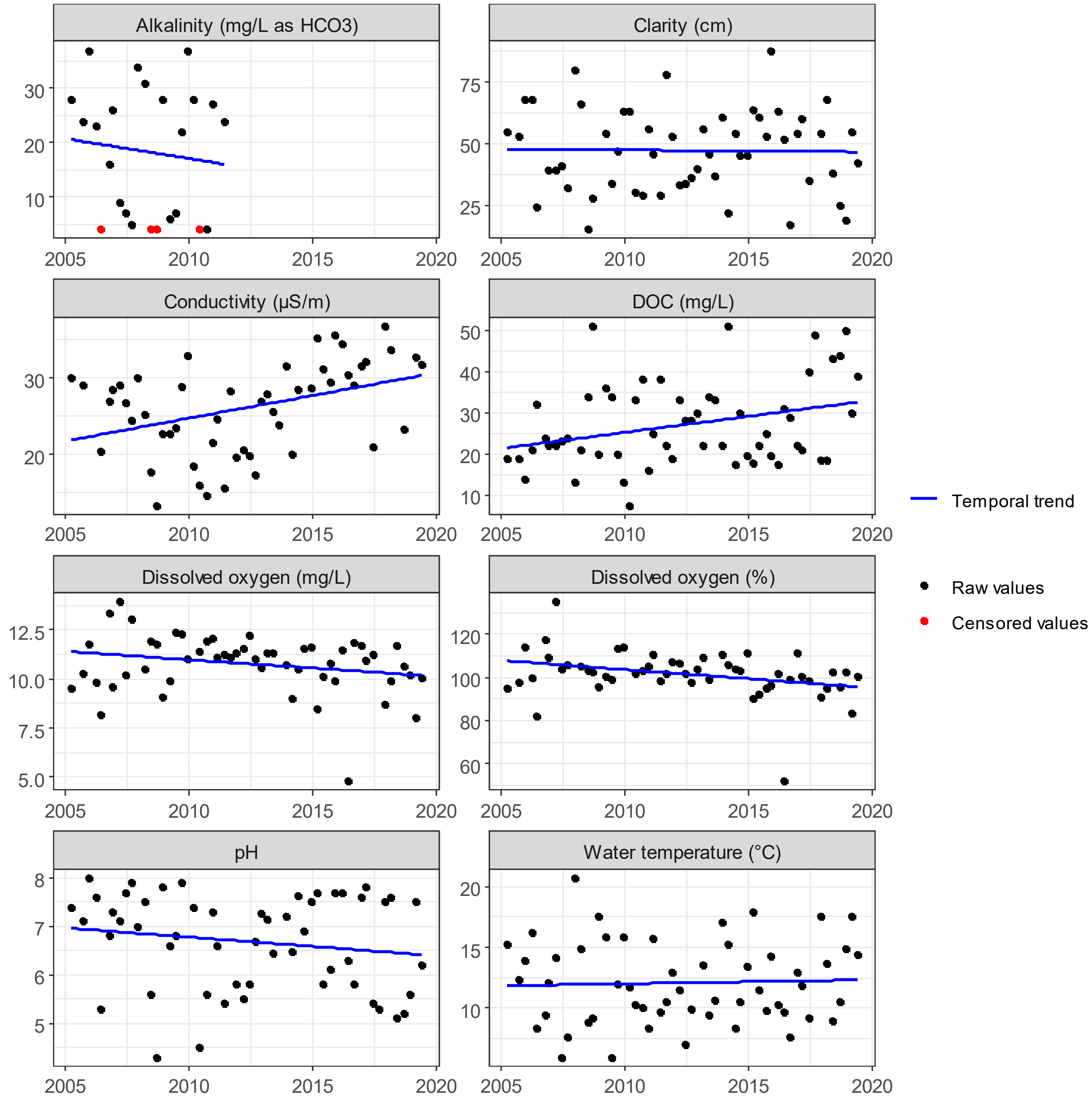


Figure 12. Awamata Stream

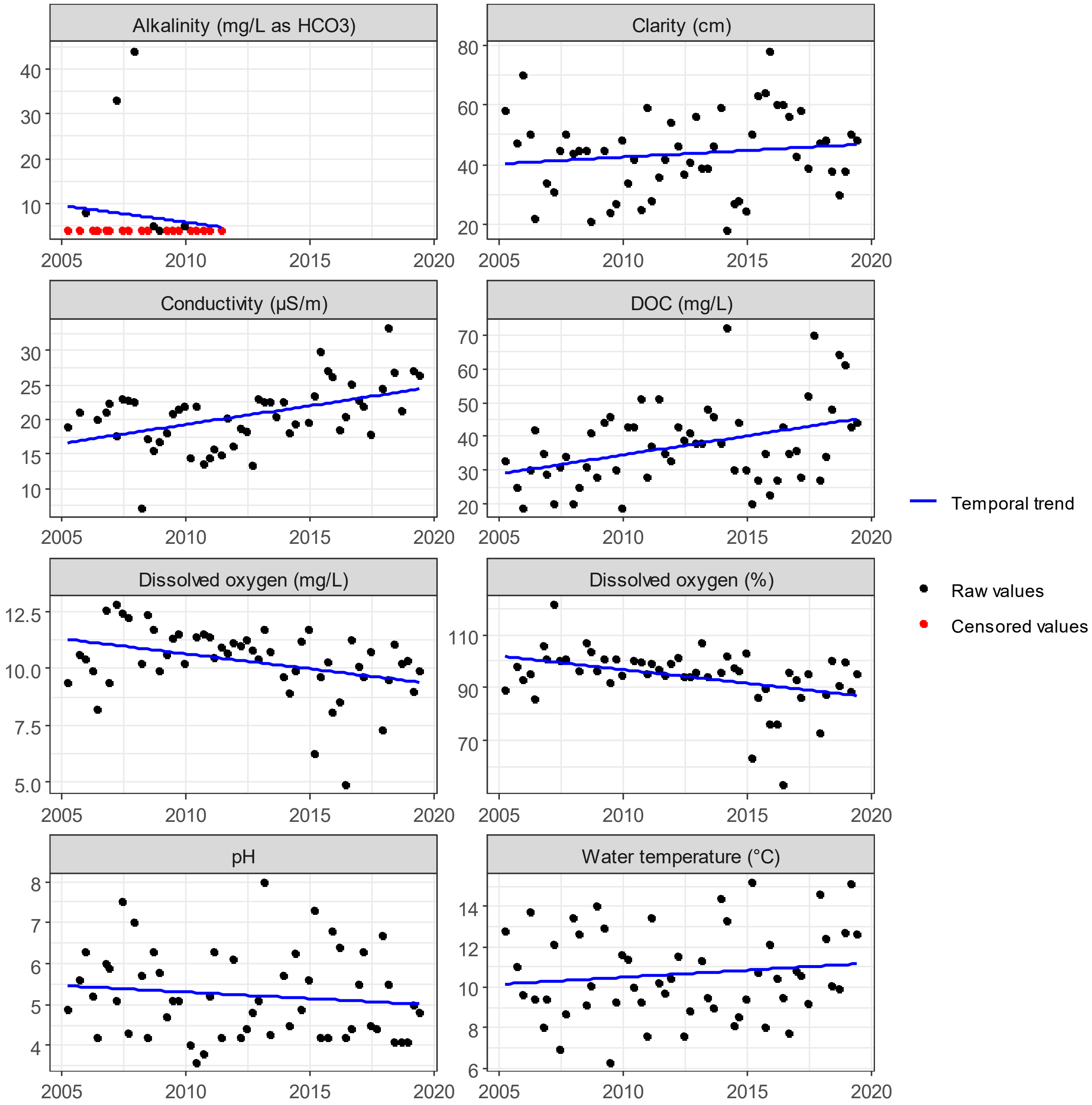


Figure 13. Awatotara Creek

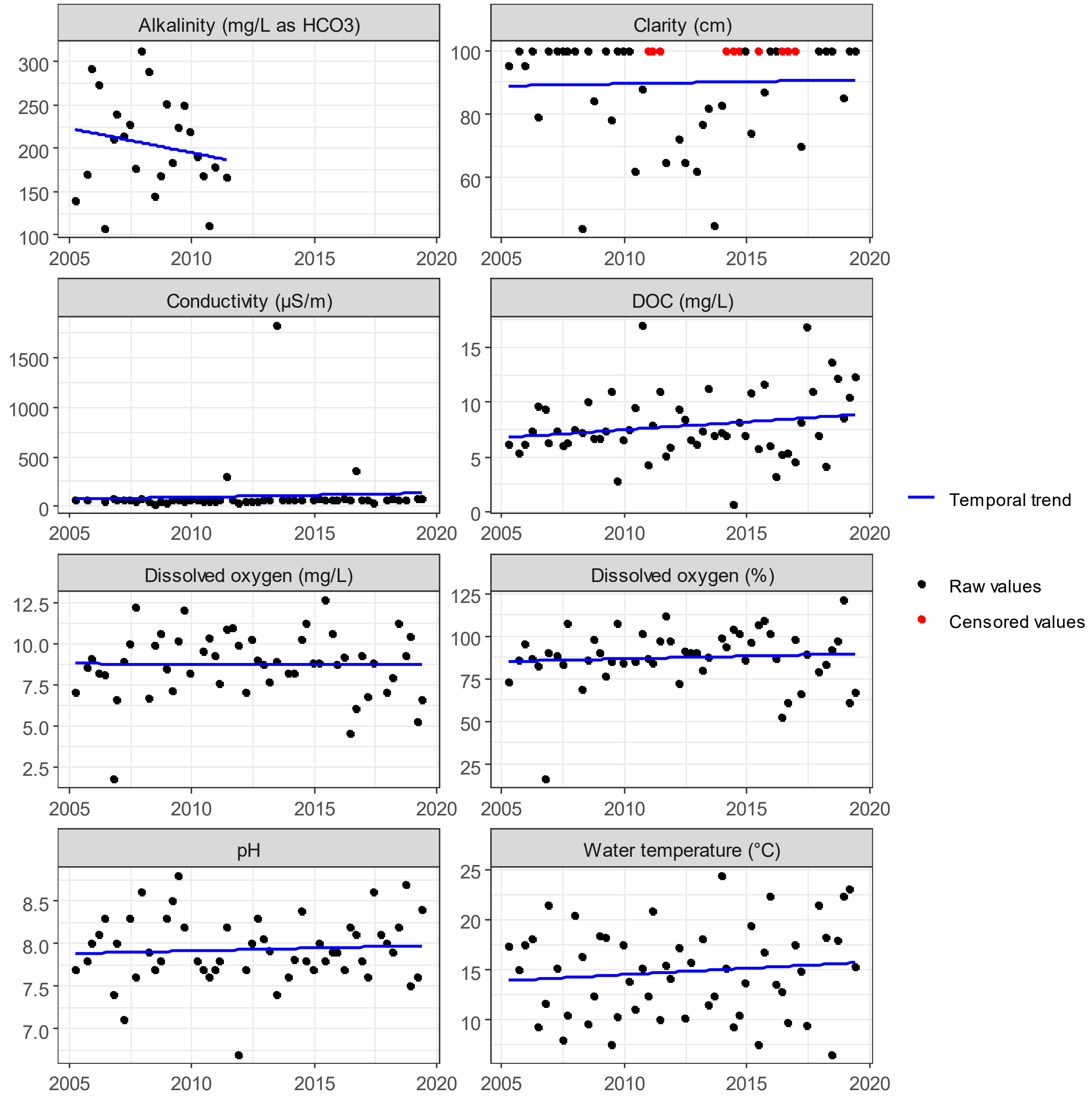


Figure 14. Blind Jim's Creek

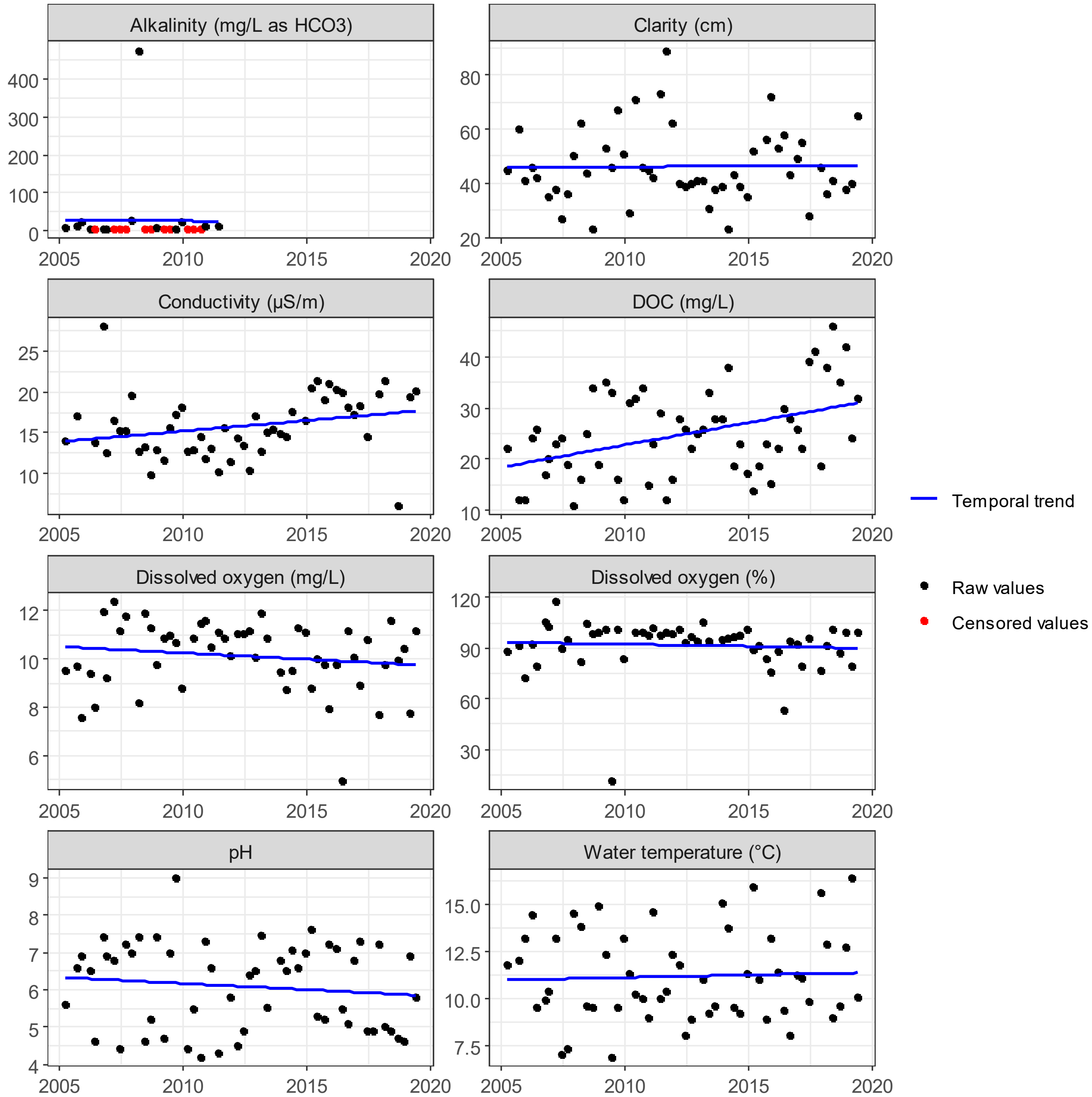


Figure 14. Mangahou Stream

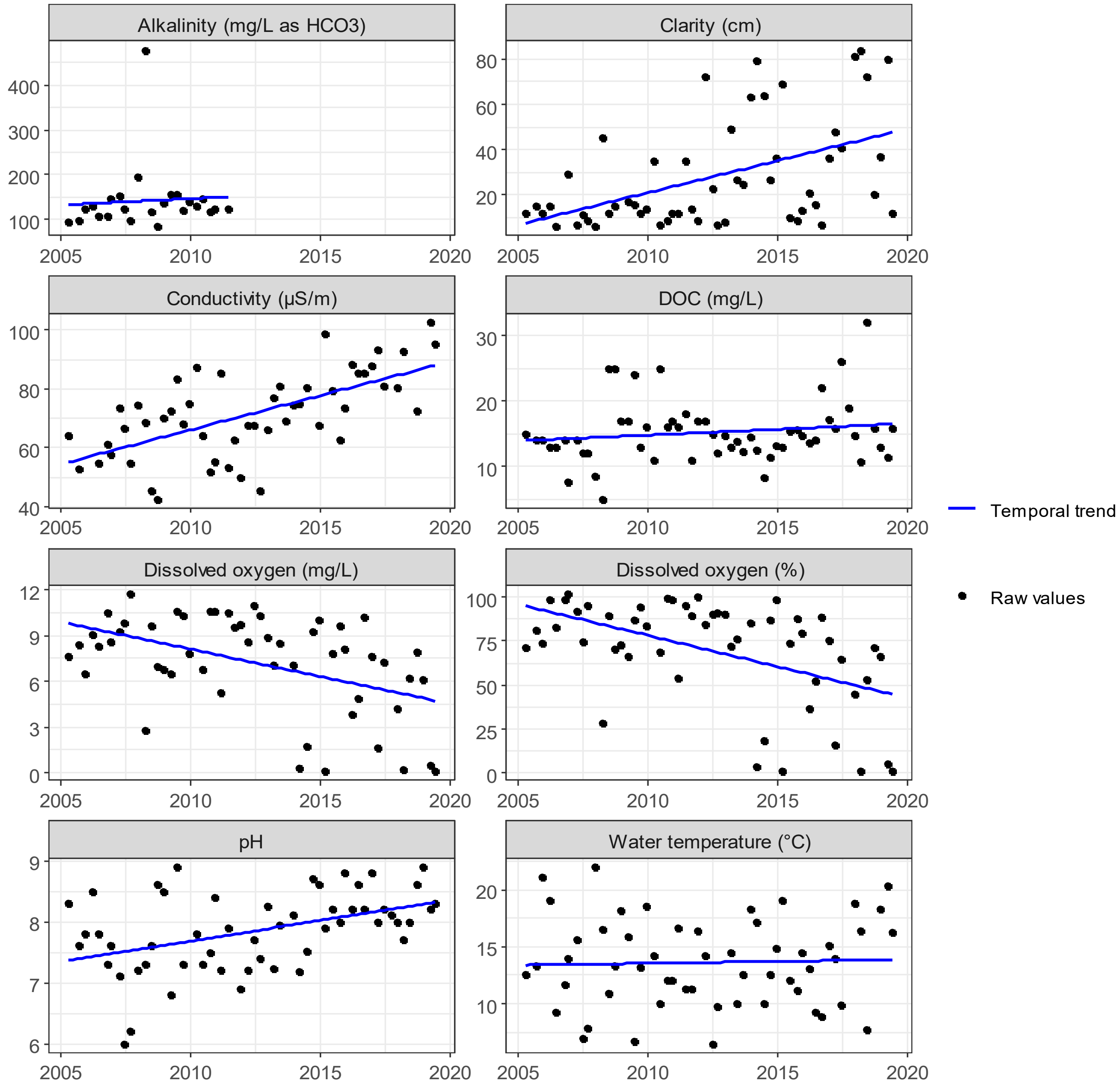


Figure 15. Mangape Creek

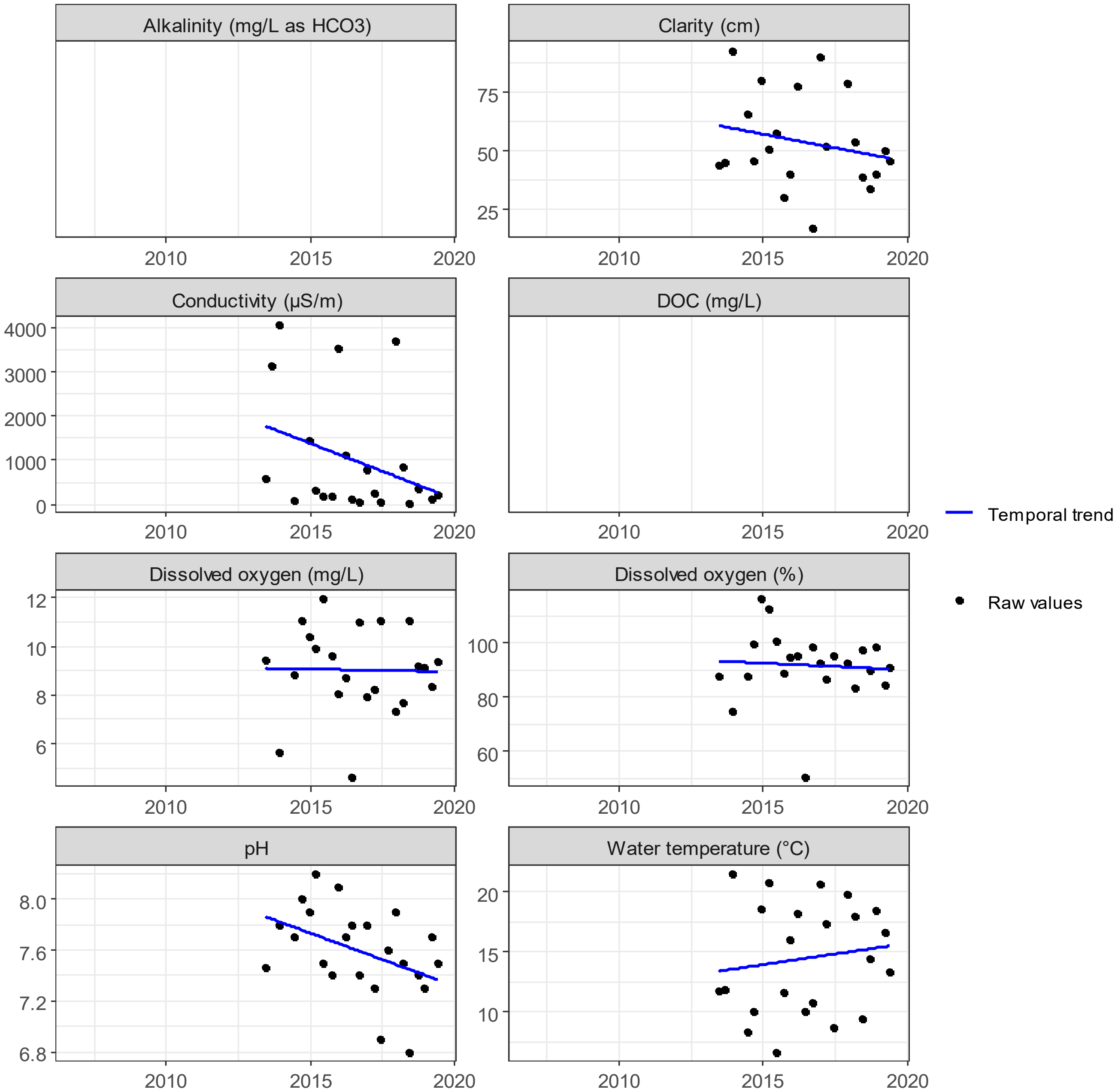


Figure 16. Nairn River

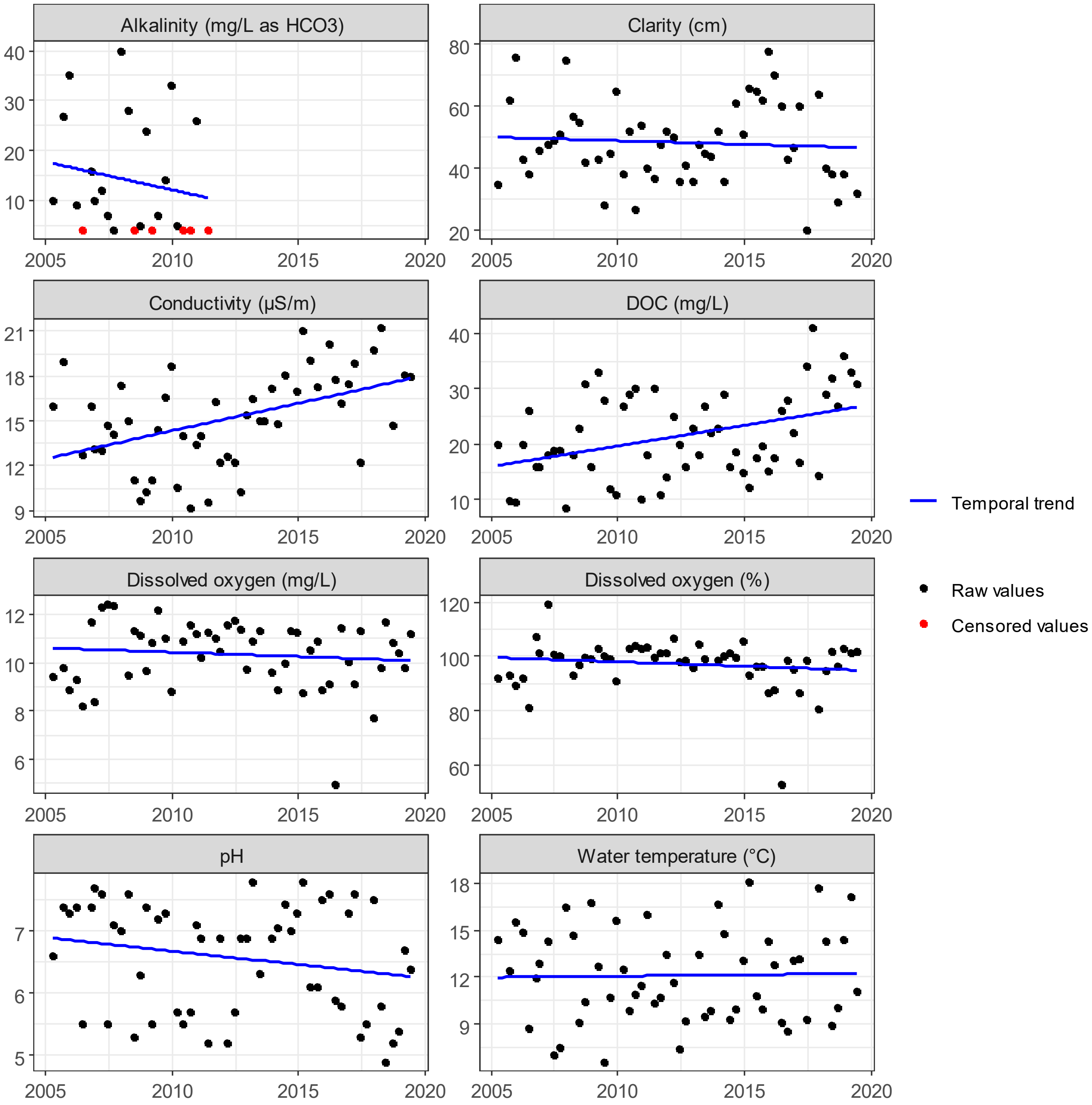


Figure 17. Te Awainanga River

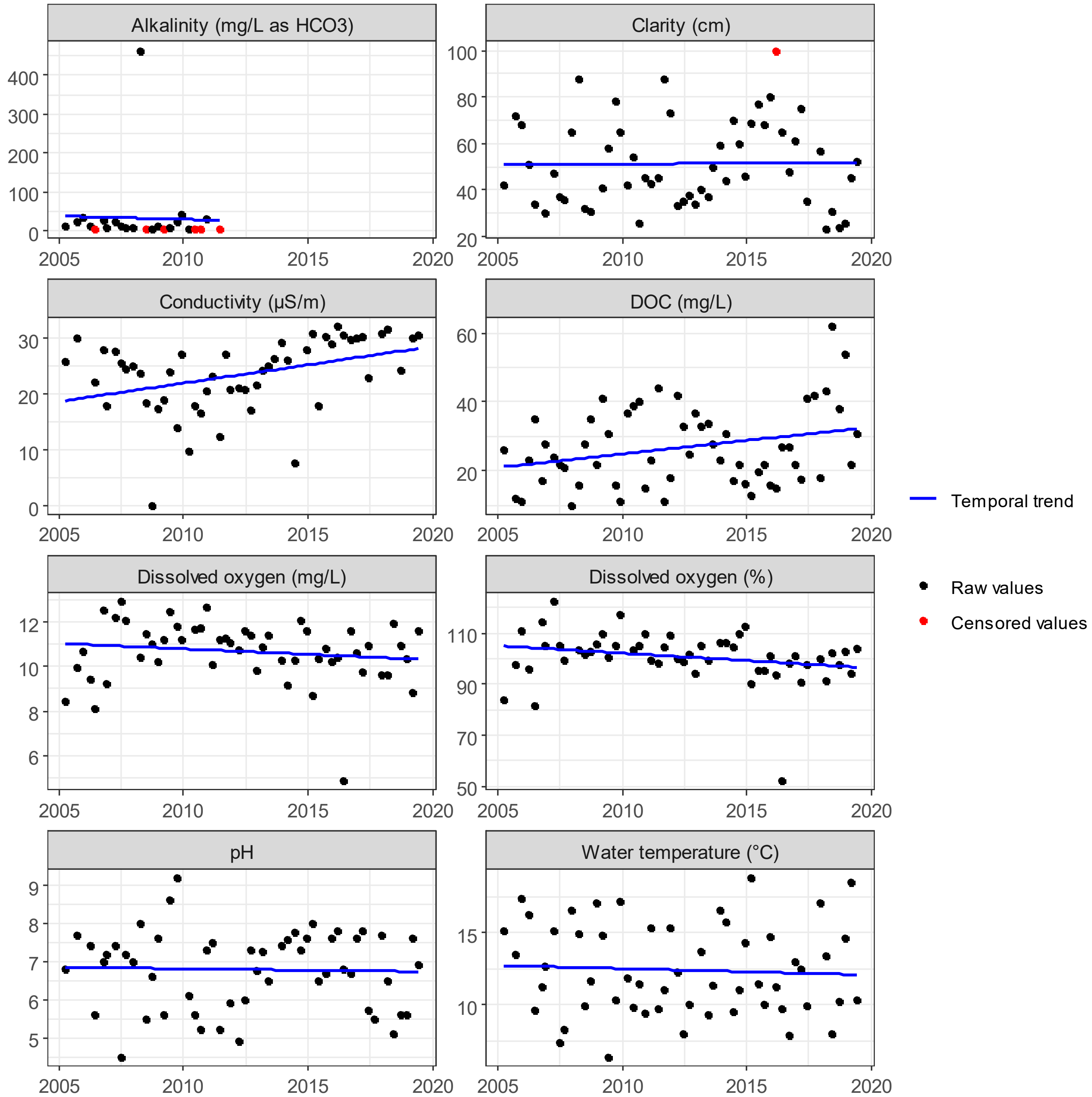


Figure 18. Te One Creek

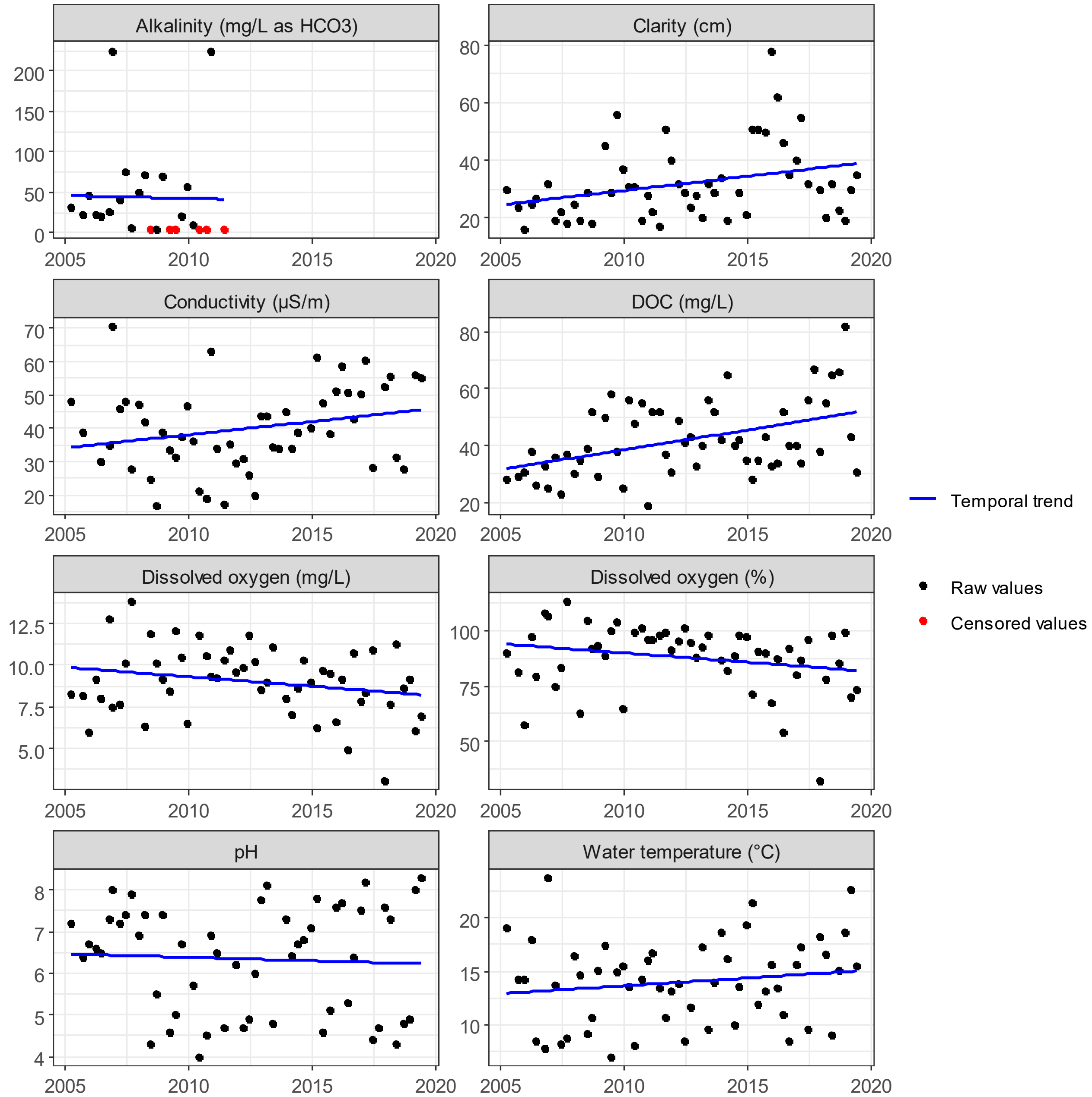


Figure 19. Rakautahi Stream

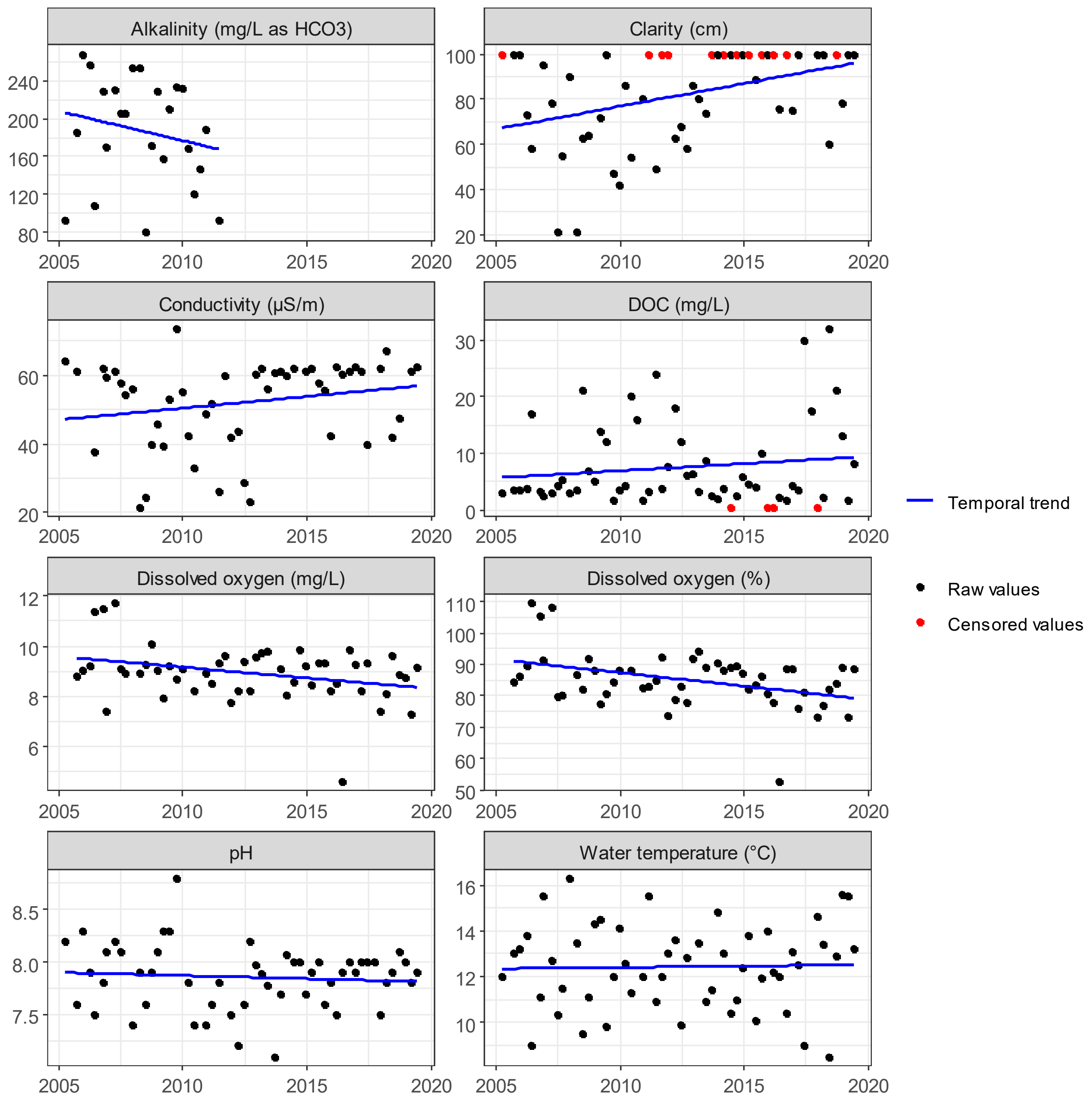


Figure 20. Waimahana Creek

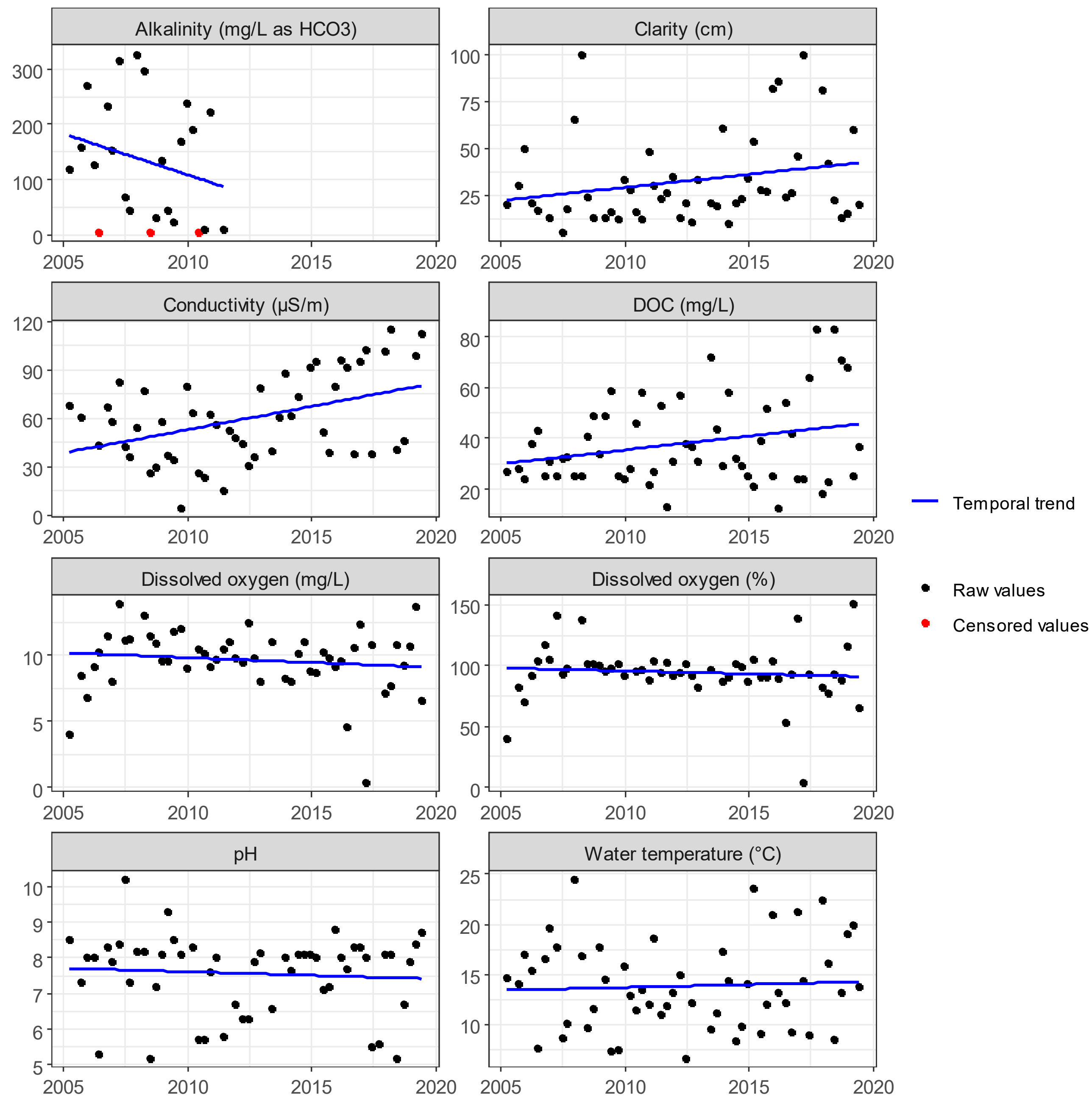


Figure 21. Waitaha Creek

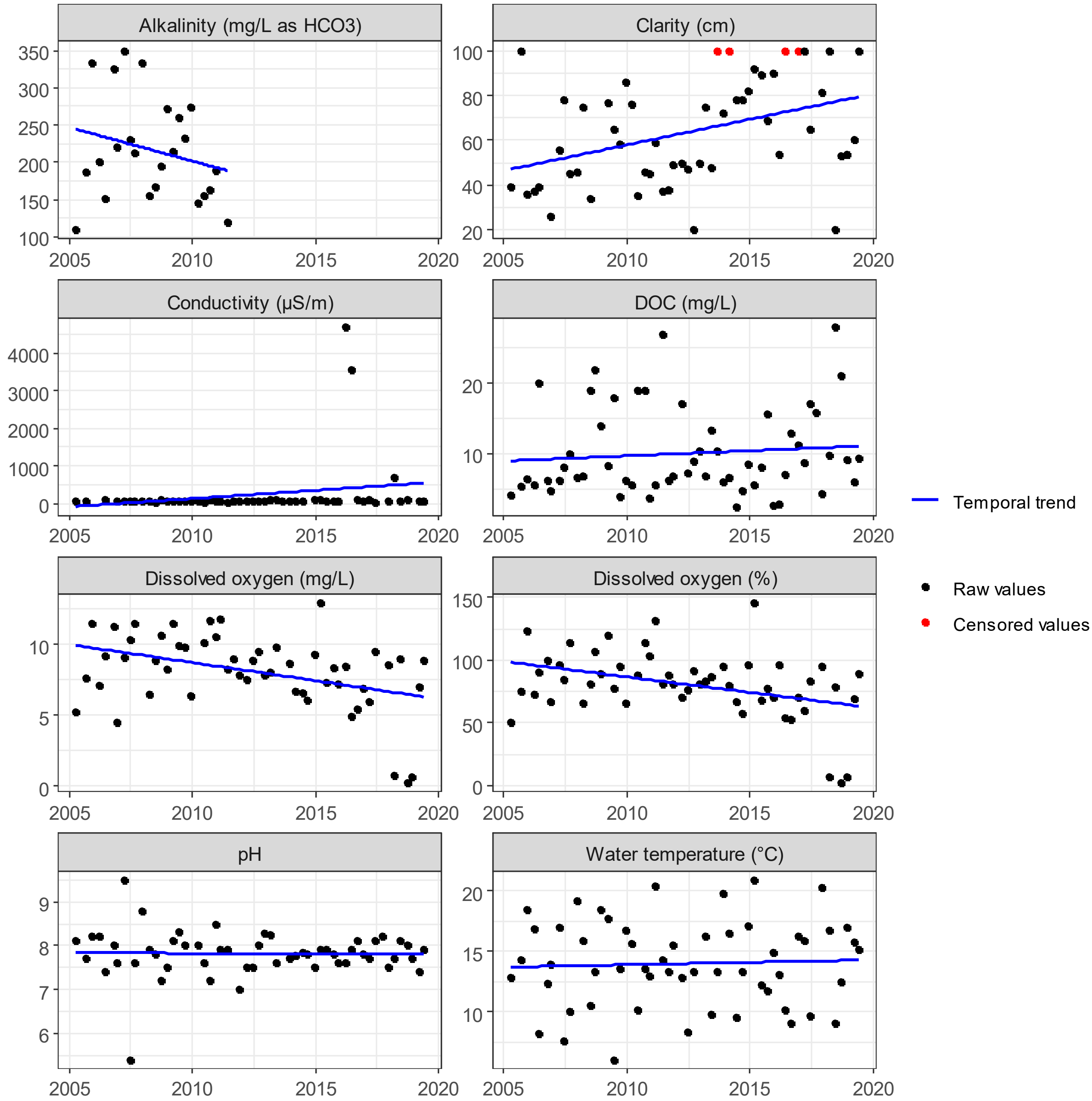


Figure 22. Waitamaki Creek

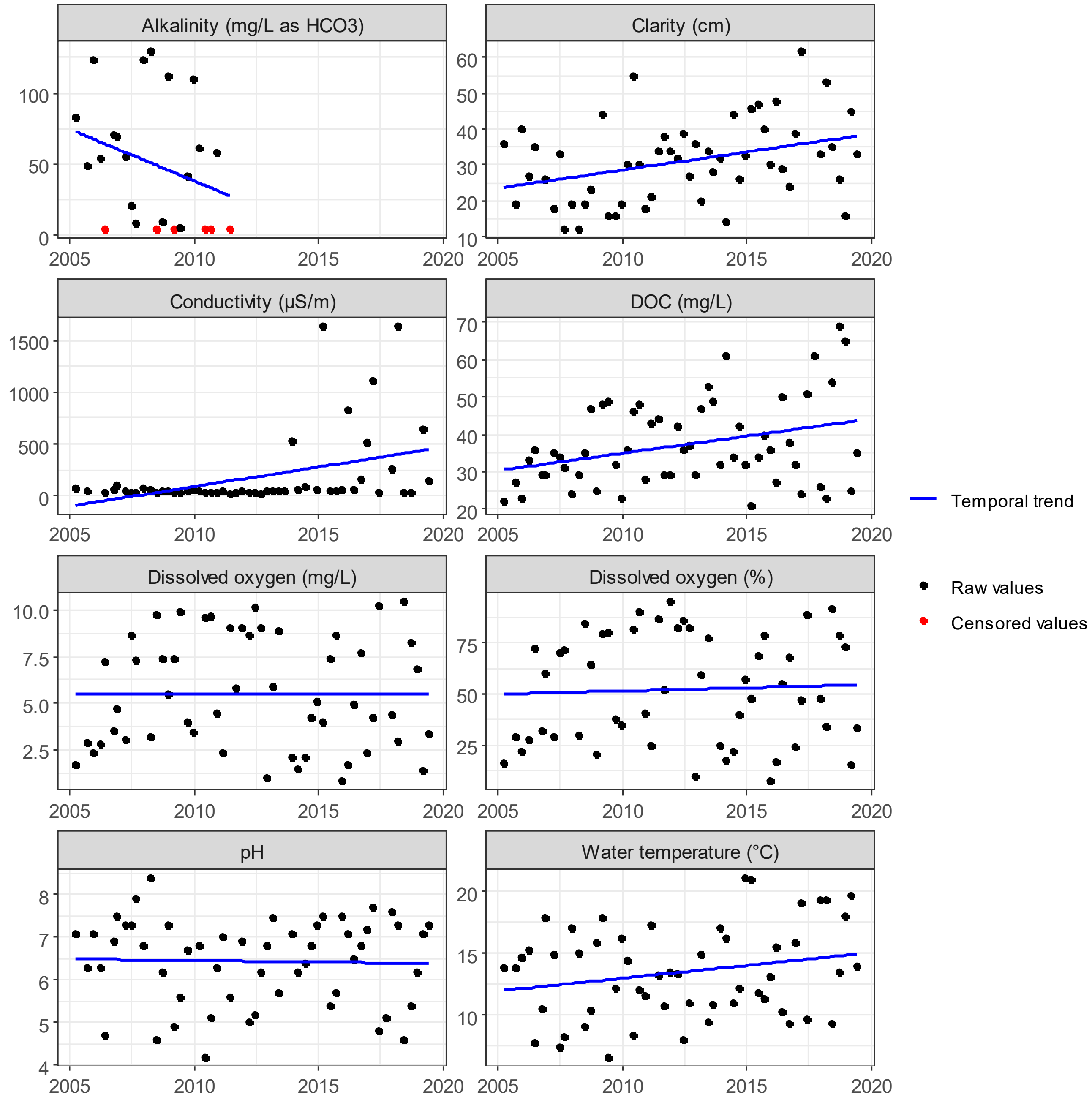


Figure 23. Washout Creek

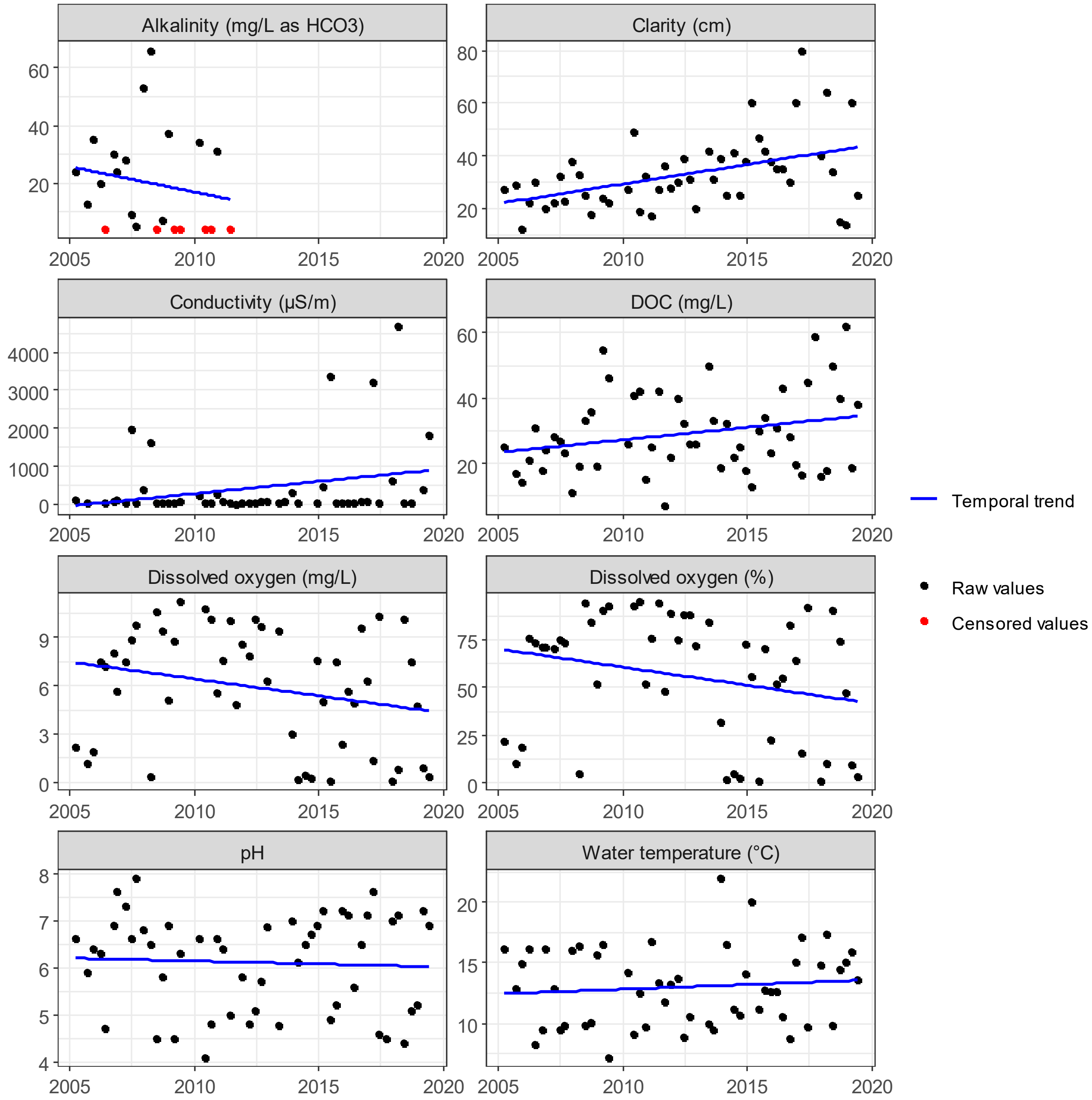


Figure 24. Whangamoe Creek

Nutrient parameters

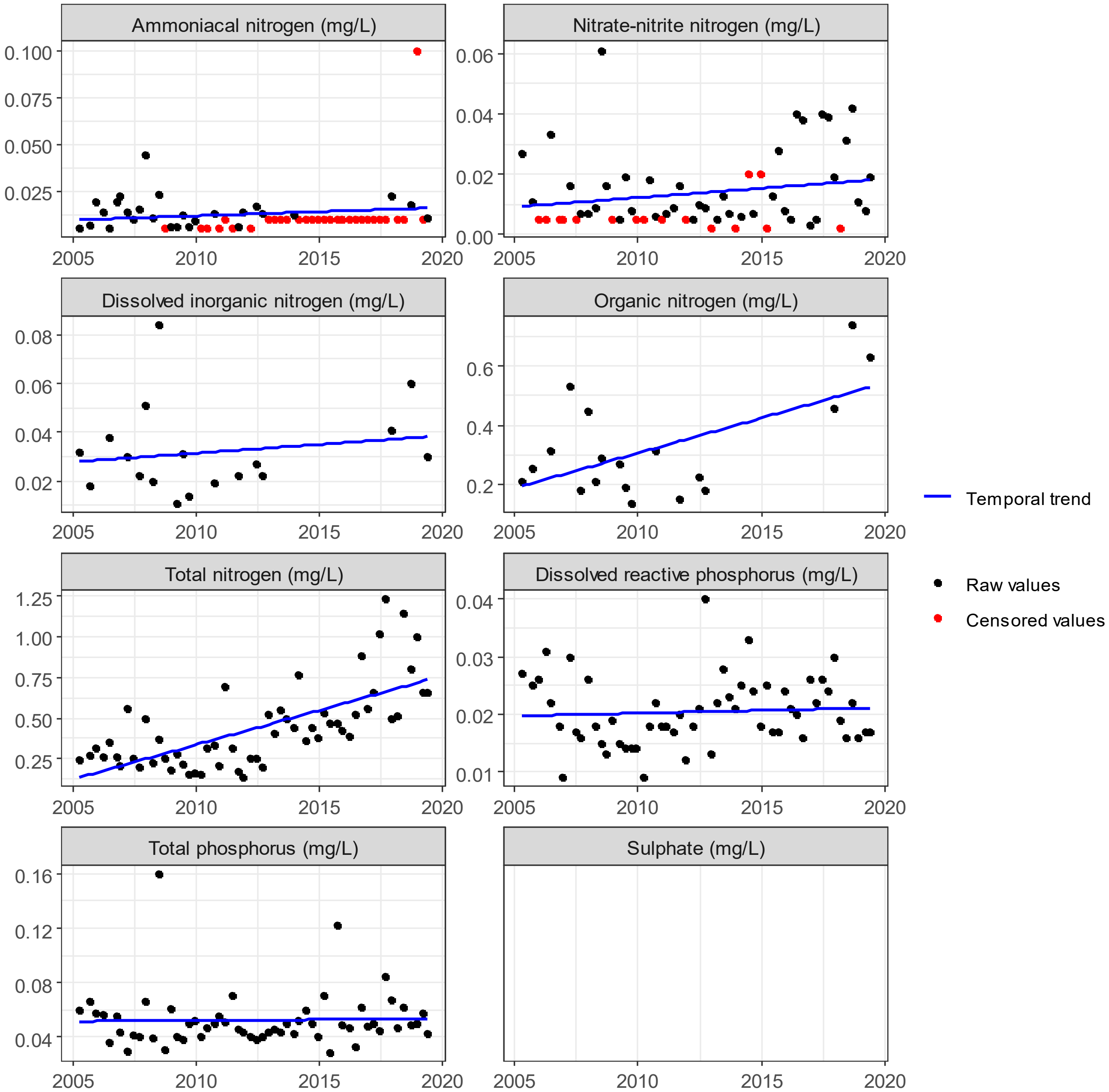


Figure 25. Awamata Stream

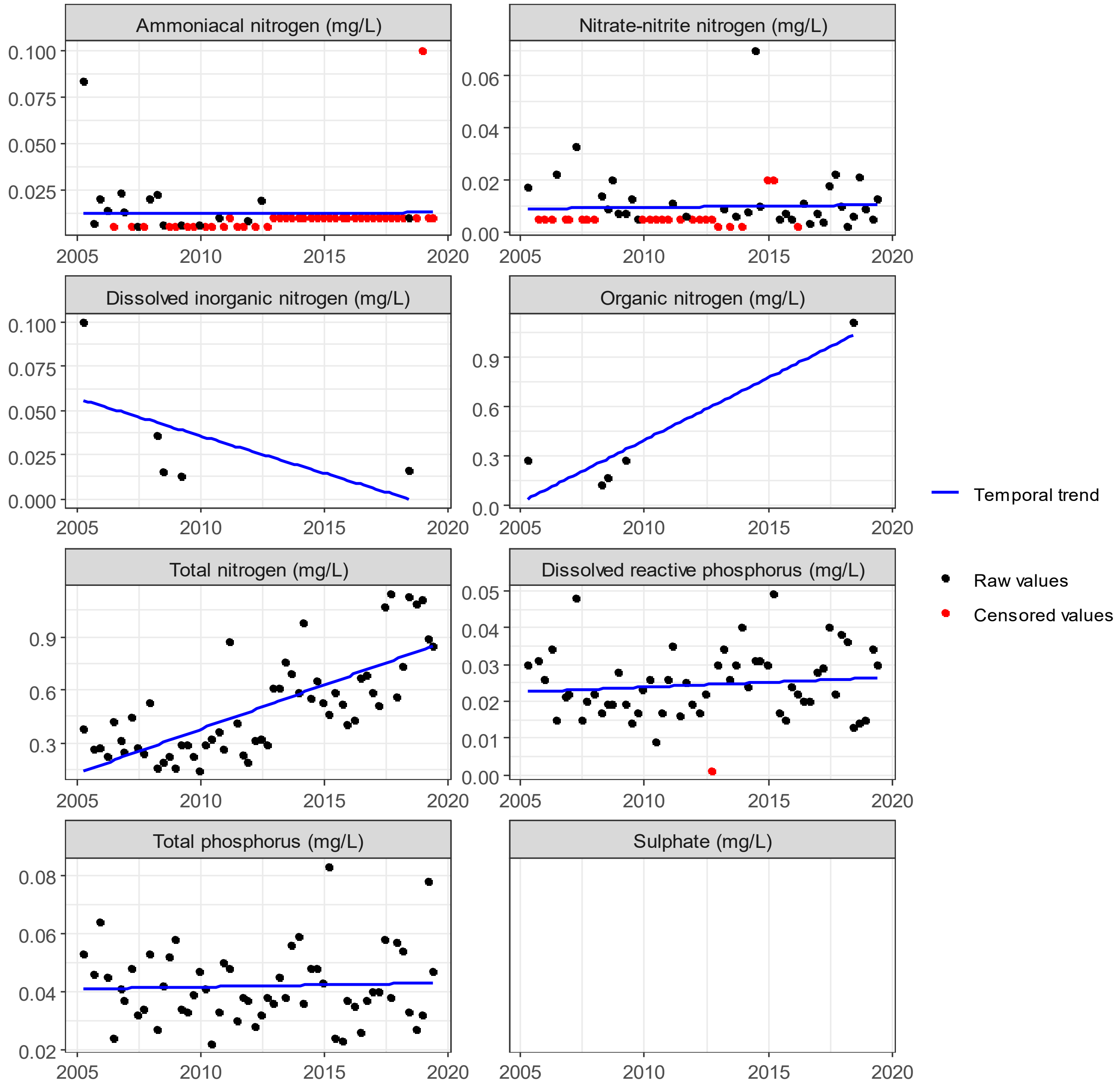


Figure 26. Awatotara Creek

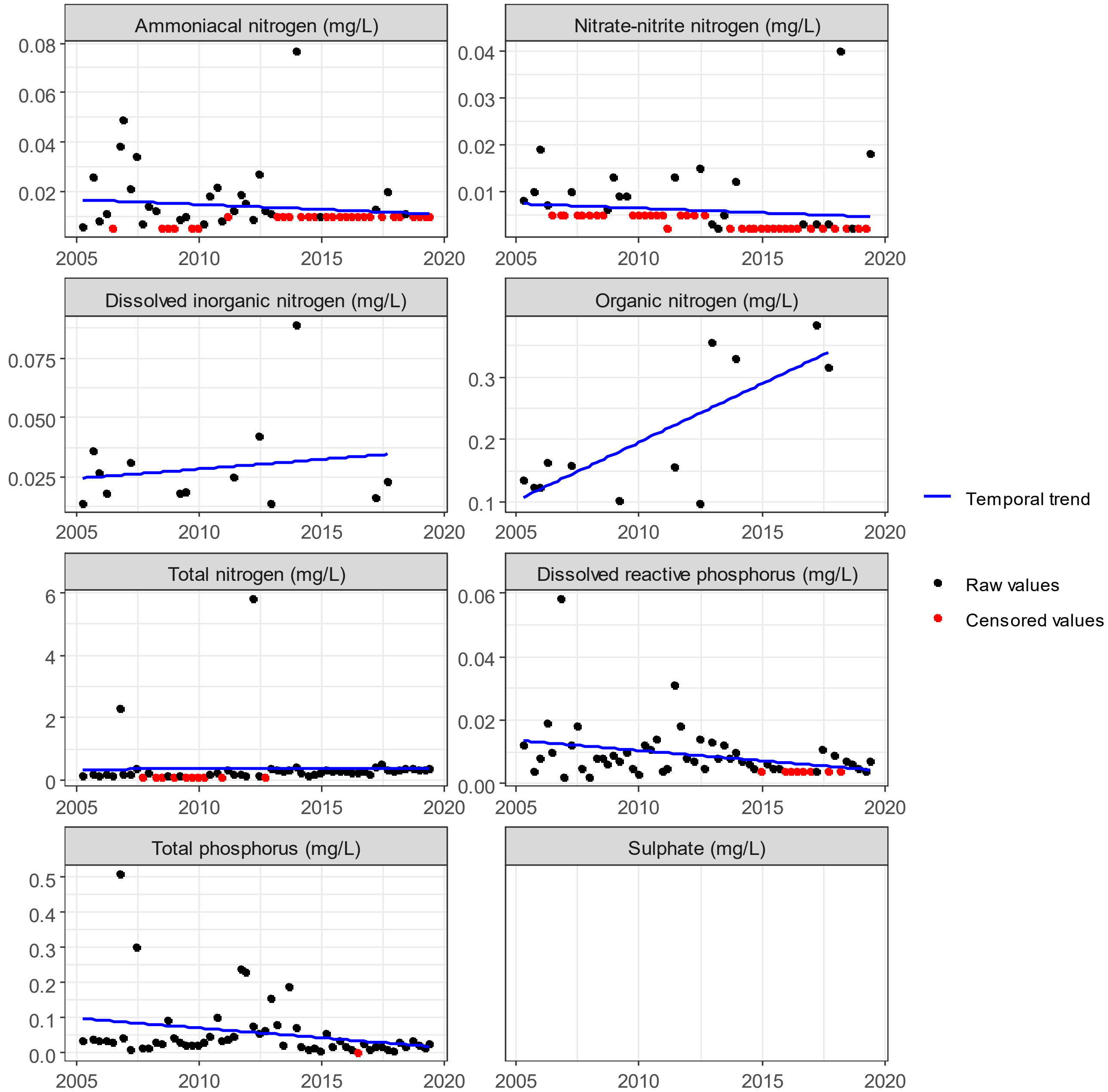


Figure 27. Blind Jim's Creek

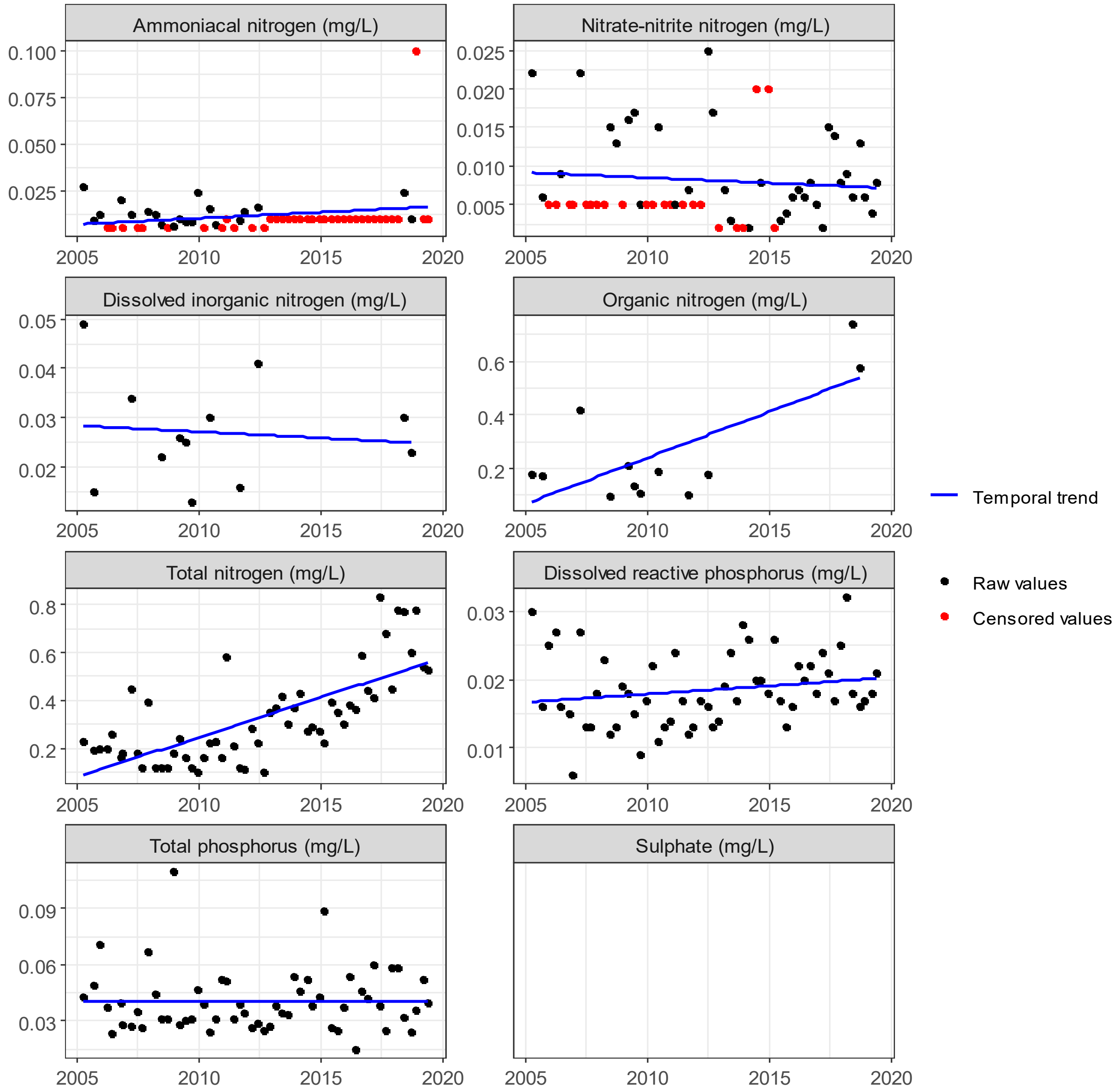


Figure 28. Mangahou Stream

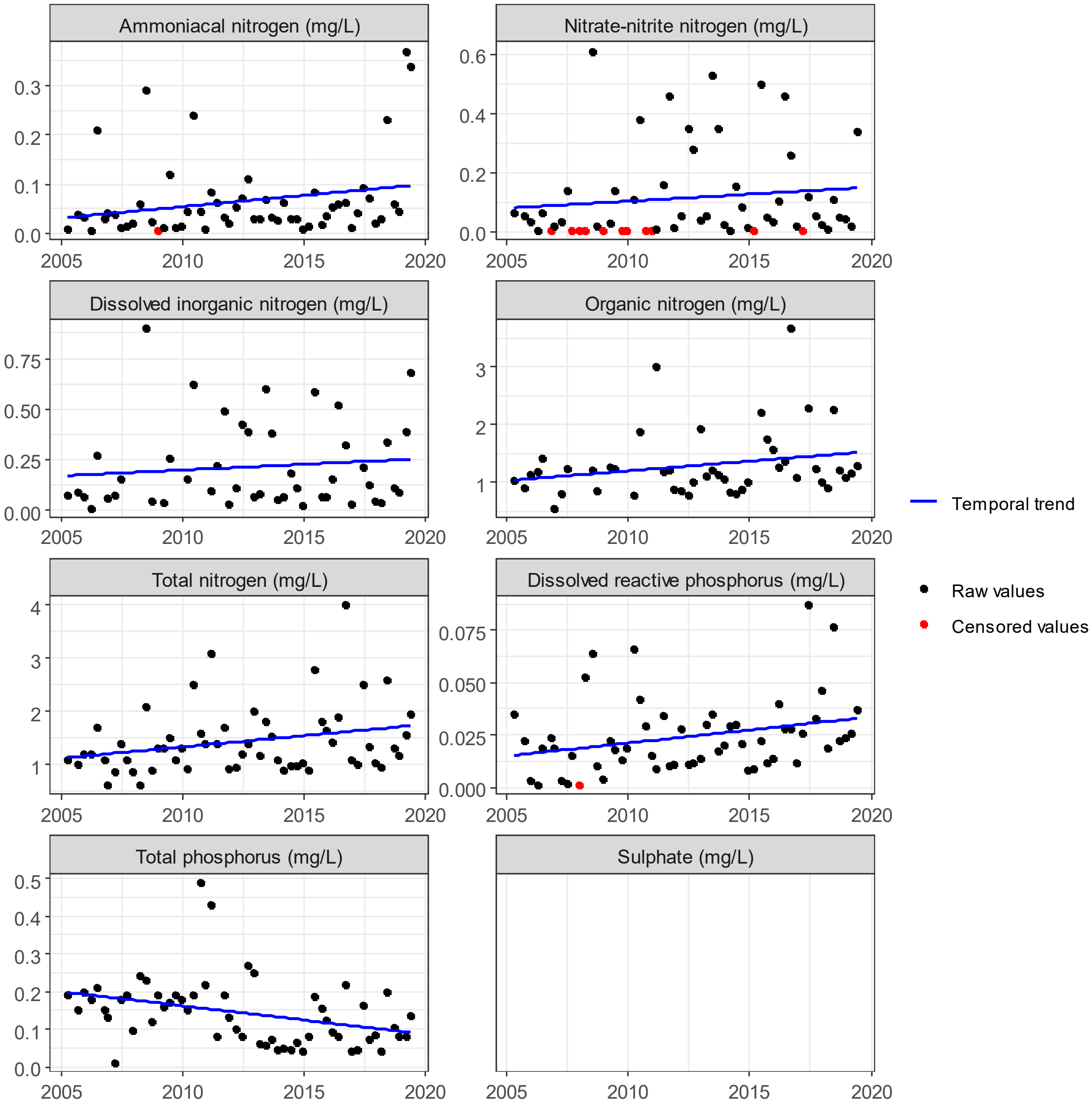


Figure 29. Mangape Creek

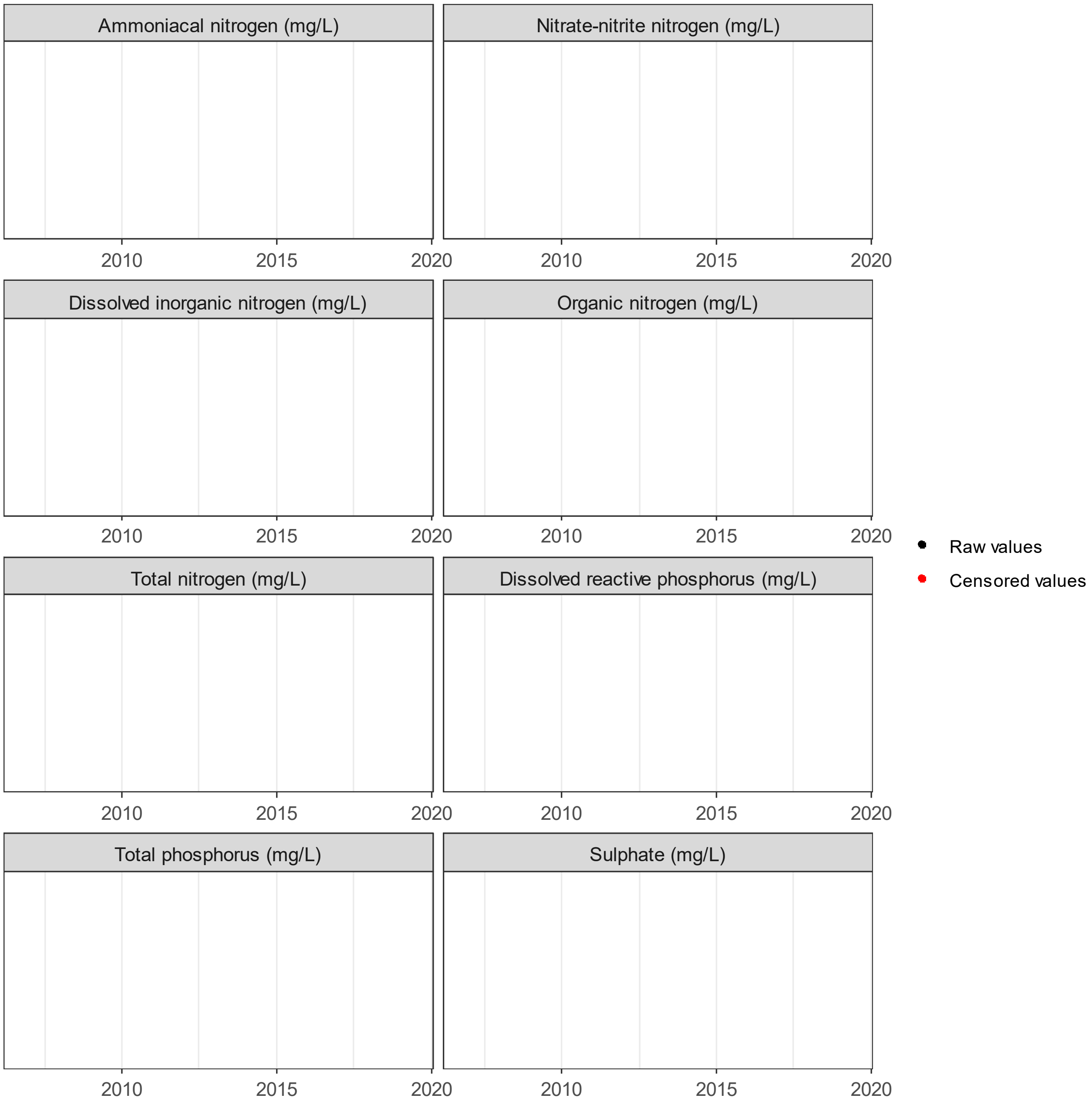


Figure 30. Nairn River

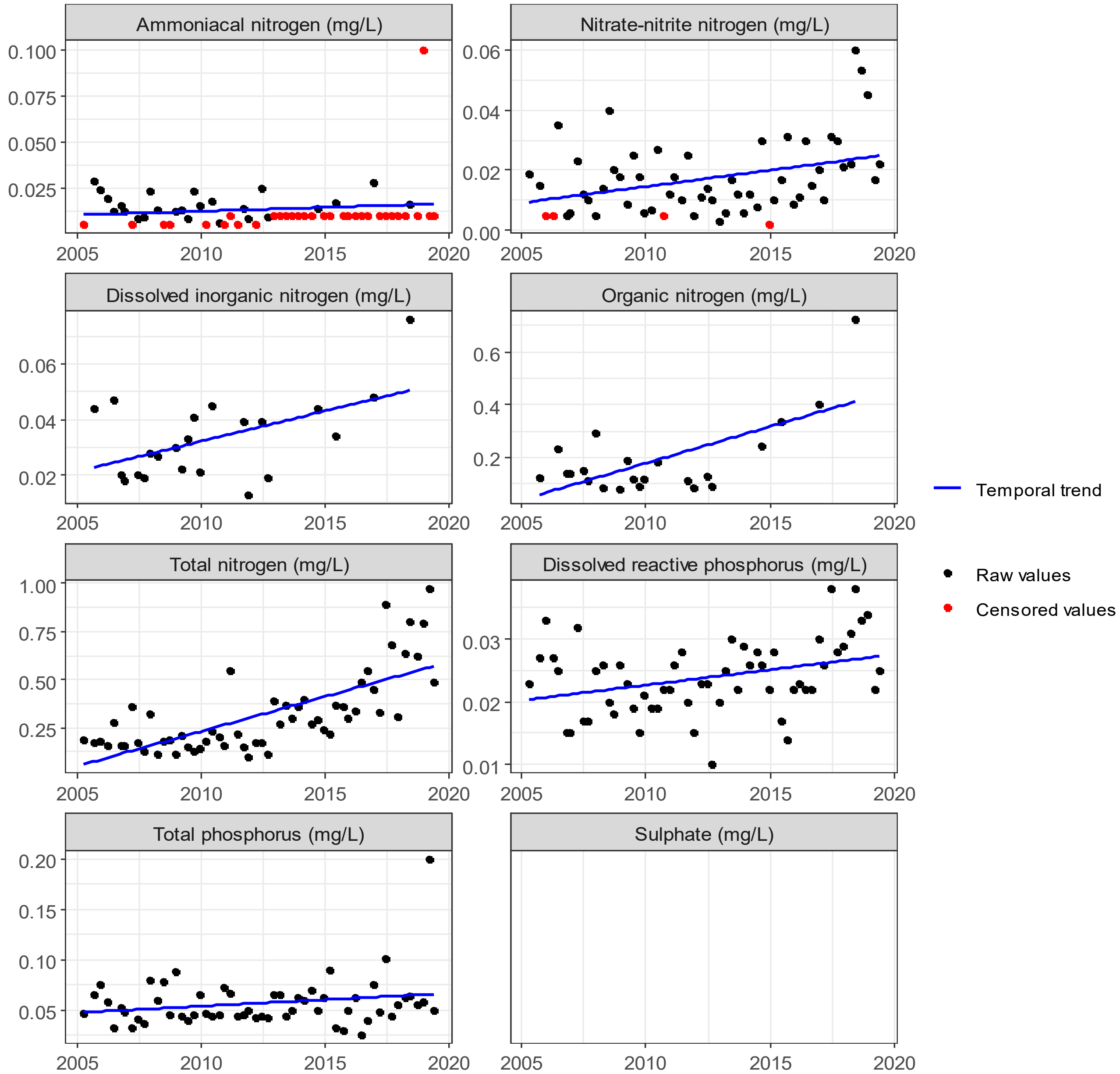


Figure 31. Te Awainanga River

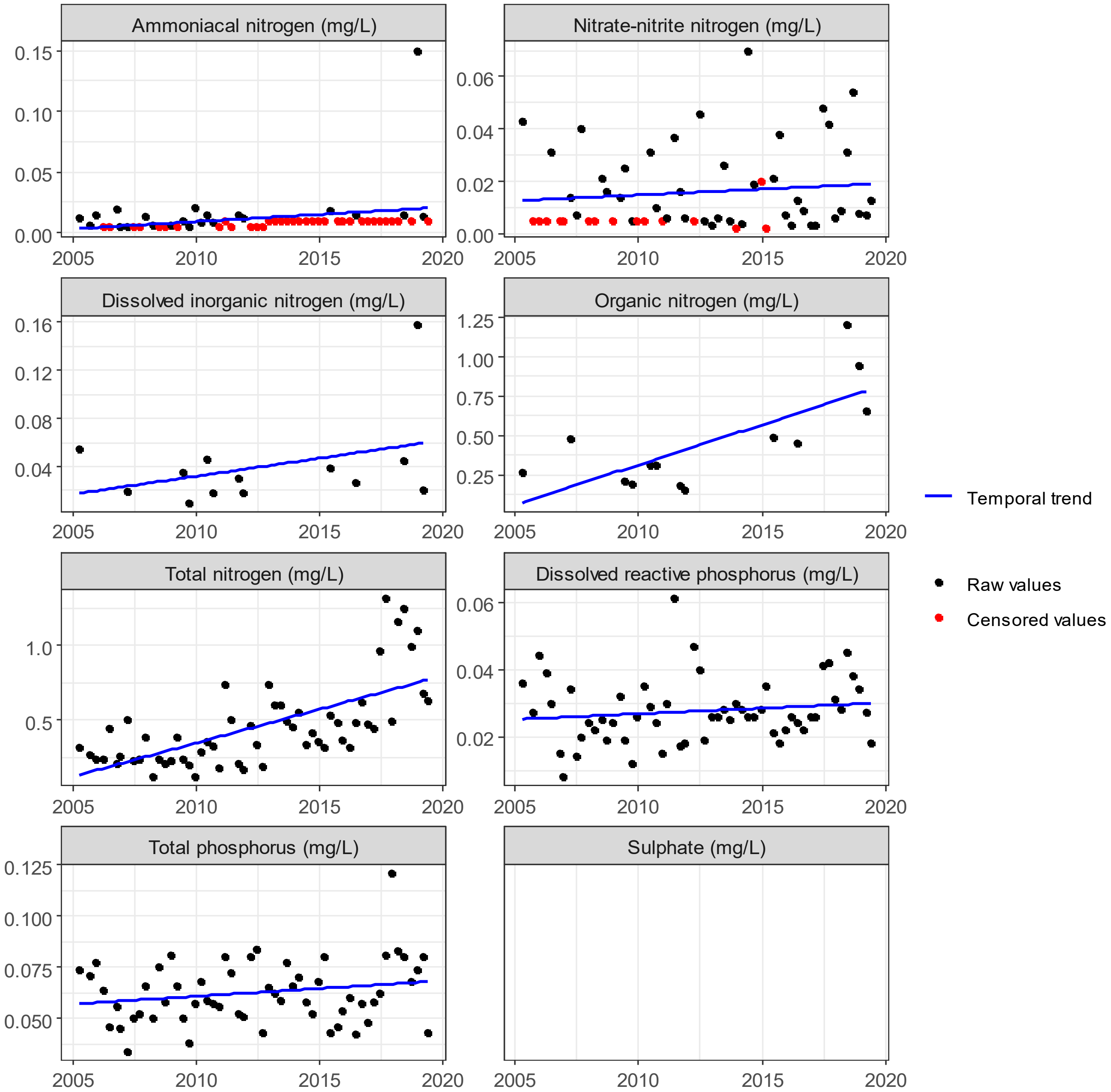


Figure 32. Te One Creek

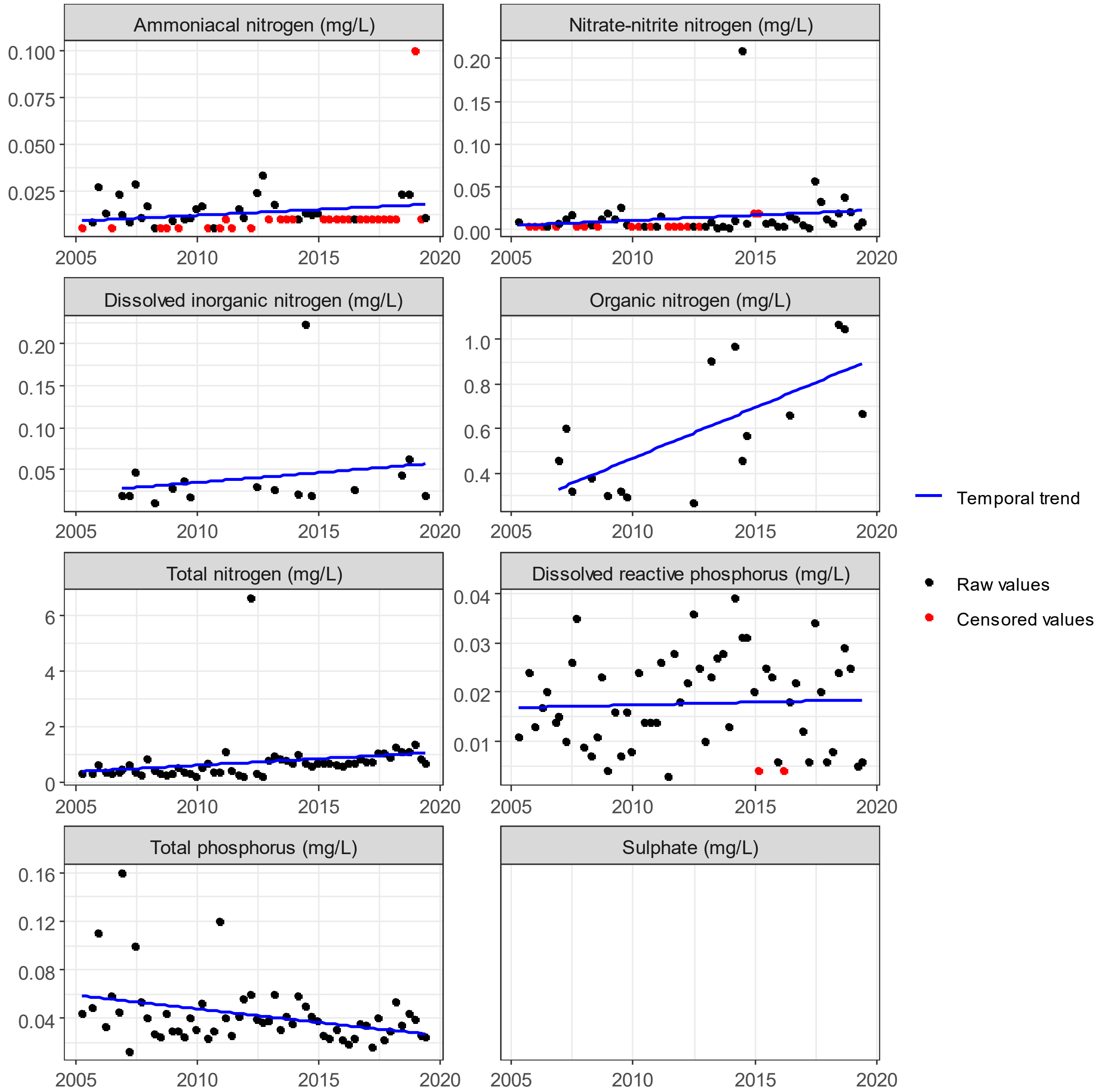


Figure 33. Rakautahi Stream

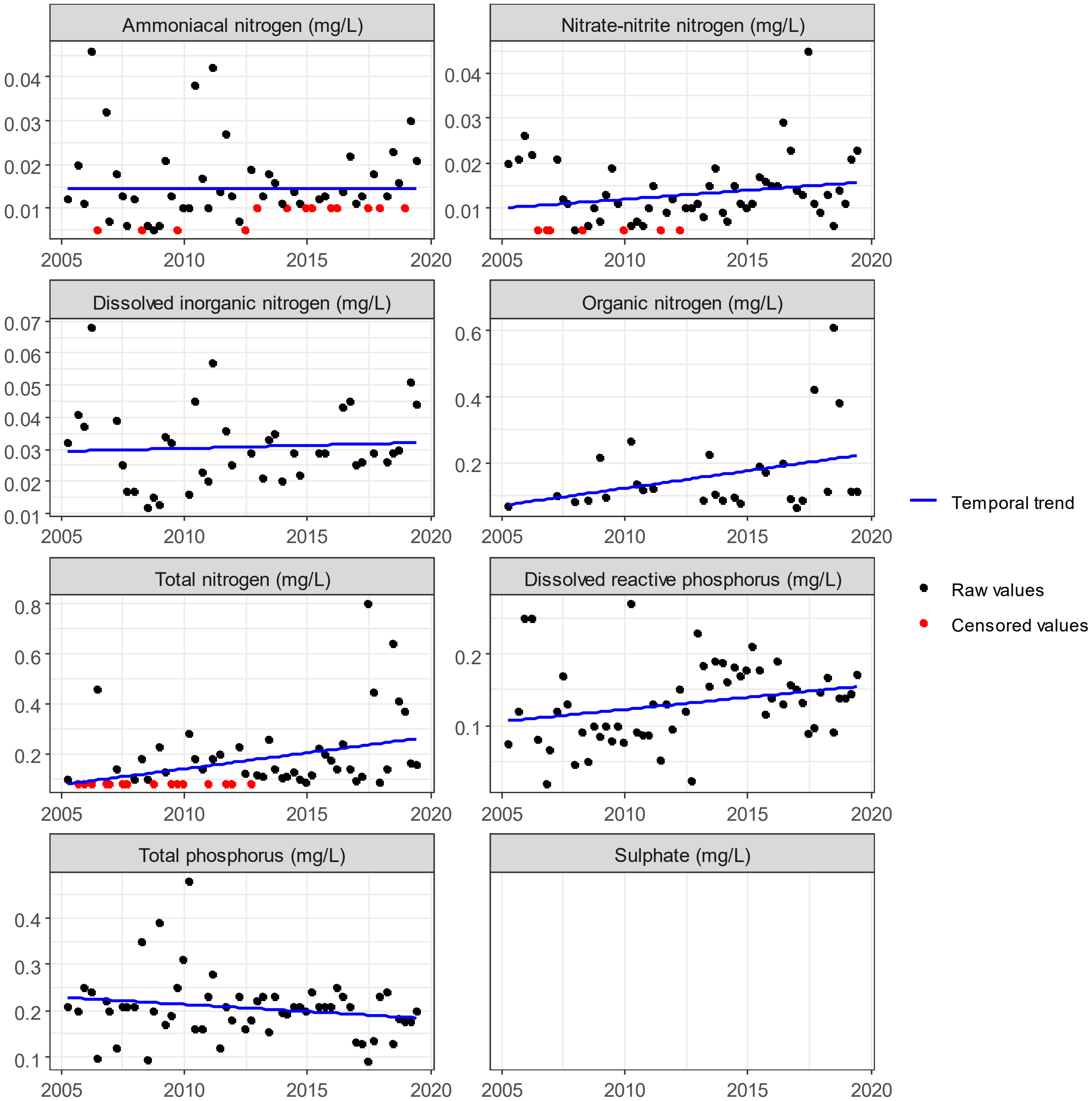


Figure 34. Waimahana Creek

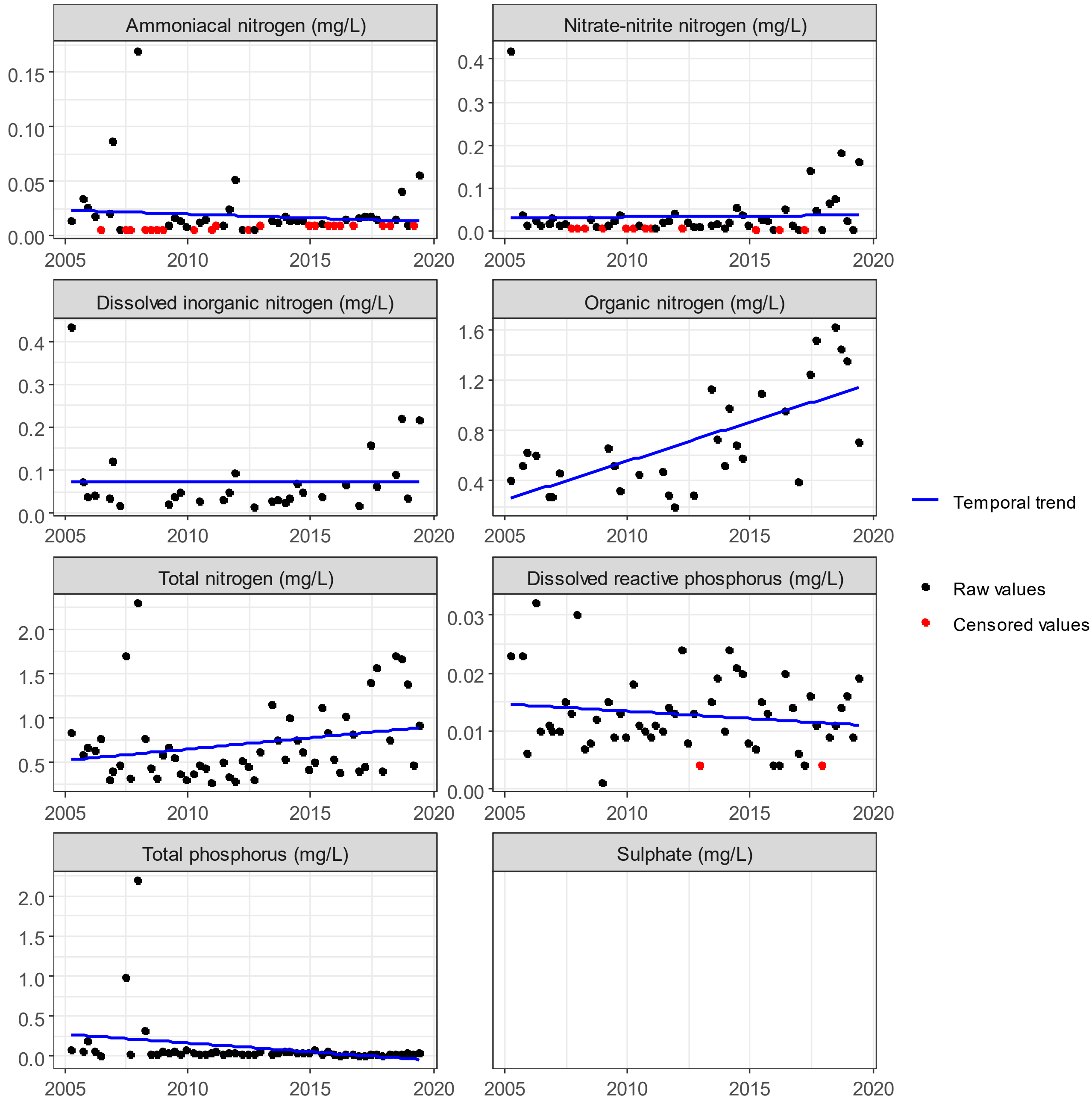


Figure 35. Waitaha Creek

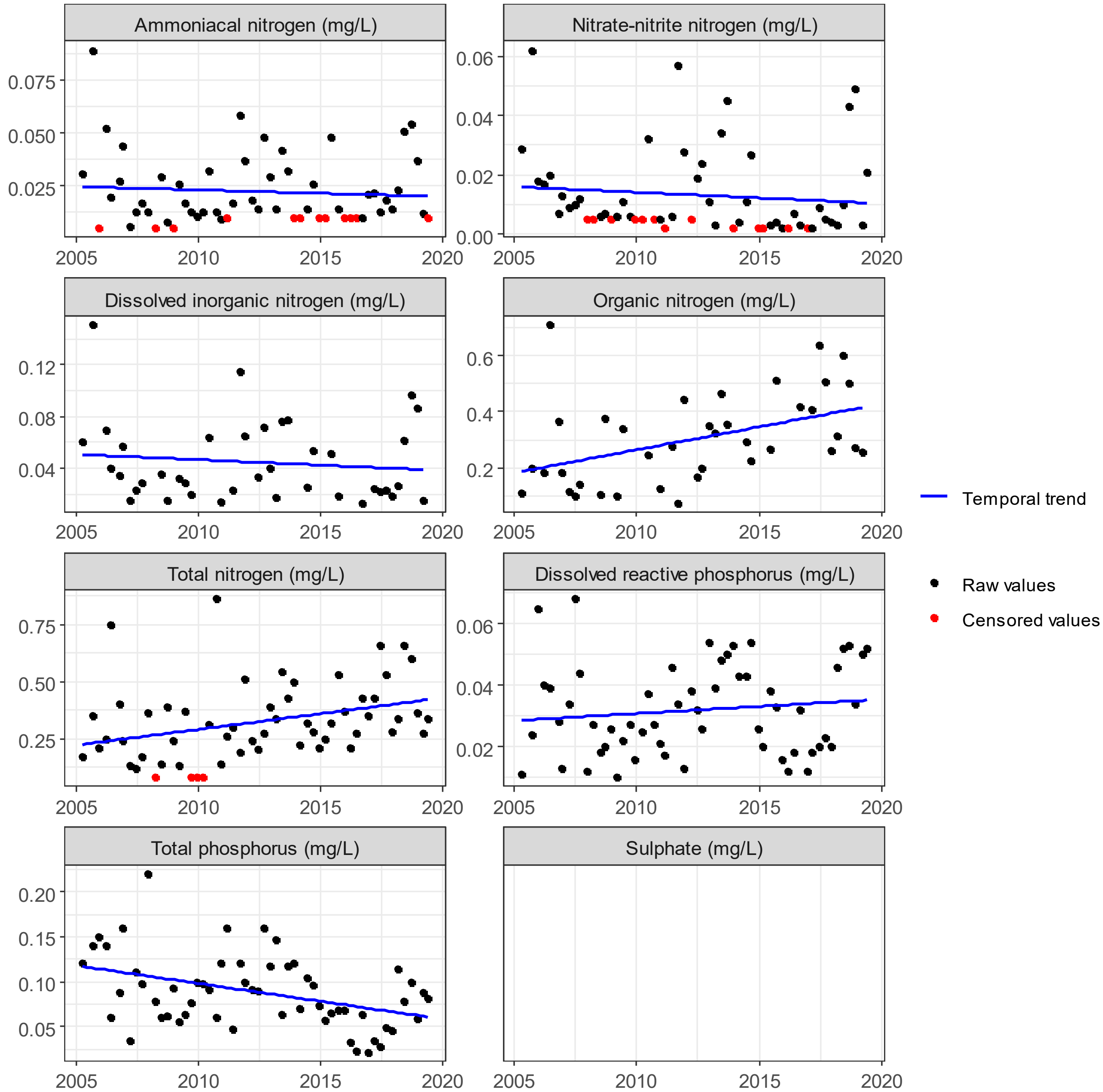


Figure 36. Waitamaki Creek

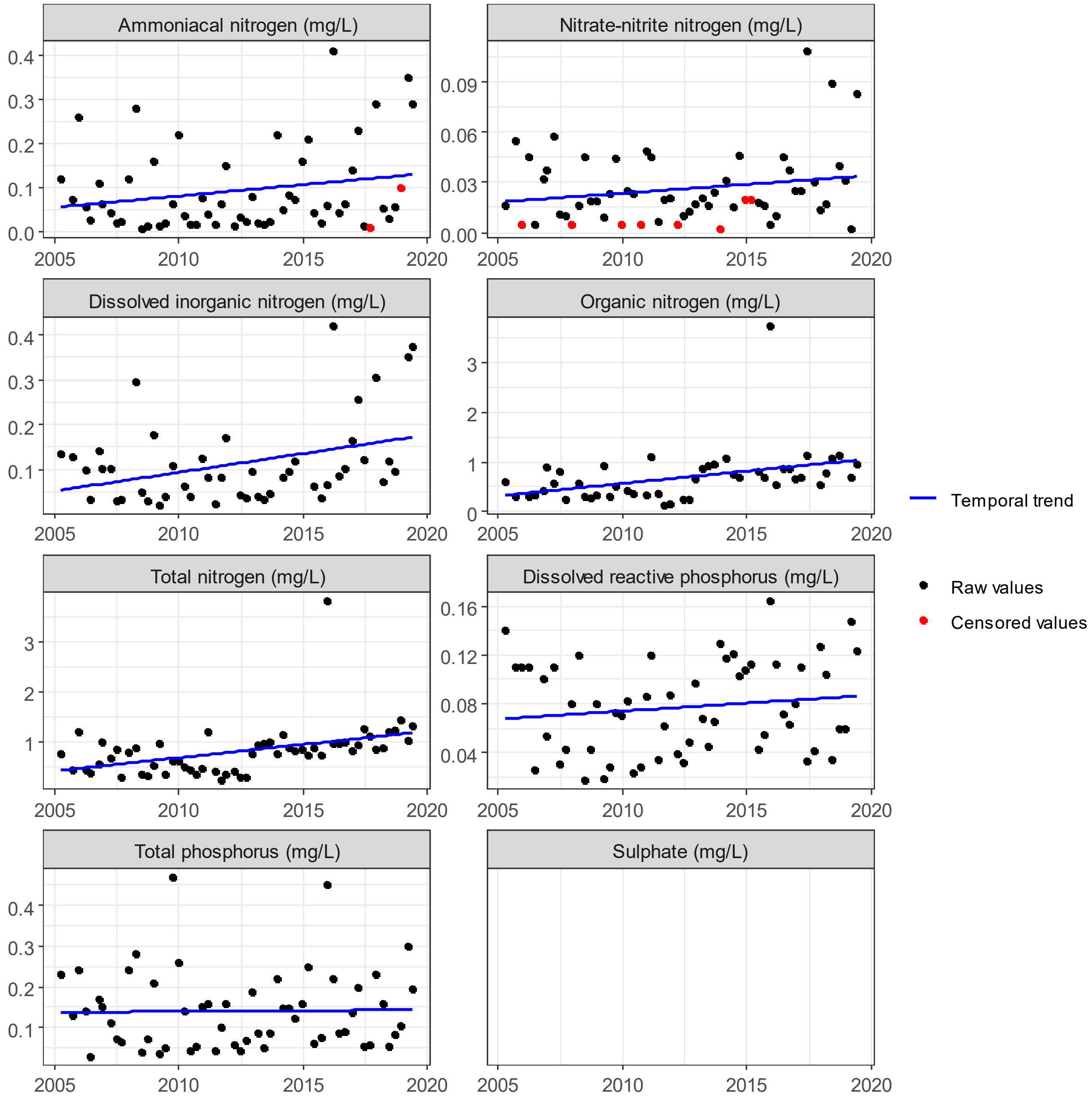


Figure 37. Washout Creek

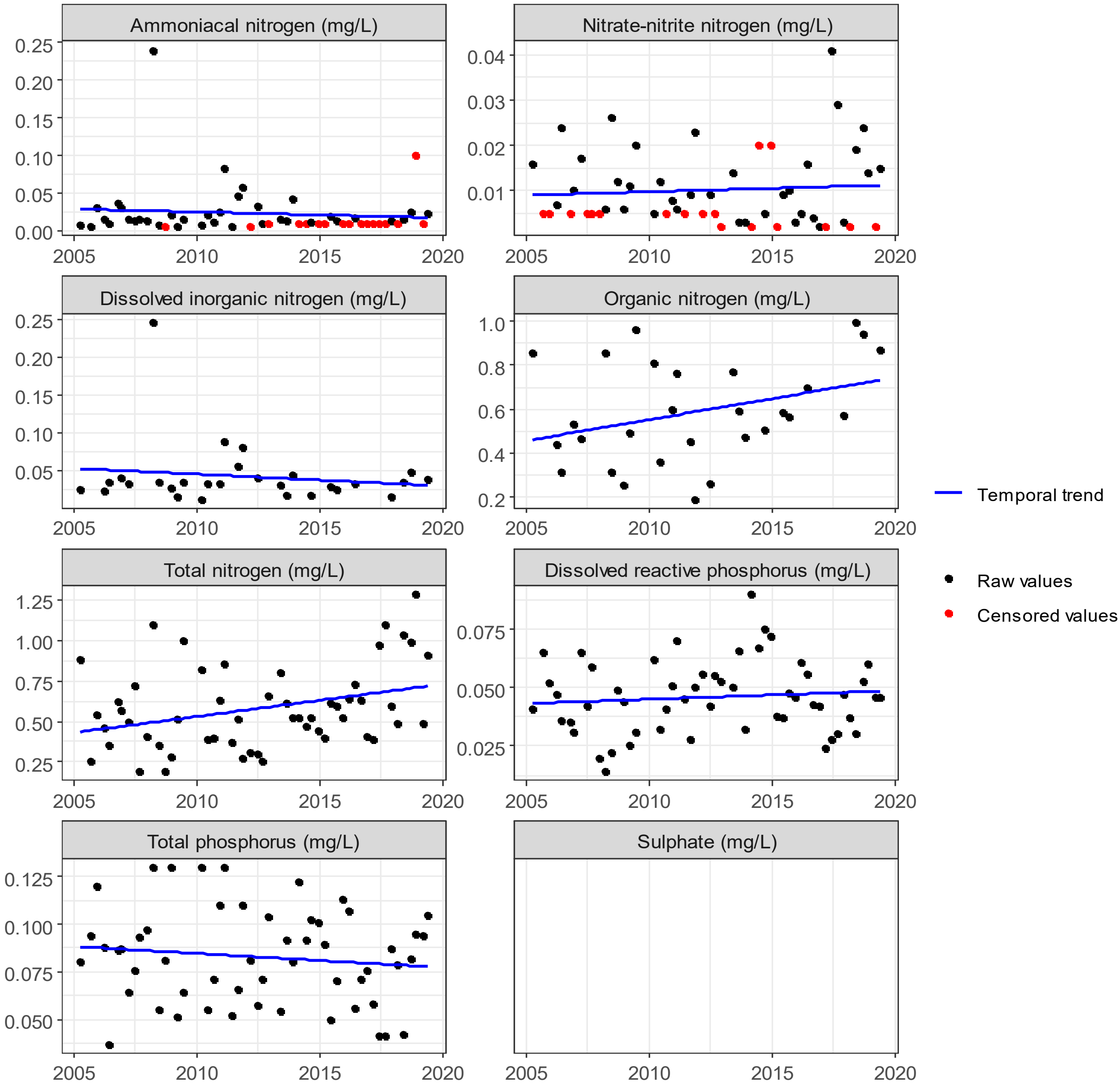


Figure 38. Whangamoe Stream

Te Whanga Lagoon

Physicochemical parameters

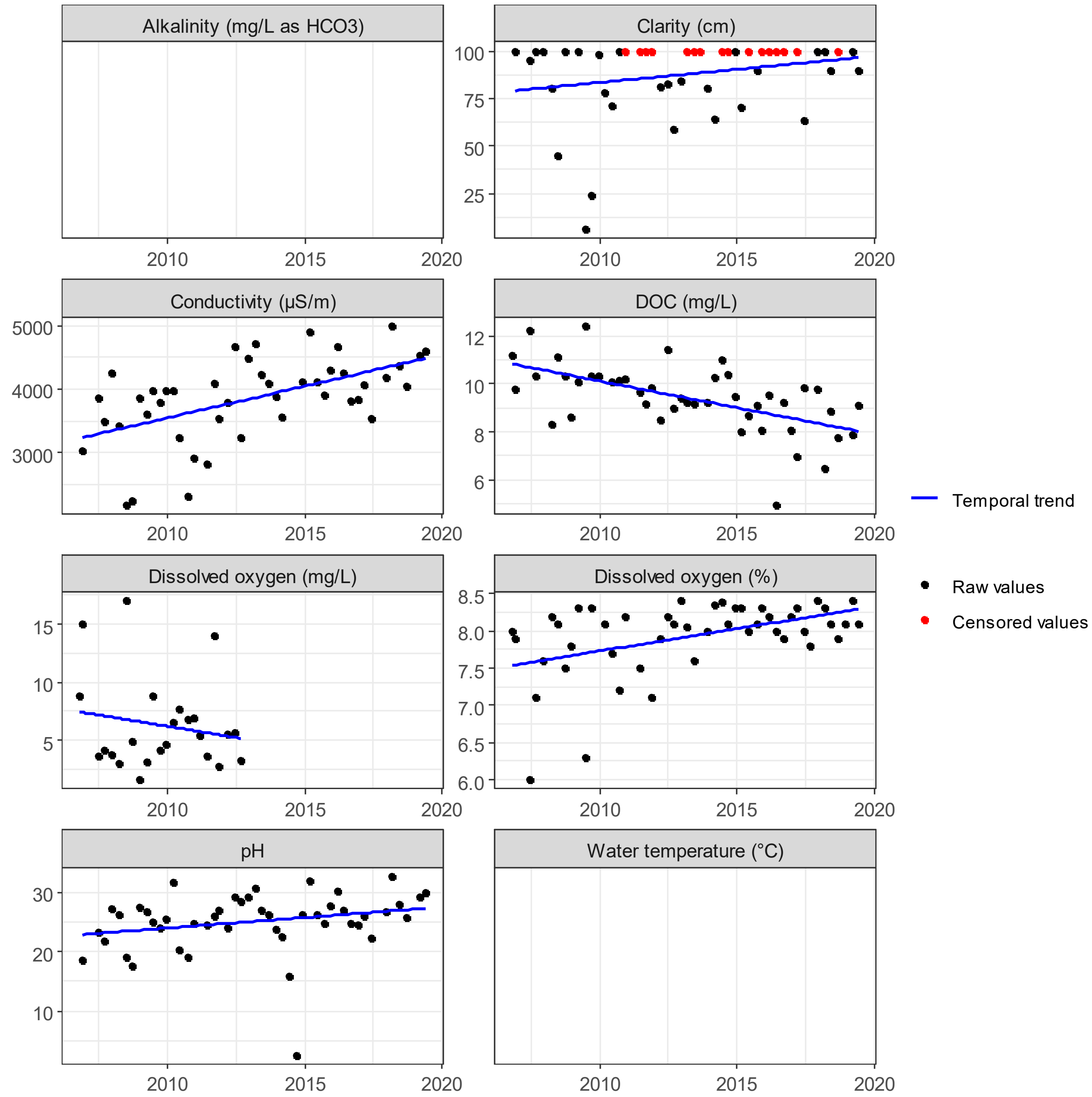


Figure 39. Te Whanga Lagoon (Southern Basin - west)

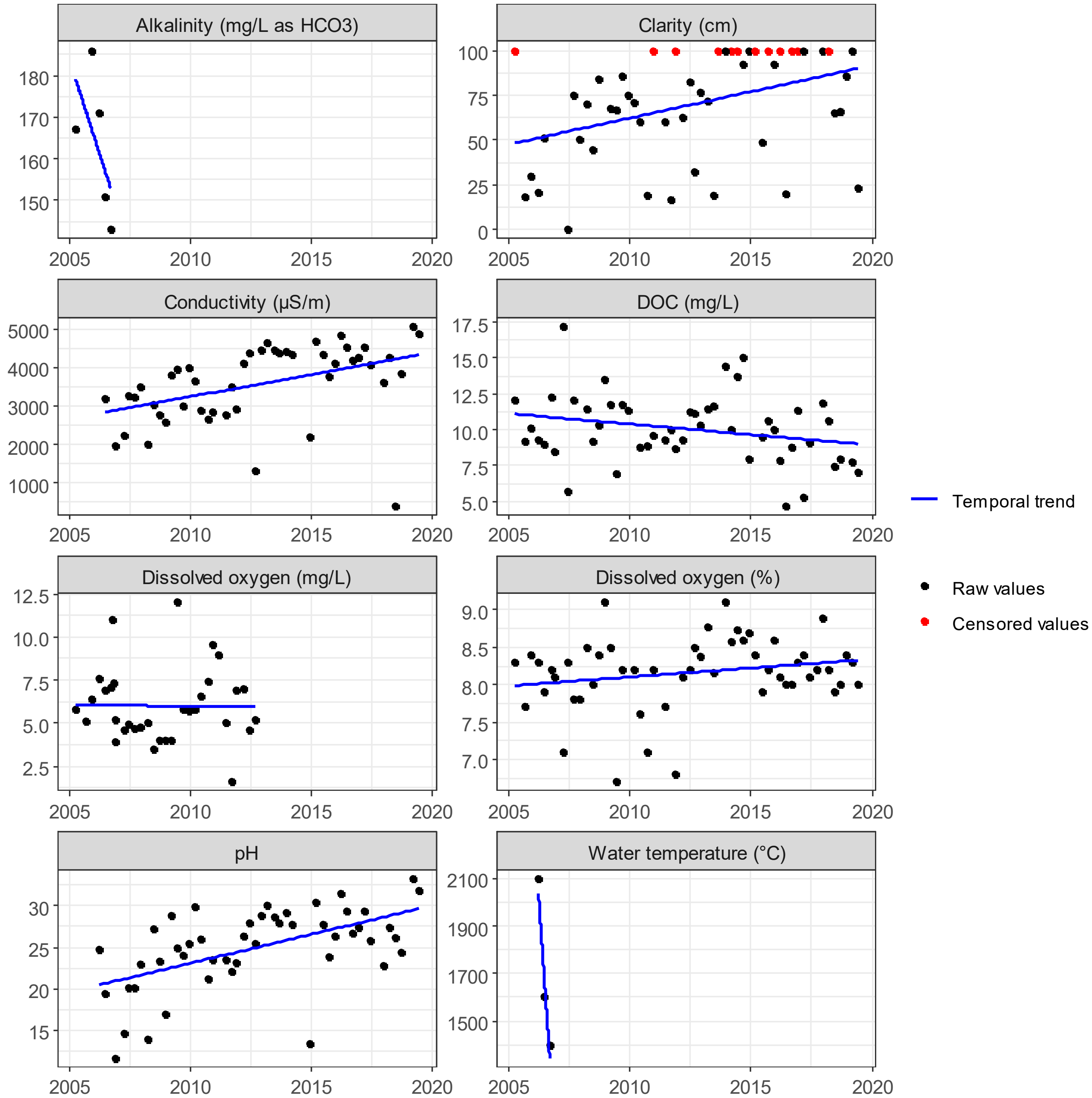


Figure 40. Te Whanga Lagoon beach (300 m north of Blind Jim's Creek)

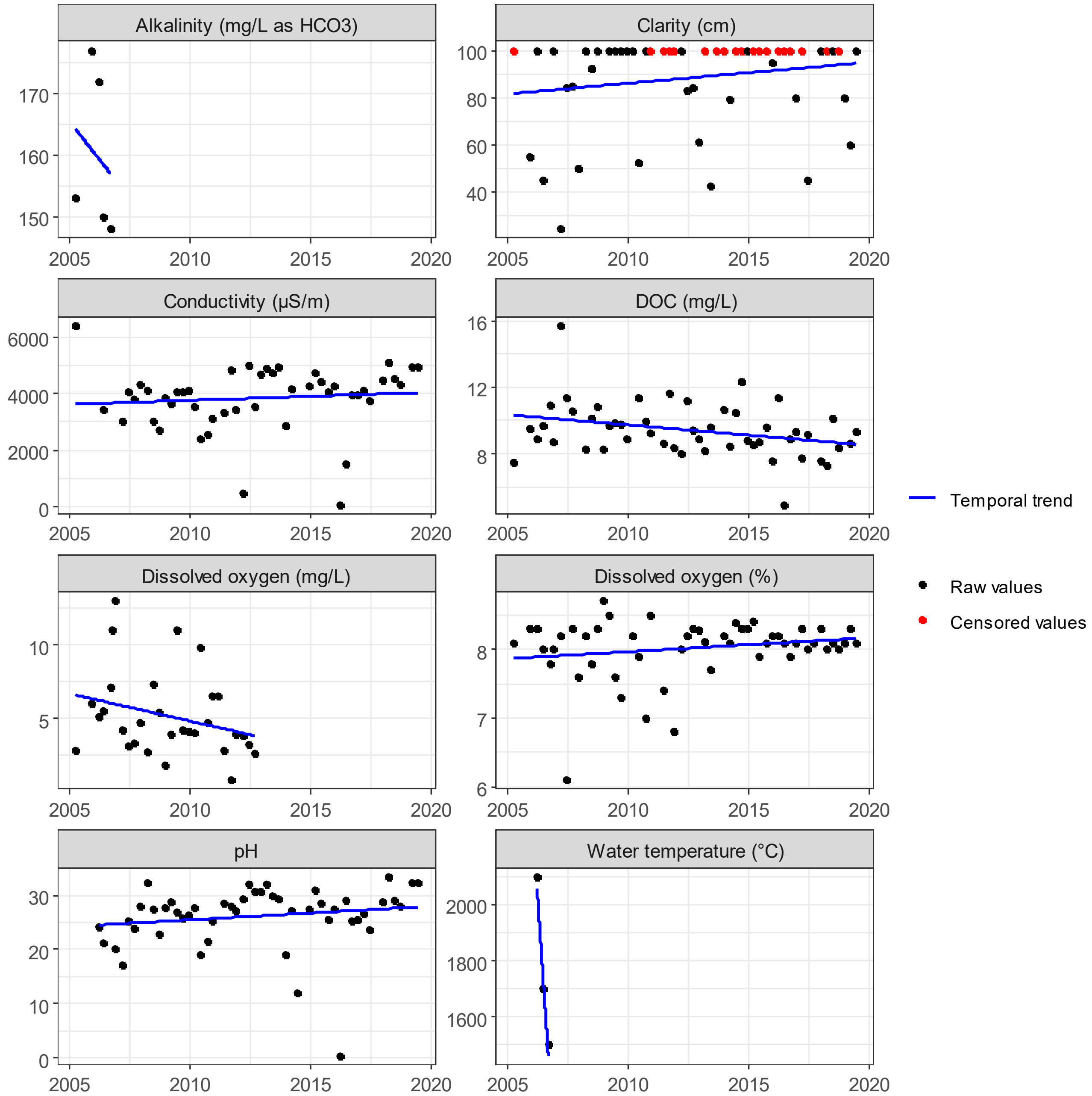


Figure 41. Te Whanga Lagoon (lake shore at Waitamaki Creek beach)

Nutrient parameters

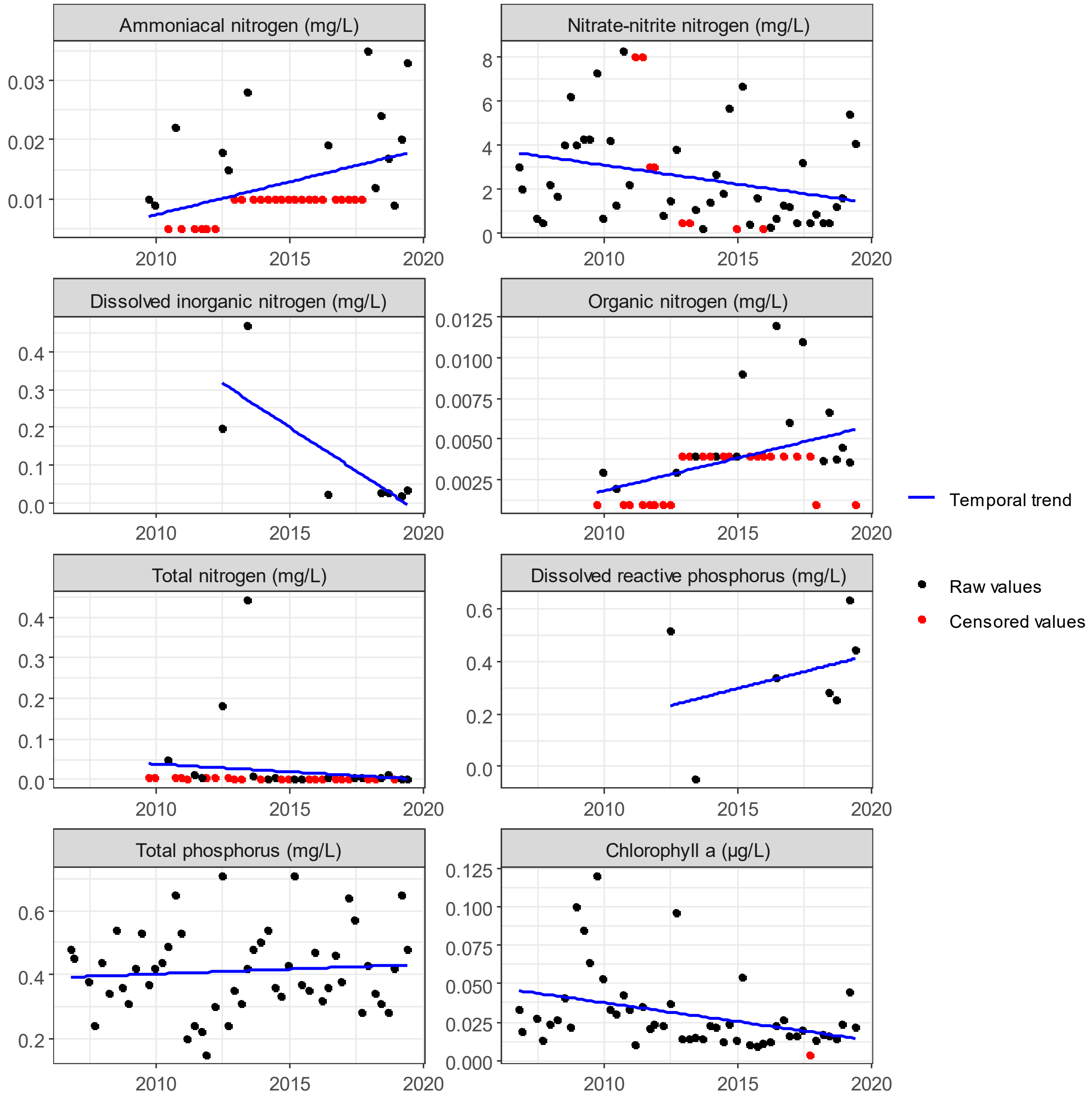


Figure 42. Te Whanga Lagoon (Southern Basin - west)

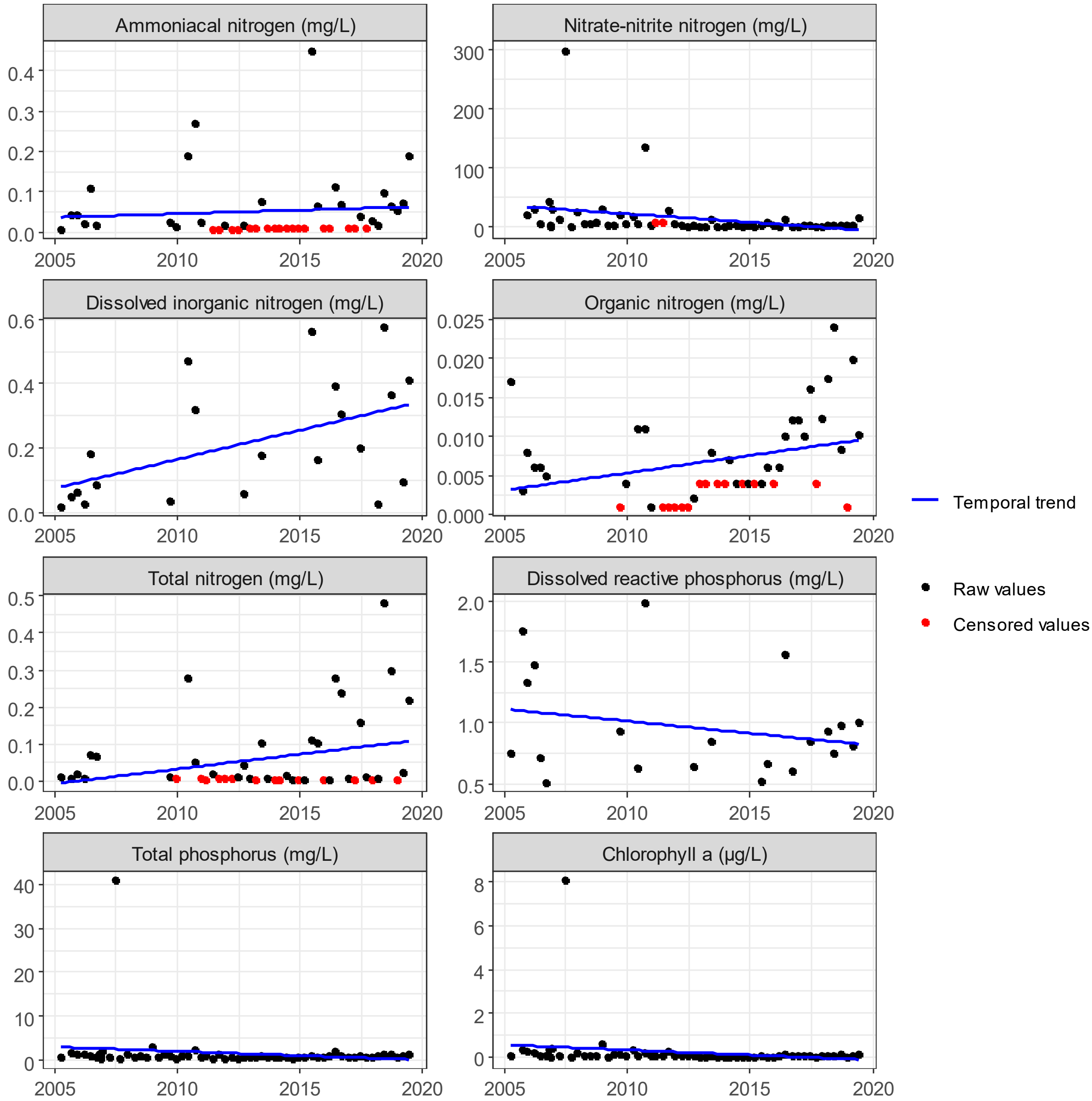


Figure 43. Te Whanga Lagoon beach (300 m north of Blind Jim's Creek)

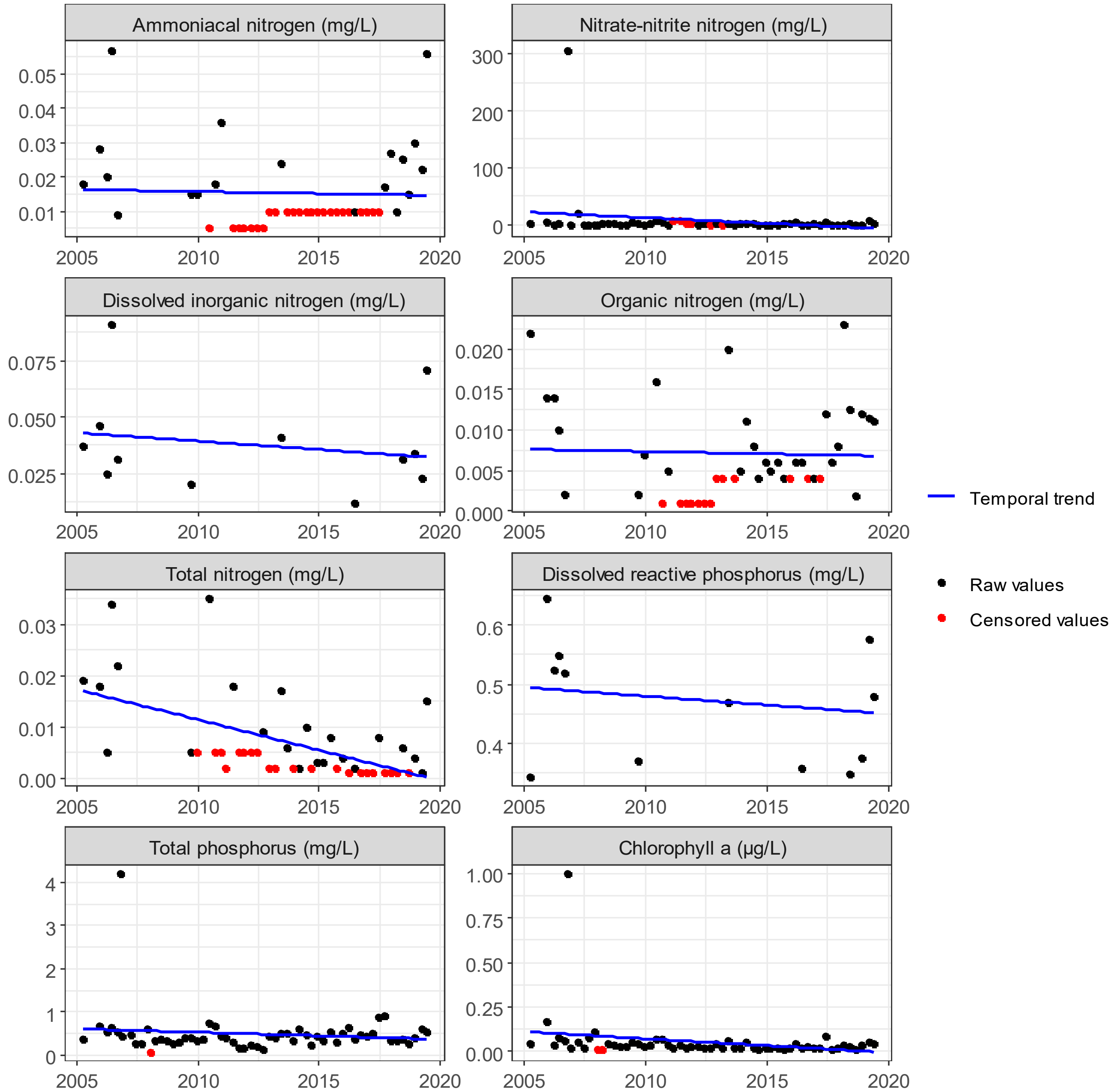


Figure 44. Te Whanga Lagoon (lake shore at Waitamaki Creek beach)

Appendix G

Te Whanga Nutrient Flux

Table 1: Estimated monthly flow for each catchment

Site	Primary recorder	Regression/scale	Catchment area (km²)	Average monthly flow (L/s)											
				Jun/11	Jul/11	Aug/11	Sep/11	Oct/11	Nov/11	Dec/11	Jan/12	Feb/12	Mar/12	Apr/12	May/12
Tutuiri River at Schist Outcrop	Tutuiri River	Primary Site	21.94	761	500	202	328	586	23	10	90	6	397	11	698
Te Awainanga at Falls	Te Awainanga	Primary Site	71.85	3,863	3,463	2,343	2,476	4,054	879	831	2,381	669	3,957	621	3,383
Awamata at Old hydro intake	Awamata	Primary Site	9.42	346	307	221	179	313	83	67	237	64	355	51	296
Blind Jims (North) Trib at North Rd	Awamata	y = 0.0964x - 4.71	0.883	29	25	17	13	25	3	2	18	1	30	0	24
Blind Jims Creek at North Road	Tutuiri River	Scale	1.44	15	10	4	7	12	0	0	2	0	8	0	14
Matanginui Creek at North Road	Tutuiri River	y = 0.0382x + 17.36	1.96	63	46	27	35	52	16	15	20	15	40	15	59
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	Te Awainanga	y = 0.1454x + 8.81	9.98	571	512	350	369	598	137	130	355	106	584	99	501
Oringi Creek at Air Base Road	Tutuiri River	Scale	2.64	92	60	24	39	71	3	1	11	1	48	1	84
Te Awainanga River- South Branch	Te Awainanga	Scale	1.2	65	58	39	41	68	15	14	40	11	66	10	57
Te Awainanga River	Te Awainanga	Primary Site	71.85	3,863	3,463	2,343	2,476	4,054	879	831	2,381	669	3,957	621	3,383
Nikau Reserve Stream at North Road	Tutuiri River	Scale	1.135	39	25	10	17	30	1	0	5	0	20	1	35
Wharekauri Stream at North Road	Tutuiri River	Scale	1.175	40	26	11	17	31	1	1	5	0	21	1	37
Waimahana Creek at Chudleigh Reserve Stream	Tutuiri River	y = 0.0656x + 12.04	8.48	62	45	25	34	50	14	13	18	12	38	13	58
Waipapa Creek at North Road	Tutuiri River	y = 0.1256x + 17.17	5.84	174	117	52	80	136	14	11	28	10	95	11	160
Waitaha Creek at North Road	Tutuiri River	y = 0.1133x + 1.35	2.53	88	58	24	39	68	4	2	12	2	46	3	80
Waitamaki Creek at Air Base Road Bridge	Tutuiri River	Scale	8.48	294	193	78	127	227	9	4	35	3	153	4	270

Table 2: Total Nitrogen (kg)

Site	Catchment Area (km²)	Jun/2011	Jul/2011	Aug/2011	Sep/2011	Oct/2011	Nov/2011	Dec/2011	Jan/2012	Feb/2012	Mar/2012	Apr/2012	May/2012	kg/km²
Blind Jims (North) Trib at North Rd	0.883	19.3	12.7	21.4	6.5	2.7	1.7	1.2	5.3	19.4	7.9	0.0	76.5	**197.76**
Blind Jims Creek at North Road	1.44	7.1	2.7	1.3	1.9	1.3	0.2	0.0	0.9	0.1	0.9	0.3	18.0	**24.02**
Matanginui Creek at North Road	1.96	42.5	17.4	12.5	15.6	5.6	3.7	3.6	9.8	1.5	4.3	1.6	268.7	**197.30**
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	9.98	310.5	178.4	140.4	143.4	64.1	38.9	45.1	228.2	39.9	219.0	10.3	1,099.8	**252.31**
Oringi Creek at Air Base Road	2.64	52.2	24.1	14.3	23.5	7.6	0.9	0.4	9.6	0.2	5.1	0.4	161.9	**113.75**
Te Awainanga River- South Branch	1.2	21.7	13.9	10.5	11.8	7.3	1.5	3.3	23.4	2.8	15.9	2.4	81.7	**163.61**
Te Awainanga River	71.85	2,203.0	1,483.9	1,255.2	513.5	1,085.9	227.8	311.7	1,530.4	268.1	2,225.6	64.4	7,793.4	**263.92**
Nikau Reserve Stream at North Road	1.135	76.2	32.7	13.7	19.5	31.2	1.6	0.8	2.5	0.3	25.4	0.8	142.6	**305.88**
Wharekauri Stream at North Road	1.175	50.9	24.0	19.6	15.2	19.0	1.1	0.3	6.1	0.2	20.7	0.5	137.8	**251.42**
Waimahana Creek at Chudleigh Reserve Stream	8.48	33.7	4.8	2.7	7.8	5.4	NO DATA	1.4	1.9	3.7	4.1	1.3	72.8	**16.47**
Waipapa Creek at North Road	5.84	162.3	62.8	33.7	49.7	36.4	3.9	5.2	53.8	6.0	35.6	1.1	557.9	**172.69**
Waitaha Creek at North Road	2.53	115.7	49.7	20.1	38.9	47.2	3.0	1.8	28.9	2.8	41.0	1.3	366.0	**283.16**
Waitamaki Creek at Air Base Road Bridge	8.48	228.6	124.1	43.9	88.7	54.6	11.9	1.6	19.6	0.9	16.4	7.0	411.6	**118.98**
Sum	**118**	**3,324**	**2,031**	**1,589**	**936**	**1,368**	**296**	**376**	**1,920**	**346**	**2,622**	**91**	**11,189**	**221.86**

Table 3: Total Phosphorous (kg)														
Site	Catchment Area (km²)	Jun/2011	Jul/2011	Aug/2011	Sep/2011	Oct/2011	Nov/2011	Dec/2011	Jan/2012	Feb/2012	Mar/2012	Apr/2012	May/2012	kg/km²
Blind Jims (North) Trib at North Rd	0.883	6.4	7.3	32.5	3.9	6.1	1.2	0.6	2.8	1.0	6.6	0.1	21.0	**101.49**
Blind Jims Creek at North Road	1.44	1.9	1.3	0.8	1.0	2.8	0.3	0.0	0.5	0.0	0.6	0.1	2.4	**8.07**
Matanginui Creek at North Road	1.96	39.2	14.9	11.0	12.9	18.1	5.8	6.5	8.7	3.1	13.9	7.1	55.3	**100.23**
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	9.98	45.8	42.5	28.1	20.1	49.7	12.0	11.1	40.9	10.9	68.8	10.0	59.0	**39.98**
Oringi Creek at Air Base Road	2.64	13.0	7.1	4.0	6.9	9.1	0.3	0.2	1.9	0.1	1.8	0.1	15.3	**22.61**
Te Awainanga River- South Branch	1.2	9.9	6.8	4.7	4.3	10.5	2.2	2.0	10.7	3.9	15.4	1.8	9.5	**68.08**
Te Awainanga River	71.85	440.6	371.0	320.1	430.1	369.2	111.6	84.6	350.7	217.8	593.5	75.7	607.2	**55.28**
Nikau Reserve Stream at North Road	1.135	13.0	6.8	2.1	4.2	7.7	0.5	0.2	1.4	0.5	6.0	0.2	11.4	**47.52**
Wharekauri Stream at North Road	1.175	2.1	2.2	16.8	1.5	4.5	0.1	0.1	1.8	0.0	2.6	0.1	2.8	**29.42**
Waimahana Creek at Chudleigh Reserve Stream	8.48	20.9	22.8	14.9	13.9	25.7	NO DATA	7.5	15.4	9.7	24.5	8.9	26.3	**22.46**
Waipapa Creek at North Road	5.84	25.2	23.2	11.4	9.5	30.2	2.6	2.5	18.2	1.8	28.0	2.6	33.9	**32.40**
Waitaha Creek at North Road	2.53	5.7	4.7	2.3	2.3	7.3	0.5	0.3	2.4	0.3	6.0	0.2	10.8	**16.83**
Waitamaki Creek at Air Base Road Bridge	8.48	35.8	50.7	20.9	28.3	66.8	2.3	1.2	12.2	0.4	33.3	1.2	70.0	**38.10**
Sum	**118**	**660**	**561**	**470**	**539**	**608**	**139**	**117**	**467**	**250**	**801**	**108**	**925**	**48.00**

Table 4: Nitrate-Nitrogen (kg)

Site	Catchment Area (km²)	Jun/2011	Jul/2011	Aug/2011	Sep/2011	Oct/2011	Nov/2011	Dec/2011	Jan/2012	Feb/2012	Mar/2012	Apr/2012	May/2012	kg/km²
Blind Jims (North) Trib at North Rd	0.883	0.7	0.7	0.5	0.1	0.2	0.1	0.0	0.1	0.0	0.2	0.0	0.5	**3.58**
Blind Jims Creek at North Road	1.44	0.5	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.5	**1.19**
Matanginui Creek at North Road	1.96	3.3	4.3	3.3	0.9	1.9	1.8	1.7	0.7	1.6	3.2	0.9	6.2	**15.27**
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	9.98	3.7	3.4	2.3	2.4	4.0	0.9	0.9	2.4	0.7	3.9	0.6	12.1	**3.74**
Oringi Creek at Air Base Road	2.64	0.6	1.8	0.3	0.3	0.5	0.0	0.0	0.1	0.0	0.3	0.0	1.8	**2.14**
Te Awainanga River- South Branch	1.2	0.4	0.4	0.3	1.7	0.5	0.3	0.1	0.3	0.1	1.2	0.1	0.4	**4.71**
Te Awainanga River	71.85	100.1	250.4	156.9	16.0	27.1	11.4	5.6	15.9	4.2	95.4	8.1	226.6	**12.77**
Nikau Reserve Stream at North Road	1.135	6.3	3.1	1.0	1.1	0.2	0.1	0.0	0.0	0.0	0.5	0.0	17.1	**25.95**
Wharekauri Stream at North Road	1.175	0.3	0.2	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.2	**1.08**
Waimahana Creek at Chudleigh Reserve Stream	8.48	1.8	0.6	0.7	0.2	0.3	NO DATA	0.1	0.1	0.2	1.7	0.3	1.7	**0.92**
Waipapa Creek at North Road	5.84	14.4	7.8	3.5	1.9	0.9	0.3	0.1	0.2	0.1	2.0	0.3	19.7	**8.78**
Waitaha Creek at North Road	2.53	4.8	1.2	0.2	0.2	1.3	0.4	0.1	0.1	0.0	1.1	0.1	8.4	**7.07**
Waitamaki Creek at Air Base Road Bridge	8.48	4.6	15.5	10.4	7.2	4.9	0.7	0.2	0.2	0.0	1.0	0.1	15.2	**7.07**
Sum	**118**	**141**	**290**	**180**	**32**	**42**	**16**	**9**	**20**	**7**	**111**	**11**	**310**	**9.94**

Table 5: Dissolved Reactive Phosphorous (kg)														
Site	Catchment Area (km²)	Jun/2011	Jul/2011	Aug/2011	Sep/2011	Oct/2011	Nov/2011	Dec/2011	Jan/2012	Feb/2012	Mar/2012	Apr/2012	May/2012	kg/km²
Blind Jims (North) Trib at North Rd	0.883	1.9	1.2	0.5	0.7	0.8	0.1	0.0	0.4	0.0	0.8	0.0	1.3	**8.85**
Blind Jims Creek at North Road	1.44	1.2	0.4	0.1	0.3	0.4	0.0	0.0	0.1	0.0	0.1	0.0	0.5	**2.13**
Matanginui Creek at North Road	1.96	5.1	7.2	4.8	3.8	6.7	2.0	2.1	2.9	1.3	5.2	3.0	4.4	**24.77**
Mangahou Creek at Waitangi Wharf Owenga Rd Bridge	9.98	25.1	20.6	11.2	10.5	32.0	4.6	6.6	21.9	4.5	34.4	4.9	24.1	**20.10**
Oringi Creek at Air Base Road	2.64	1.2	1.3	0.3	0.7	1.6	0.0	0.0	0.2	0.0	0.5	0.0	2.0	**3.01**
Te Awainanga River- South Branch	1.2	4.8	3.7	1.7	1.8	4.5	0.6	1.1	4.8	0.8	6.7	0.6	4.5	**29.85**
Te Awainanga River	71.85	280.4	185.5	100.4	250.3	195.5	34.2	40.1	172.2	40.2	243.8	38.7	181.2	**24.53**
Nikau Reserve Stream at North Road	1.135	3.9	2.9	0.9	1.6	4.3	0.1	0.0	0.3	0.0	2.6	0.1	4.2	**18.38**
Wharekauri Stream at North Road	1.175	0.8	1.1	0.6	0.1	2.6	0.0	0.0	0.2	0.0	1.2	0.0	0.5	**6.20**
Waimahana Creek at Chudleigh Reserve Stream	8.48	7.5	11.2	12.2	9.6	9.9	NO DATA	3.7	2.6	2.0	4.5	2.1	12.7	**9.19**
Waipapa Creek at North Road	5.84	10.8	9.1	2.4	2.0	9.5	0.5	0.6	3.3	0.4	6.9	0.5	7.7	**9.20**
Waitaha Creek at North Road	2.53	2.3	2.3	0.9	0.8	3.3	0.1	0.1	0.4	0.0	2.4	0.1	1.9	**5.76**
Waitamaki Creek at Air Base Road Bridge	8.48	35.0	17.1	6.9	11.5	17.0	0.3	0.4	1.6	0.1	8.2	0.2	23.1	**14.32**
Sum	**118**	**380**	**263**	**143**	**294**	**288**	**43**	**55**	**211**	**49**	**317**	**50**	**268**	**20.09**