Surface Water Quality Monitoring Report for Christchurch City Waterways: January – December 2018

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Figures

Tables

Christchurch City Council

Executive Summary

- This report summarises the results of the Christchurch City Council (CCC) surface water quality monitoring for the period January to December 2018, in accordance with the CCC Interim Global Stormwater Consent, South-West Stormwater Management Plan and the Styx Stormwater Management Plan.
- Monthly water samples were collected from 42 sites within the five major river catchments of Christchurch City (the Ōtākaro/ Avon, Ōpāwaho/ Heathcote, Huritini/ Halswell, Pūharakekenui/ Styx and Ōtūkaikino Rivers) and Linwood Canal, as well as two sites within Halswell Retention Basin. Wet weather sampling from the Pūharakekenui/Styx River catchment had not been completed at the time of writing and will be included in the 2020 water quality report. Results of community monitoring at ten sites in the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust are also presented in this report.
- The water quality parameters specifically assessed in this report include metals (copper, lead and zinc), pH, conductivity, total suspended solids (TSS), turbidity, dissolved oxygen, temperature, biochemical oxygen demand (BOD_5), ammonia, nitrogen, phosphorus and *Escherichia coli* (as an indicator of pathogens).
- Over 11,000 tests were conducted for the monthly monitoring, with 7,500 of these allowing the assessment of each waterway site against relevant guideline levels. There were a number of parameters that were recorded at levels unlikely to cause adverse effects, including dissolved lead, total ammonia and nitrate. However, twenty-two percent of all samples did not meet the guideline level, with 100% of sites not meeting the guideline for at least one parameter. The contaminants of most concern were nitrogen, phosphorus and *E. coli*, as well as dissolved copper, dissolved zinc, pH, TSS, turbidity, dissolved oxygen and BOD_5 at certain sites.
- The majority of waterways recorded a Water Quality Index (WQI) of 'poor'. Generally, there was little difference in catchment WQI between 2013 and 2018. The Ōpāwaho/ Heathcote River catchment recorded the poorest water quality, and the worst site was Curletts Road Stream at Motorway followed jointly by Curletts Road Stream Upstream of Heathcote River and Heathcote River at Mackenzie Avenue. The Ōtūkaikino River catchment recorded the best water quality, and the best site was Wairarapa Stream in the Ōtākaro/ Avon catchment.
- The results of this year's monitoring are largely consistent with those recorded in previous years, indicating that many of the waterways are historically and currently subjected to contamination, potentially from stormwater, waterfowl and other inputs. These contaminants may be having effects that include short-term and long-term adverse effects on biota, proliferation of aquatic plants and/or algae, human health risks from contact recreation, and deterioration of the aesthetics of the water column.
- The sites and parameters of concern in this report should be the focus of improved catchment management practices in Christchurch. Recommendations are made in the report for priority areas of focus.

1 Introduction & Sampling Sites

This report summarises the results of the Christchurch City Council (CCC) surface water quality monitoring for the period January 2018 to December 2018. This monitoring is in accordance with the requirements of the Interim Global Stormwater Consent (IGSC; CRC090292; Dewson & Rodrigo 2009), South-West Stormwater Management Plan (SMP) (CRC120223; Golder Associates 2012) and Styx SMP (CRC131249; Golder Associates 2013).

Monthly water samples were collected by CCC from 42 waterway sites: 41 sites within the five major river catchments of Christchurch City (the Ōtākaro/ Avon, Ōpāwaho/ Heathcote, Huritini/ Halswell, Pūharakekenui/ Styx and Ōtūkaikino Rivers), and one site in Linwood Canal (Table 1, Figure 1). Although not waterway sites, two sites within the Halswell Retention Basin (inlet and outlet) were also sampled. Six of the waterway sites were specifically chosen because they are located in proximity to stormwater outfalls[1]. However, it should be noted that there are hundreds of outfalls throughout the catchments and many of the other sites are also located near stormwater discharge pipes. There are five sites that are located in strongly tidal areas, where sampling is undertaken at low tide (± 30 minutes)[2].

The results of community monitoring at ten sites in the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust (SLLT)[3] are also presented in this report (Table 1, Figure 1). The Styx River catchment was due to be monitored during two wet weather occasions, however lack of suitable rain events meant that results were not available at the time of writing. The wet weather results will be presented in the 2020 water quality report.

[1] Avon River at Carlton Mill Corner, Avon River at Avondale Road, Heathcote River at Catherine Street, Heathcote River at Mackenzie Avenue, Haytons Stream at Retention Basin, Curletts Road Stream at Southern Motorway

[2] Avon River at Bridge Street, Avon River at Pages/Seaview Bridge, Heathcote River at Ferrymead Bridge, Heathcote River at Tunnel Road and Linwood Canal/ City Outfall Drain

[3] More information about this community group, including their monitoring programme, can be found at https://www.thestyx.org.nz/styx-living-laboratory-trust

Christchurch City Council

Table 1. Christchurch City Council water quality monitoring sites required under the four Environment Canterbury (ECan) stormwater consents

Catchment	Site ID	Site	Easting (NZTM)	Northing (NZTM)	ECan Consent	LWRP or WRRP Classification
Ōtākaro/ Avon	AVON01	Avon River at Pages/Seaview Bridge[4]	1577484	5182589	IGSC	Spring-fed – plains – urban (LWRP)
	AVON02	Avon River at Bridge Street[4]	1577691	5180813	IGSC	Spring-fed – plains – urban (LWRP)
	AVON03	Avon River at Dallington Terrace/Gayhurst Road[4]	1573560	5181210	IGSC	Spring-fed – plains – urban (LWRP)
	AVON04	Avon River at Manchester Street	1570890	5180481	IGSC	Spring-fed – plains – urban (LWRP)
	AVON05	Wairarapa Stream	1568250	5181303	IGSC	Spring-fed – plains – urban (LWRP)
	AVON06	Waimairi Stream	1568233	5181172	IGSC	Spring-fed – plains – urban (LWRP)
	AVON07	Avon River at Mona Vale	1568334	5181046	IGSC	Spring-fed – plains – urban (LWRP)
	AVON08	Riccarton Main Drain	1568683	5180019	IGSC	Spring-fed – plains – urban (LWRP)
	AVON09	Addington Brook	1569427	5179826	IGSC	Spring-fed – plains – urban (LWRP)
	AVON10	Dudley Creek	1572574	5182150	IGSC	Spring-fed – plains – urban (LWRP)
	AVON11	Horseshoe Lake Discharge[4]	1574342	5183294	IGSC	Spring-fed – plains – urban (LWRP)
	AVON12	Avon River at Carlton Mill Corner[5]	1569737	5181259	IGSC	Spring-fed – plains – urban (LWRP)
	AVON13	Avon River at Avondale Road[4,5]	1574752	5183557	IGSC	Spring-fed – plains – urban (LWRP)

IGSC = Interim Global Stormwater Consent; SMP = Stormwater Management Plan; LWRP = Land & Water Regional Plan; WRRP = Waimakariri River Regional Plan; SLLT = Styx Living Laboratory Trust.

[4] Tidally influenced site
[5] These sites are specifically located in proximity to stormwater outfalls

Catchment	Site ID	Site	Easting (NZTM)	Northing (NZTM)	ECan Consent	LWRP or WRRP Classification
Ōpāwaho/ Heathcote	HEATH01	Heathcote River at Ferrymead Bridge[4]	1576491	5177150	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH02	Heathcote River at Tunnel Road[4]	1575074	5177543	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH03	Heathcote River at Opawa Road/Clarendon Terrace[4]	1573071	5177615	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH04	Heathcote River at Bowenvale Avenue	1571198	5175780	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH05	Cashmere Stream at Worsleys Road	1569030	5175155	South-West SMP	Banks Peninsula (LWRP)
	HEATH06	Heathcote River at Rose Street	1568701	5175918	South-West SMP	Spring-fed – plains – urban (LWRP)
	HEATH07	Heathcote River at Ferniehurst Street	1569157	5175612	South-West SMP	Spring-fed – plains – urban (LWRP)
	HEATH08	Heathcote River at Templetons Road	1565915	5176897	South-West SMP	Spring-fed – plains – urban (LWRP)
	HEATH09	Haytons Stream at Retention Basin[5]	1566020	5177596	South-West SMP	Spring-fed – plains – urban (LWRP)
	HEATH10	Curletts Road Stream Upstream of Heathcote River Confluence	1566928	5177711	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH11	Heathcote River at Catherine Street[5]	1574413	5177883	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH12	Heathcote River at Mackenzie Avenue Footbridge[5]	1573520	5177917	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH14	Curletts Road Stream at Southern Motorway[5]	1566405	5178358	IGSC	Spring-fed – plains – urban (LWRP)
	HEATH16	Cashmere Stream at Sutherlands Road	1566086	5173988	South-West SMP	Not classified[6]

[6] But considered in this report a Banks Peninsula waterway, as per the lower reaches

Catchment	Site ID	Site	Easting (NZTM)	Northing (NZTM)	ECan Consent	LWRP or WRRP Classification
Pūharakekenui / Styx	STYX01	Smacks Creek at Gardiners Road near Styx Mill Road	1566804	5187956	Styx SMP	Unclassified[7]
	STYX02	Styx River at Gardiners Road	1566790	5187226	Styx SMP	Unclassified[7]
	STYX03	Styx River at Main North Road	1569066	5187219	Styx SMP	Unclassified[7]
	STYX04	Kā Pūtahi[8] Creek at Blakes Road	1570401	5188030	Styx SMP	Unclassified[7]
	STYX05	Kā Pūtahi[8] Creek at Belfast Road	1572194	5188267	Styx SMP	Unclassified[7]
	STYX06	Styx River at Marshland Road Bridge	1572358	5187778	Styx SMP	Unclassified[7]
	STYX07	Styx River at Richards Bridge	1573975	5189640	Styx SMP	Unclassified[7]
	STYX08	Styx River at Harbour Road Bridge[4]	1574998	5194749	Styx SMP	Unclassified[7]
Huritini/ Halswell	HALS01	Halswell Retention Basin Inlet	1561701	5177022	IGSC	Not relevant
	HALS02	Halswell Retention Basin Outlet	1561796	5176914	IGSC	Not relevant
	HALS03	Nottingham Stream at Candys Road	1564532	5173080	South-West SMP	Spring-fed – plains (LWRP)
	HALS04	Halswell River at Akaroa Highway	1564446	5171721	South-West SMP	Spring-fed – plains (LWRP)
	HALS05	Knights Stream at Sabys Road	1563723	5172852	South-West SMP	Spring-fed – plains (LWRP)
Ōtūkaikino	OTUKAI01	Ōtūkaikino River at Groynes Inlet	1567878	5188869	IGSC	OTU/GROYNES (WRRP)
	OTUKAI02	Wilsons Drain at Main North Road	1571241	5190793	Styx SMP	WAIM-TRIB (WRRP)
	OTUKAI03	Ōtūkaikino Creek at Omaka Scout Camp	1565664	5188038	IGSC	OTU/GROYNES (WRRP)
Linwood	OUT01	Linwood Canal/City Outfall Drain[4]	1575952	5178026	IGSC	Unclassified[9]

[7] These waterways were originally classified as WAIM-TRIB in the WRRP, but an amendment was made for this catchment to be covered by the NRRP (where the waterways were classified 'spring-fed - plains'). The LWRP may be amended in the future to be in line with the now inoperative NRRP (Michele Stevenson, Environment Canterbury, personal communication). Therefore, these locations are considered as 'spring-fed - plains' in this report. This is a conservative approach, as the standards for 'spring-fed - plains' in the LWRP are more stringent than the standards for WAIM-TRIB in the WRRP.
[8] While officially shown on maps as Kaputone Creek, CCC has recently endorsed the use of the original Māori name for the area, Kā Pūtahi Creek.
[9] It is considered that 'spring-fed – plains – urban' is the most appropriate classification for this waterway under the LWRP

Catchment	Site ID	Site	Easting (NZTM)	Northing (NZTM)	ECan Consent	LWRP or WRRP Classification
Pūharakekenui / Styx (SLLT sites)	N/A	Smacks Creek at Wilkinsons Road	1567089	5068802	N/A	Unclassified[6]
	N/A	Smacks Creek Conservation Reserve	1566844	5187922	N/A	Unclassified[6]
	N/A	Styx River at Willowbank	1567218	5187641	N/A	Unclassified[6]
	N/A	Styx River at Styx Mill Conservation Reserve	1567918	5187613	N/A	Unclassified[6]
	N/A	Styx Drain at Redbrook Road	1568628	5069246	N/A	Unclassified[6]
	N/A	Styx River at Radcliffe Road	1571720	5187413	N/A	Unclassified[6]
	N/A	Kā Pūtahi Creek at Blakes Road	1570925	5068237	N/A	Unclassified[6]
	N/A	Kā Pūtahi Creek at Ouruhia Domain	1571771	5190129	N/A	Unclassified[6]
	N/A	Kā Pūtahi Creek at Everglades Golf Course	1571798	5189270	N/A	Unclassified[6]
	N/A	Styx River at Brooklands	1575110	5193308	N/A	Unclassified[6]

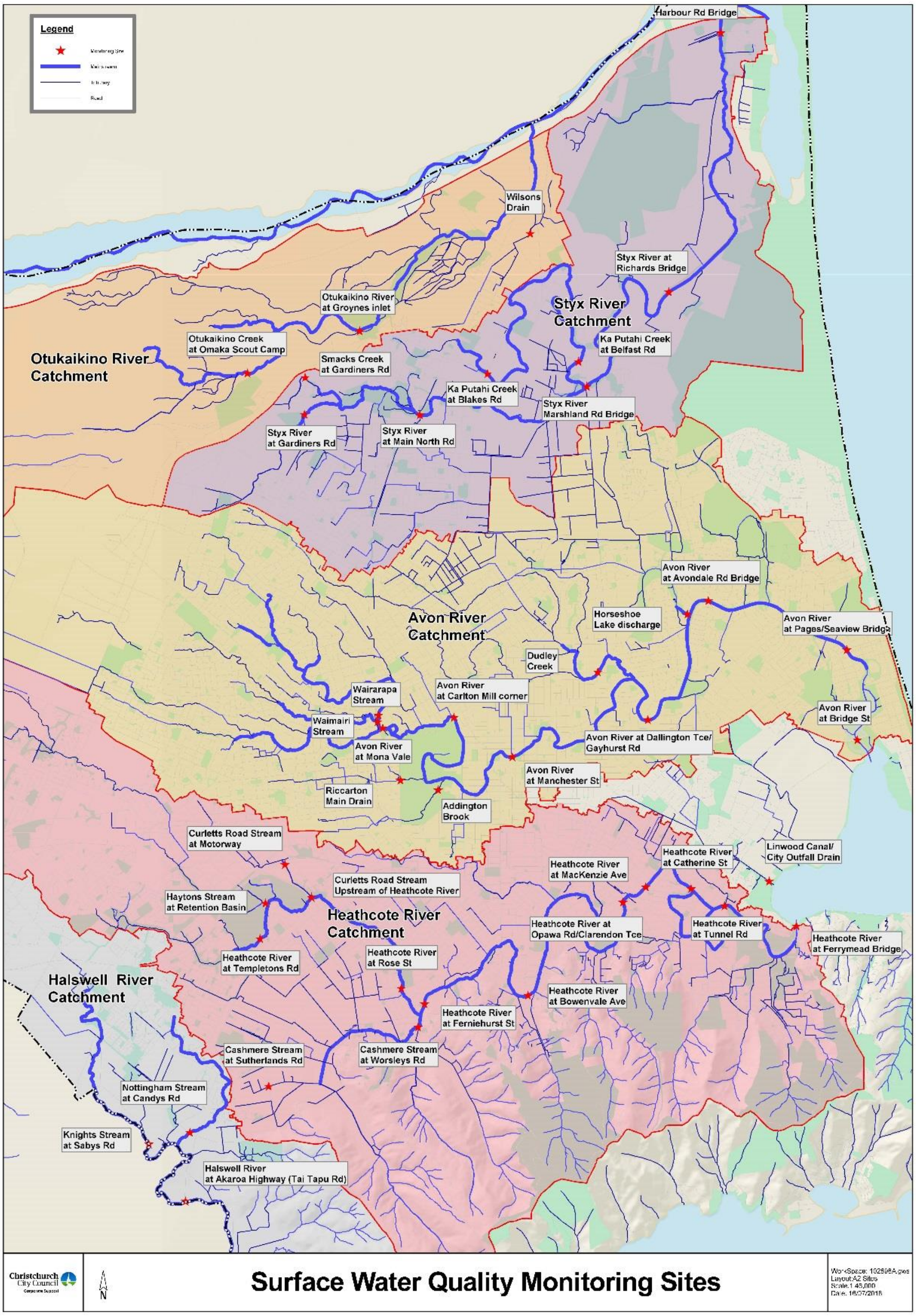

Figure 1. Location of Christchurch City Council surface water quality monitoring sites

2 Methods

2.1 Sample Collection and Testing

CCC monthly samples were collected predominantly via grab sampling, with field testing of temperature and oxygen using a hand-held meter (YSI Pro ODO meter). During the 2018 monitoring year, all sites were monitored every month.

SLLT volunteers have analysed water in the field for pH (Eutech pH pocket testers 30), conductivity (Eutech Cybernetics TDScan 3), water clarity (clarity tube) and water temperature (glass spirit thermometer) since 2004. Samples were aimed to be taken every third Saturday of the month, but as this was based on volunteer availability, the number of samples taken annually at each site ranged from 4 – 14. Of note:

- 2018 records ranged from 4 – 11 per site
- There was no data available for 2016
- 2015 and 2017 had a small number of recordings
- pH readings changed from using test strips to a handheld meter in February 2010; therefore, pH data prior to this time have been excluded from this report

The CCC monthly samples were analysed at the CCC International Accreditation New Zealand (IANZ) laboratory for the parameters outlined in Table 2 (except for those measured in the field). Not all parameters were tested at all sites, and only the most pertinent parameters (typically with guideline levels) are analysed and discussed in this report. The methods used to analyse each parameter, including laboratory Limits of Detection (LOD), are presented in Table i in Appendix A. Some of these methods have changed over time, as more advanced equipment has become available, and timeframes for changes are detailed in this table.

Table 2. Parameters analysed in monthly and wet weather water samples taken in accordance with consenting requirements

Parameter	Units of Measurement
Total ammonia (ammoniacal nitrogen)	mg/L
Total arsenic*	mg/L
Biochemical Oxygen Demand (BOD_5)	mg/L
Conductivity	µS/cm
Total and dissolved copper	mg/L
Dissolved Oxygen (DO)	mg/L and % saturation
Enterococci	MPN/100ml
Escherichia coli	CFU/100ml
Total water hardness	g/m^3 as calcium carbonate
Total and dissolved lead	mg/L
Nitrate nitrogen	mg/L
Nitrite nitrogen	mg/L
Nitrate Nitrite Nitrogen (NNN)	mg/L
Dissolved Inorganic Nitrogen (DIN)	mg/L
pH	
Dissolved Reactive Phosphorus (DRP)	mg/L
Total Petroleum Hydrocarbons*	mg/L
Total phosphorus	mg/L
Total Suspended Solids (TSS)	mg/L
Water temperature	°C
Total nitrogen	mg/L
Turbidity	NTU
Total and dissolved zinc	mg/L

* Wet weather samples only

2.2 Stream Classifications for Guideline Levels

The classification of each waterway site with respect to the Environment Canterbury (ECan) Land and Water Regional Plan (LWRP; Environment Canterbury, 2017) and the Waimakariri River Regional Plan (WRRP; Environment Canterbury, 2011) are shown in Table 1. These classifications determine the relevant guideline levels for each of the measured parameters for the various sites.

The WRRP does not have guideline levels for a number of the parameters analysed in this report. It was considered most appropriate in these cases, given these sites are all within the Ōtūkaikino River catchment, that the LWRP 'spring-fed – plains' guidelines be used. The two stormwater basin sites (Halswell Retention Basin Inlet and Outlet) are not classified as waterways and therefore are not compared to receiving water guidelines in this report.

2.3 Water Quality Parameters and Guideline Levels

Metals, in particular, *copper*, *lead* and *zinc*, can be toxic to aquatic organisms, negatively affecting fecundity, maturation, respiration, physical structure and behaviour (Harding, 2005). The toxicity of metals in freshwater, and therefore the risk of adverse biological effects, alters depending on the hardness, pH and alkalinity of the water (ANZECC, 2000). Therefore, trigger levels should be calculated with consideration of water hardness (ANZECC, 2000). CCC has previously calculated Hardness Modified Trigger Values (HMTV) for metals that are monitored monthly (copper, lead and zinc), in accordance with ANZECC (2000) methodology (see Appendix B). These values are therefore used in this monitoring report.

pH is a measure of acidity or alkalinity, on a scale from 0 to 14; a pH value of seven is neutral, less than seven is acidic and greater than seven is alkaline. Appropriate pH levels are essential for the physiological functions of biota, such as respiration and excretion (Environment Canterbury, 2009). Aquatic species typically have tolerances for certain pH levels and alteration of pH can result in changes in the composition of fish and invertebrate communities, with generally a positive relationship between pH and the number of species present (Collier et al. 1990). The guidelines in the LWRP for all waterways are a lower limit of 6.5 and an upper limit of 8.5. The WRRP, which covers the Ōtūkaikino River catchment sites in this report, does not detail a guideline level.

Conductivity is a measure of how well water conducts an electrical current. Pure water has very low conductivity, but dissolved ions in the water (e.g. contaminants such as metals and nutrients) increase conductivity. Traditionally, conductivity has been compared to the guideline value of <175 μS/cm recommended by Biggs (1988) to avoid excessive periphyton growth. However, this guideline may be less relevant in urban waterways, where other contaminants that will not encourage periphyton growth may be contributing to high conductivity, such as metals. It is also noted that ECan do not consider this guideline value is useful, due to natural variations in levels (Abigail Bartram, ECan, personal communication 2013). They instead consider that analysis of trends is more useful, which is the approach adopted in this report.

Elevated levels of suspended sediment (*Total Suspended Solids*, TSS) in the water column decrease the clarity of the water and can adversely affect aquatic plants, invertebrates and fish (Crowe & Hay, 2004; Ryan, 1991). For example, sediment can affect photosynthesis of plants and therefore primary productivity within streams, interfere with feeding through the smothering of food supply, and can clog suitable habitat for species (Crowe & Hay, 2004; Ryan, 1991). The LWRP details in Rule 5.95 standards for TSS in stormwater prior to discharge, but does not detail specifically a guideline value within waterways (Environment Canterbury, 2017). The WRRP also does not detail a guideline level. A guideline level of 25 mg/L is considered an appropriate threshold to prevent detriment effects on biota (Hayward et al., 2009; Stevenson et al., 2010) and is therefore used in this report.

Turbidity is a measure of the transmission of light through water. Suspended matter in the water column causes light to be scattered or absorbed as is travels through the water. As for TSS, turbidity decreases the clarity of the water and can negatively affect stream biota (Ryan, 1991). A guideline level for this parameter is not provided in the LWRP or the WRRP. ANZECC (2000) provides a guideline of 5.6 Nephelometric Turbidity Units (NTU) for lowland rivers, which is used in this report.

Water clarity was used by the SLLT as a proxy for turbidity and TSS loads. ANZECC (2000) provides a guideline of 80 cm for lowland rivers.

Dissolved Oxygen (DO) is the concentration of oxygen dissolved or freely available in water and is commonly expressed as percent saturation. Adequate DO levels are essential for aquatic animals, such as fish and invertebrates, and can be influenced by many factors, including temperature, velocity, decomposition of organic material, and the photosynthesis and respiration of aquatic plants. The LWRP details a minimum DO level of 70% for 'spring-fed – plains' and 'spring-fed – plains – urban' waterways, and 90% for Banks Peninsula waterways (i.e. Cashmere Stream in this monitoring report). The WRRP details a minimum of 80% for the waterways relevant to this monitoring report (i.e. Ōtūkaikino River catchment).

High *water temperature* can affect aquatic biota, with some studies showing that the presence of sensitive macroinvertebrates decreases with increasing temperature (Wahl et al., 2013). The LWRP water quality standard for temperature is a maximum of 20°C for all waterway classifications; the WRRP details a maximum of 25°C for the waterways relevant to this monitoring report (i.e. Ōtūkaikino River catchment).

Biochemical Oxygen Demand (BOD_5) is an indicator of the amount of biodegradable organic material in the water and the amount of oxygen required by bacteria to break down this material. High BOD_5 values are due to plant matter, nitrogen and phosphorus, and indicate the potential for bacteria to deplete oxygen levels in the water. The LWRP does not have a guideline level for this parameter. The WRRP and the Ministry for the Environment (1992) guideline level is 2 mg/L, which is the value used in this report. However, this guideline value is conservative as the presented data relates to total BOD5.

Total ammonia (ammoniacal nitrogen) is typically a minor component of the nitrogen available for plant growth, but at high levels can have toxic effects on aquatic ecosystems. The toxicity of ammonia varies with pH (ANZECC, 2000). Therefore, the LWRP water quality standards also vary depending on pH, ranging from 2.57 mg/L at pH 6 to 0.18 mg/L at pH 9 (Environment Canterbury, 2017). For this report, the water quality standard (for both monthly and wet weather sampling) was adjusted based on the median pH levels from monthly sampling for the relevant catchments. The exception to this is for Banks Peninsula waterways (i.e. Cashmere Stream in this monitoring report), that have a set guideline value regardless of pH (0.32 mg/L). The WRRP does not have a guideline level.

Nitrate can be toxic to stream biota at high concentrations (Hickey, 2013). Guidelines are available for different species protection levels: 99% (pristine environment with high biodiversity and conservation values), 95% (environments which are subject to a range of disturbances from human activities, but with minor effects), 90% (environments which have naturally seasonally elevated concentrations for significant periods of the year (1-3 months)), 80% (environments which are measurably degraded and which have seasonally elevated concentrations for significant periods of the year (1-3 months)), and acute (environments which are significantly degraded; probable chronic effects on multiple species) (Hickey, 2013). Based on these descriptions and the predominantly urban nature of the waterways monitored, most of the waterways in this report would fall under the 80% to acute species description (i.e. Ōtākaro/ Avon, Ōpāwaho/ Heathcote and Huritini/ Halswell River catchments). However, the Pūharakekenui/ Styx and Ōtūkaikino River catchments (and Cashmere Stream) likely fall under the 90% species protection; these catchments have much better water quality, but exceed some of the receiving water quality guidelines throughout the year. To be conservative, the 90% species protection was chosen as the guideline level for all waterways in this report. Within this 90% level of species protection there are two guideline values: the ‘grading’ guideline (3.8 mg N/L) that provides for ecosystem protection for average long-term exposure (measured against medians) and the ‘surveillance’ guideline (5.6 mg N/L) that assesses seasonal maximum concentrations (measured against annual 95^{th} percentiles). Both guideline levels have been assessed in this report to investigate both long-term and short-term effects. It is also noted that Schedule 8 (region-wide water quality limits) of ECan's LWRP gives a nitrate toxicity limit for lowland streams of 3.8 mg N/L (measured against annual median).

Elevated concentrations of *Nitrate and Nitrite Nitrogen* (NNN) can lead to proliferation of algae and aquatic plants (i.e., eutrophication), because nitrate and nitrite are oxidised forms of nitrogen that are readily available to plants. Eutrophication occurs at much lower nitrate concentrations than toxicity. The LWRP and the WRRP do not have a guideline value for this parameter, but the ANZECC (2000) water quality guidelines provide a trigger value of 0.444 mg/L for lowland rivers to avoid excessive plant growth. Note that this guideline is based on the 80th percentile of measurements from three lowland reference sites, so it is not "effects-based". Rather, compliance with the guideline indicates the risk of eutrophication is relatively low. Compliance with NNN guidelines will also protect against nitrate toxicity.

Dissolved Inorganic Nitrogen (DIN), which is the sum of ammonia, nitrite and nitrate, provides a similar measure of eutrophication risk to NNN. The LWRP details a DIN value of 1.5 mg/L for 'spring-fed – plains' and 'spring-fed – plains – urban' waterways, and 0.09 mg/L for Banks Peninsula waterways. The DIN guideline of 1.5 mg/L is based on the median of Canterbury Spring-fed plains streams, whereas the 0.09 mg/L guideline is derived from the New Zealand Periphyton Guideline, based on flow data from Canterbury streams (Biggs, 2000; Hayward et al., 2009). There is no DIN guideline value in the WRRP.

Dissolved Reactive Phosphorus (DRP) is a soluble form of phosphorus that is readily available for use by plants. Phosphorus is an essential nutrient for plant growth and can limit primary production at low levels, but can cause eutrophication at high levels. The guideline levels in the LWRP for 'spring-fed - plains' and 'spring-fed – plains – urban' waterways are 0.016 mg/L, and 0.025 mg/L for Banks Peninsula waterways. There is no guideline value for this parameter in the WRRP.

Escherichia coli is a bacterium that is commonly used as an indicator of faecal contamination in freshwater and therefore health risk from contact recreation (Ministry for the Environment, 2003). The guideline level in the LWRP for 'spring-fed – plains', 'spring-fed – plains – urban' and Banks Peninsula waterways is 550 *E. coli* per 100ml (for 95% of samples). The WRRP does not have a guideline value for this parameter.

Total petroleum hydrocarbon (TPH) is the term used to describe a wide variety of chemical compounds that are found in oil and petroleum-based products. Some of the hydrocarbons found in petroleum products are toxic to aquatic life. In addition, hydrocarbons are broken down by microbial activity that then reduces oxygen levels in the water, which can also be harmful to sensitive fish and invertebrate species (ANZECC 2000). There are no guidelines for TPH in New Zealand freshwaters.

2.4 Data Analysis

2.4.1 Summary Statistics and Graphs

Boxplots (for monthly data) were produced using the program R (Version 3.5.2). To allow statistical analyses of monthly samples, values less than the LOD were converted to half the detection limit. In some years, monthly *E.coli* levels exceeded the maximum laboratory limit for counting (24,000 CFU/100ml) and were analysed as 24,000, although levels may have been much higher than this. There were three such *E. coli* cases during the 2018 monitoring year.

The dark lines in the boxes of the boxplots represent the medians, and the bottom and top lines of the boxes represent the 25th and 75th percentiles (the interquartile range), respectively. The T-bars that extend from the boxes approximate the location of 90% of the data (i.e. the 5th and 95th percentiles, HAZEN methodology). Circles represent outliers. In some cases, boxplots do not show all components, such as the percentiles, due to a lack of variation in the data, with some showing only the medians. This usually occurred where a large proportion of the data were below the laboratory limit of detection.

In line with the respective guideline documents and ECan guidance (Dr Lesley Bolton-Ritchie, Environment Canterbury, 6th April 2016, personal communication), the monthly data were compared to guideline levels using median levels. The exceptions being for *E. coli*, toxicants (metals and ammonia) and the 'surveillance' nitrate level, which were compared to the 95th percentiles.

2.4.2 Temporal Trends Analysis

Temporal trends analysis was carried out on the monthly data from each of the sites, to determine whether water quality is declining, improving or staying the same over time. Some of the sites have been monitored for longer periods than others, as detailed in Appendix C, Table i. Dissolved metals have only been analysed since 2011, with total metals sampled prior to this. Dissolved metals are now considered to be more relevant because they constitute the bio-available proportion of metals that can have adverse effects on biota (ANZECC, 2000). The guidelines also essentially pertain to dissolved metal concentrations, not total metals. As NNN is predominantly comprised of nitrate, trends analysis was also only conducted on NNN and not nitrate as well.

Trends analysis was conducted using Time Trends V 6.3, build 12 (NIWA, 2014). The Seasonal Kendall trend test was used to test the significance, magnitude and direction of the trends, providing an average annual percentage change. This software requires three years of data and all CCC sites met this requirement. However, when a large proportion of data is below the LOD (e.g. dissolved copper and lead) or missing (e.g. missing SLLT data in some years) these analyses may be less accurate. SLLT monitoring included three new sites in 2018: Kā Pūtahi Creek at Blakes Road, Styx Drain at Redbrook Road and Smacks Creek at Wilkinsons Road, therefore, there was insufficient data to run trends analysis.

Concentrations of parameters may vary depending on flow rates at the time of sampling, due to variations in the level of dilution. Therefore, flow-adjusted data can be used in the Time Trends software to account for this potentially confounding factor. Flow adjustment was only undertaken at the one site where a flow recorder was directly present (Heathcote River at Ferniehurst Street). It is considered that extrapolation of this flow data to other locations, as well as the use of other flow gauges in Christchurch not directly at the monitoring sites, may bias the results through differences in habitat and additional discharge inputs. This may lead to inaccurate trend conclusions. For the sites where flow at the time of sampling is unknown, given the long period of monitoring, it is considered that variations in flow rates between sampling events will not strongly influence the trends analysis, as most events will have been conducted during baseflow conditions.

Data for the Heathcote River at Ferniehurst Street site were adjusted in Time Trends by the flow (m^3/s) for the period 24-hours prior to sampling, using the Locally Weighted Scatterplot Smoothing (LOWESS) method.

2.4.1 Water Quality Index

A Water Quality Index (WQI) was developed for the CCC monthly monitoring sites, based on a Canadian WQI (CCME; Canadian Council of Ministers for the Environment, 2001). This index uses three factors to assess water quality: scope (the percentage of parameters not meeting the guideline on at least one occasion); frequency (the percentage of samples that did not meet the guideline); and amplitude (the amount by which the guideline was not met). The WQI ranges from 0 – 100, with 100 representing high water quality. The user can choose which parameters to include and what guideline levels are appropriate to their system.

The parameters used in the CCC WQI were copper, zinc, pH, TSS, DO, temperature, BOD_5, total ammonia, NNN, DRP and *E. coli*. WQI scores were used to categorise the CCC sites as being 'very poor' (0 – 39.9), 'poor' (40 – 69.99), 'fair' (70 – 79.9), 'good' (80 – 89.9) or 'very good (90 – 100). The categories were selected based on local knowledge of water quality compared to other waterways nationally. These categorise Christchurch City waterways as expected. The WQI index was calculated for every year from 2013, to allow comparisons over time.

Auckland Council (Holland, *et al* 2016) and ECan (Robinson & Stevenson, 2016) have also adapted this CCME WQI index for their own purposes. However, because the parameters used to calculate these indices and/or their categories are different, these indices cannot be compared.

To test for significant relationships in WQI between catchments and years, statistical models were run in the program R (Version 3.5.1). Generalised Linear Mixed Effects Models with a binomial error structure and logit link function were used (Crawley, 2007), with the following combinations of fixed effects: (1) a null model with intercept only; (2) a model that considered 'year'; (3) a model that considered 'catchment'; and (4) a model that considered the interaction between 'year' and 'catchment'. 'Year' was also included in each model as a random effect to account for temporal autocorrelation (repeated measures). 'Site' was also included as an observational level random effect, due to the models exhibiting overdispersion (Harrison, 2014; Harrison, 2015). Boxplots of WQI across years was also graphed in R for each catchment (see the explanation of how to interpret boxplots in the Summary Statistics and Graphs section).

Temporal trends analysis was carried out on the WQI at each site, to determine whether overall water quality is declining, improving or staying the same over time. Analysis was undertaken on data collected from 2013- 2018 inclusive. Trends analysis was conducted using Time Trends (NIWA, 2014). The Seasonal Kendall trend test was used to test the significance, magnitude and direction of the trends, providing an average annual percentage change. This software requires three years of data and all sites met this requirement.

3 Results: Monthly Monitoring

3.1 Rainfall

- Daily rainfall has been collected at the Christchurch Botanic Gardens by the CCC since the early 1960's.
- 2015 and 2016 were dry years, while 2017 and 2018 were much wetter (rolling weekly average of the previous 52 weeks; Figure 2).
- For the 2018 monitoring year (for the CCC monthly data only) the Ōtūkaikino and Pūharakekenui/ Styx River catchments recorded the most number of sampling days affected by rain (50% each), followed by the Ōpāwaho/ Heathcote River, Huritini/ Halswell River and Linwood Canal catchments (33% each), and the Ōtākaro/ Avon River catchment (29%). This was based on observations of the water quality samplers as to whether it had rained within 24 hours of sampling.

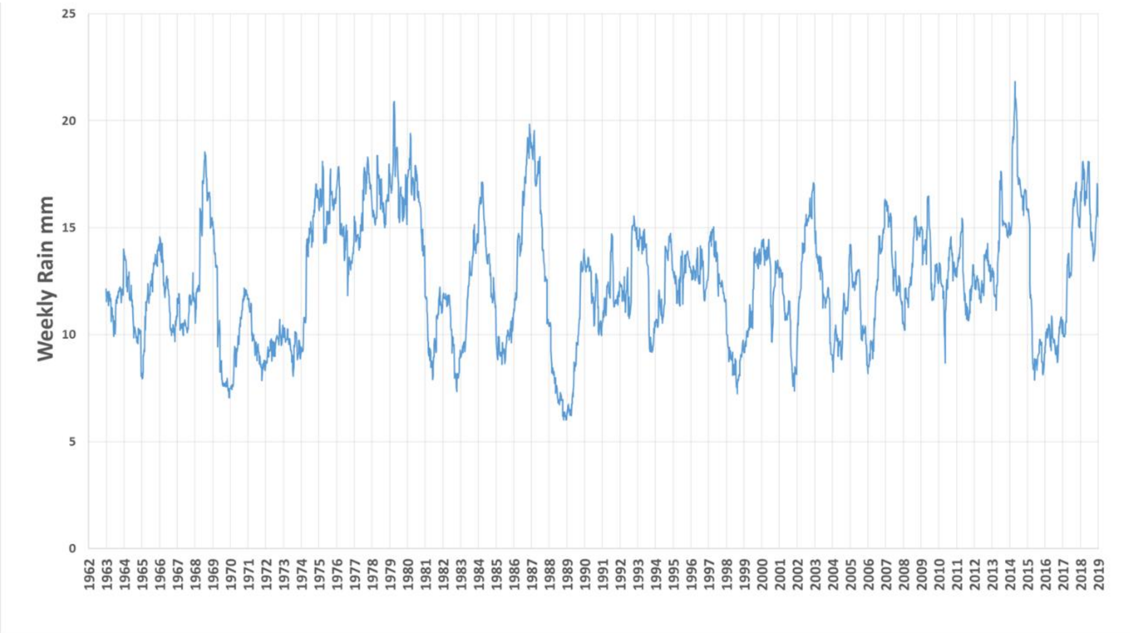

Figure 2. Average weekly rainfall at the Botanic Gardens in Hagley Park

3.2 Water Quality Parameters

- Over 11,000 tests were conducted during the monitoring year for the CCC monthly monitoring, with 7,500 of these allowing the assessment of each waterway site against relevant guideline levels (Table 3). Twenty-two percent of these samples did not meet the guideline level, with 42 sites (100%) not meeting the guideline for at least one parameter.
- The NNN guideline was exceeded most frequently (82% of samples and 35 sites), followed by DRP (64% of samples and 27 sites) and DIN (45% of samples and 20 sites).
- The majority of parameters did not change in concentration since monitoring began (as detailed in Table i in Appendix C), with 383 (59%) parameter-site combinations

recording no significant upwards or downwards trends in concentrations (Tables 4a to 4d). However, 70 (11%) parameter-site combinations recorded a significant decline in water quality, 172 (26%) recorded a significant improvement in water quality, and 28 (4%) recorded a significant change that could represent either a decline or improvement in water quality (pH).

- The largest increase in parameter concentrations were:
  - 25% rise in NNN and 23% increase in DIN at the Ōtūkaikino Creek at Omaka Scout Camp site (Figures 3 – 4)
- The largest decreases in parameter concentrations were:
  - 44% reduction in BOD_5 at Knights Stream (Figure 5)
  - 37% reduction in total ammonia and dissolved lead at the Halswell Retention Basin Outlet (Figures 6 - 7)
  - 28% reduction in BOD_5 at Nottingham Stream and Cashmere Stream at Sutherlands Road (Figure 8)

3.2.1 Dissolved Copper

- 95th percentiles of all sites complied with their respective guidelines, with the exception of Avon River at Avondale Road Bridge, both Curletts Road Stream sites, Kā Pūtahi Creek at Belfast Road, Styx River at Marshland Road Bridge and Wilsons Stream (Appendix D, Figure i (a) – (b)).
- No sites other than those listed above recorded individual samples exceeding the guidelines.
- Of the three highest values recorded (0.014 mg/L, 0.011 mg/L (two occasions) and 0.0106 mg/L), all were from the two Curletts Road Stream sites and two were associated with rain. The highest level was not associated with rain.
- The Halswell Retention Basin sites recorded levels generally higher than the waterway sites, with the exception of the Curletts Road Stream at Motorway site. Levels were more variable and higher at the inlet compared to the outlet.
- No site recorded much lower copper concentrations compared to the 2017 monitoring year. Curletts Road Stream at Motorway and Halswell Retention Basin Inlet sites showed higher concentrations compared to the last monitoring year.
- Concentrations have remained stable (lack of significant trends) since regular monitoring of dissolved metals was instigated, except for the Curletts Road Stream Upstream of Heathcote River site where a 13% decrease was recorded (Tables 4 (a) – (d)).

3.2.2 Dissolved Lead

- All site samples complied with their respective guidelines (Appendix D, Figure ii (a) – (b)).
- The three highest values were at Avon River at Bridge Street (0.0052 mg/L), Styx River at Gardiners Road (0.0033 mg/L) and Linwood Canal (0.0032 mg/L). The first and the third highest values were associated with rain.
- Concentrations remained stable over time at all sites except Halswell Retention Basin Outlet which recorded a 37% reduction (Tables 4 (a) – (d)).

3.2.3 Dissolved Zinc

- 95th percentiles for most sites in the Ōtākaro/ Avon, about half of the sites in the Ōpāwaho/ Heathcote and Pūharakekenui/ Styx catchments, as well as Wilsons

Stream, Nottingham Stream and Linwood Canal all exceeded their respective guideline levels (Appendix D, Figure iii (a) – (b)). Note that this is substantially more exceedances this year compared to 2017.
- The three highest values (0.51 mg/L, 0.38 mg/L and 0.31 mg/L) were from the Curletts Road Stream at Motorway site and only the second highest was not associated with rain.
- Levels in the Halswell Retention Basin sites were higher than the waterway sites, with the exception of Haytons Stream, Curletts Stream, and the Heathcote River at Rose Street. Outlet concentrations were lower than the inlet.
- Zinc levels in the Pūharakekenui/ Styx and Ōtūkaikino River catchments were generally lower than the other catchments, however still exceeded their respective guideline levels which are lower compared to the Ōpāwaho/ Heathcote and Ōtākaro/ Avon catchments.
- The upper tributaries of the Ōpāwaho/ Heathcote River, which have industrial land use, typically had higher concentrations than the lower reaches.
- The Haytons Stream site recorded generally lower zinc concentrations this year compared to the 2017 monitoring year, while Linwood Canal recorded higher.
- Concentrations have generally remained stable since sampling was instigated (Tables 4 (a) – (d)). A few sites showed large decreases: Wairarapa Stream (15%), Avon River at Pages/Seaview Bridge (10%), Styx River at Gardiners Road (12%), Smacks Creek at Gardiners Road (17%) and Ōtūkaikino River at Groynes Inlet (16%). However, large increases were recorded at Curletts Stream at Motorway (21%) and Heathcote River at Ferrymead Bridge (16%).

3.2.4 pH

- Medians of all CCC and SLLT sites complied with the guideline levels (Appendix D, Figure iv (a) – (c)).
- For the CCC sites, exceedances of the lower guideline in individual samples were recorded once each at six of the eight sites in the Styx catchment and two in the Ōtūkaikino in April. On two occasions the upper guideline was exceeded at the Halswell Retention Basin Inlet and on four occasions at the Retention Basin Outlet.
- No waterway site exceeded the upper guideline. The three highest values were all from the Halswell Retention Basin Outlet (pH of 9.7, 9.4 and 9.3), with the second highest value the only one associated with rain. All of the lower guideline exceedances ranged from pH 6.0 – 6.4, were recorded in April and not in association with rain.
- None of the SLLT sites had individual recordings that breached either guideline.
- The Halswell Retention Basin sites recorded higher pH than the waterway sites. Levels were much higher at the outlet than the inlet, with many outlet samples breaching the upper guideline of 8.5.
- Lower guideline level exceedances in the Styx and Ōtūkaikino catchments were not present in 2017.
- Concentrations did not change over time by any large degree (Tables 4 (a) – (e)).

3.2.5 Conductivity

- No relevant guidelines exist for conductivity.
- The tidal sites had greater conductivity and variability in these values than non-tidal sites, due to saline influence (Appendix D, Figure v (a) – (c)).

- Addington Brook and both Curletts Road Stream sites had more variability and higher concentrations compared to other non-tidal sites, indicating pollution sources.
- Both Halswell Retention Basin sites had levels comparable to the waterway sites, and levels were lower at the outlet.
- Conductivity at the SLLT sites were similar to the CCC waterway sites.
- Concentrations generally did not change over time by any large degree, except for increases at the Linwood Canal (10%), Avon River at Bridge Street (8%), Avon River at Pages/Seaview Bridge (7%) and Ōtūkaikino River at Omaka Scout Camp (6%) (Tables 4 (a) – (e)). All sites except Ōtūkaikino River at Omaka Scout Camp are tidal sites.

3.2.6 TSS

- Medians of all waterway sites complied with the guideline level, with the exception of Heathcote River at Tunnel Road and Heathcote River at Ferrymead Bridge (Appendix D, Figure vi (a) – (b)).
- Many sites in the Ōtākaro/Avon and Ōpāwaho/ Heathcote River catchments, two sites in the Pūharakekenui/Styx catchment (Styx River at Marshland Road Bridge and Styx River at Richards Bridge) and the Linwood Canal site recorded samples above the guideline level.
- The three highest TSS values were recorded from the Ōpāwaho/ Heathcote catchment in association with either major instream works or aquatic weed clearing: Heathcote River at Mackenzie Avenue (2,700 mg/L, major instream works), Heathcote River at Templetons Road (450 mg/L, aquatic weed clearing) and Heathcote River at Catherine Street (220 mg/L, instream works) with only the second highest value not recorded in association with rain.
- The Halswell Retention Basin Inlet generally recorded levels higher than the waterway sites. Levels were lower at the outlet than the inlet.
- Higher TSS was recorded in the lower, tidal sites of the Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments, potentially due to resuspension of the naturally softer substrate at these locations compared to non-tidal sites.
- Compared to 2017, the Ōtākaro/ Avon catchment generally recorded higher one-off values. In addition, Curletts Road Stream at Motorway, Styx River at Marshland Road and Styx River at Richards Bridge had much higher concentrations this year.
- Three sites recorded a substantial decrease in concentrations over time (Tables 4 (a) – (d)): Avon River at Dallington Terrace (20%), Curletts Road Stream Upstream of Heathcote River (16%), Halswell Retention Basin Outlet (17%).

3.2.7 Turbidity

- The medians of the following sites exceeded the guideline: Addington Brook, Horseshoe Lake Discharge, Avon River at Bridge Street, Haytons Stream, Cashmere Stream at Worsleys Road, Heathcote River at Ferniehurst Street, Heathcote River at Bowenvale Avenue, Heathcote River at Opawa Road/Clarendon Terrace, Heathcote River at Tunnel Road and Heathcote River at Ferrymead Bridge (Appendix D, Figure vii (a) – (b)).
- A number of other sites also had individual samples that exceeded the guideline.
- The three highest turbidity readings were recorded from the Ōpāwaho/ Heathcote catchment: Heathcote River at Templetons Road (200 NTU), Heathcote River at Tunnel Road (63 NTU) and Curletts Road Stream Upstream of Heathcote River (60 NTU). None of these recordings were associated with rain. The two highest turbidity

readings were recorded in association with either upstream aquatic weed clearance (Heathcote River at Templetons Road) or major instream earthworks (Heathcote River at Tunnel Road).

- Turbidity was often higher in the Ōtākaro/ Avon River tributaries than the mainstem. The bottom two Ōpāwaho/ Heathcote River tidal sites recorded much higher and variable turbidity than the other catchment sites.
- The Ōpāwaho/ Heathcote River catchment, followed by the Ōtākaro/ Avon River catchment, generally recorded higher turbidity levels compared to the other catchments.
- Compared to 2017, the Ōtākaro/ Avon catchment generally recorded higher one-off values, while the Ōpāwaho/ Heathcote catchment has recorded generally lower.
- Large decreases over time were recorded at Ōtūkaikino River at Groynes Inlet (13%) and Curletts Road Stream Upstream of Heathcote River (11% decrease) (Tables 4 (a) – (d)).

3.2.1 Water Clarity (SLLT sites only)

- The medians of all sites did not comply with the guidelines, except for Styx River at Styx Mill Conservation Reserve and Styx River at Brooklands (Appendix D, Figure viii).
- The three worst values recorded were from Kā Pūtahi Creek at Ouruhia Domain (41 cm), Kā Pūtahi Creek at Everglades Golf Course (50 cm) and Styx River at Radcliffe Road (51 cm).
- Water clarity was similar across sites, and between the mainstem and tributaries.
- No substantial changes in levels were recorded over time (Table 4 (e)).

3.2.2 DO

- Medians of the following sites did not meet the guideline: Horseshoe Lake Discharge, Heathcote River at Templetons Road, both Curletts Road Stream sites, both Cashmere Stream sites, Styx River at Gardeners Road, Smacks Creek at Gardiners Road and Linwood Canal (Appendix D, Figure ix (a) – (b)).
- Many other sites had individual samples that did not meet the guideline.
- The three lowest readings were 24% (Curletts Road Stream Upstream of Heathcote River; associated with rain), 25% (Curletts Road Stream at Motorway; not associated with rain) and 26% (Curletts Road Stream Upstream of Heathcote River; not associated with rain).
- DO levels were generally higher at the Halswell Retention Basin Outlet than the Inlet, and fairly comparable to the waterway sites.
- Dissolved oxygen levels were lower in the Ōpāwaho/ Heathcote catchment, particularly at the upstream sites.
- The Linwood Canal site recorded higher DO concentrations during the monitoring year compared to 2017.
- Levels did not change over time by any large degree (Tables 4 (a) – (d)).

3.2.3 Water Temperature

- Medians of all CCC and SLLT sites complied with their respective guidelines (Appendix D, Figure x (a) – (c)).
- However, individual samples for the CCC sites exceeded this guideline at the three most downstream sites in the Ōtākaro/ Avon catchment, Haytons Stream, Curletts

Road Stream at Motorway, Heathcote River at Ferrymead Bridge, Styx River at Harbour Road Bridge and in Linwood Canal. The SLLT Kā Pūtahi Creek at Ouruhia Domain and Kā Pūtahi Creek at Everglades Golf Course sites also exceeded the guideline on one occasion each.

- The three highest readings were recorded from the Halswell Retention Basin Outlet (25.2 °C), Halswell Retention Basin Inlet (25 °C) and Linwood Canal (23.2 °C).
- The inlet and the outlet of the Halswell Retention Basin recorded similar levels. These two sites recorded higher and more variable temperatures than the waterway sites, with the exception of Linwood Canal.
- Water temperature was generally more variable in the downstream reaches of the catchments.
- The SLLT sites typically recorded similar temperatures to the CCC sites, although levels were higher at the SLLT Kā Pūtahi Creek sites.
- Levels did not change over time by any large degree (Tables 4 (a) – (e)).

3.2.4 BOD_5

- Medians of all sites complied with the guideline, with the exception of Curletts Road Stream at Motorway (Appendix D, Figure xi (a) – (b)).
- However, a number of individual samples exceeded the guideline, particularly in the Ōpāwaho/ Heathcote River catchment.
- The highest values recorded were 8 mg/L at the Haytons Stream site (associated with rain), 7.3 mg/L at the Heathcote River at Templetons Road site (not associated with rain) and 6.8 mg/L at Curletts Road Stream at Motorway (not associated with rain).
- Levels in the Halswell Retention Basin sites were generally higher than the waterway sites and levels were lower at the outlet.
- Levels were typically higher in the Ōpāwaho/ Heathcote River catchment.
- Compared to 2017, a marked reduction in BOD_5 was recorded this monitoring year at the Kā Pūtahi Creek at Blakes Road site, while levels in Haytons Stream were generally lower. However, higher concentrations were generally recorded in the Ōtākaro/ Avon, Pūharakekenui/ Styx and Ōtūkaikino catchments, at Curletts Road Stream at Motorway and Heathcote River at Ferrymead Bridge in 2018 compared to 2017.
- Most sites across all catchments recorded large decreases in BOD_5 since sampling was instigated, however two sites recorded significant increases (Heathcote River at Templetons Road and Heathcote River at Ferniehurst Street) (Tables 4 (a) – (d)).

3.2.5 Total Ammonia

- 95^{th} percentiles of all sites complied with their respective guidelines and no individual samples exceeded the guidelines either (Appendix D, Figure xii (a) – (b)).
- The highest level of 1.5 mg/L was recorded from Kā Pūtahi Creek at Blakes Road (1.5 mg/L on two occasions, one in association with rain), the second highest was from the Halswell Retention Basin Inlet (0.93 mg/L, associated with rain) and the third was from the Halswell Retention Basin Outlet (0.61 mg/L, not associated with rain).
- Both Halswell Retention Basin sites generally recorded values higher than the waterway sites, and levels were lower at the outlet.
- Ammonia was generally higher in the tributaries compared to mainstems.

- Kā Pūtahi Creek at Blakes Road showed lower levels of ammonia this monitoring year compared to last monitoring year.
- Over half of sites remained stable over time (Tables 4 (a) – (d)). The following sites recorded large decreases in concentrations: Halswell Retention Basin Outlet (37%), Halswell Retention Basin Inlet (21%), Heathcote River at Ferrymead Bridge (14%), Ōtūkaikino River at Groynes Inlet (12%) and Heathcote River at Tunnel Road (10%). Wilsons Stream recorded a significant increase of 12%.

3.2.6 Nitrate, NNN and DIN

- All waterway sites complied with the nitrate guidelines, except for Knights Stream where the median exceeded the grading guideline (Appendix D, Figure xiii (a) – (b)), most sites did not comply with the NNN guideline (Appendix D, Figure xiv (a) – (b)) and nearly half of sites did not comply with their respective DIN guideline (Appendix D, Figure xv (a) – (b)).
- Knights Stream recorded much higher levels of nitrogen than the other sites, with the three highest exceedances of nitrate, NNN and DIN (4.6 mg/L, 4.4 mg/L (two samples) and 4.2 mg/L (two samples) for all three parameters) all from this site. Only one record was associated with rain (4.4 mg/L).
- Both Halswell Retention Basin sites recorded levels comparable to the waterway sites. Levels were generally slightly lower at the outlet, which is the opposite of 2017.
- All three parameters typically decreased downstream in the mainstem, and were lower in the Pūharakekenui/ Styx, Ōtūkaikino and Linwood Canal catchments.
- Compared to last monitoring year, an increase in nitrate was recorded at the Waimairi Stream, Avon River at Mona Vale, Avon River at Carlton Mill Corner and all Halswell catchment sites. DIN concentrations were lower at the Kā Pūtahi Creek at Blakes Road site this monitoring year compared to last.
- NNN and DIN concentrations of all three parameters generally remained stable or decreased over time (Tables 4 (a) – (d)). Large decreases were recorded at Haytons Stream at Retention Basin (NNN = 13%, DIN = 12%), Curletts Road Stream at Motorway (NNN = 23%, DIN = 21%), Halswell Retention Basin Outlet (DIN = 15%), Halswell Retention Basin Inlet (DIN = 11%) and Linwood Canal (NNN = 10%). An increase in NNN (25%) and DIN (23%) was recorded at Ōtūkaikino River at Omaka Scout Camp.

3.2.7 DRP

- Over half of sites did not comply with their respective guidelines (Appendix D, Figure xvi (a) – (b)).
- Particularly high levels were recorded in Haytons Stream.
- The two highest values (0.65 mg/L and 0.49 mg/L) were from Haytons Stream, while the third highest (0.47 mg/L) was from Wilsons Stream. Only the Wilsons Stream value was associated with rain.
- The Halswell Retention Basin sites were within the higher range of the waterway sites, and concentrations were lower at the outlet.
- DRP generally increased downstream.
- Haytons Stream recorded markedly lower concentrations this year compared to the 2017 monitoring year.

- The majority of sites recorded a decrease in DRP concentrations since monitoring began (Tables 4 (a) – (d)). The largest decreases were from Cashmere Stream at Sutherlands Road (20%), Halswell Retention Basin Outlet (15%), Heathcote River at Ferrymead Bridge (14%), Heathcote River at Templetons Road (12%), Wairarapa Stream (11%), Avon River at Mona Vale (11%), Haytons Stream at Retention Basin (11%), Waimairi Stream (10%), Avon River at Carlton Mill Corner (10%). No site increased in concentration.

3.2.8 *E. coli*

- Cashmere Stream at Sutherlands Road was the only site that complied with the guideline (Appendix D, Figure xvii (a) – (b)).
- The highest value (>24,000 CFU/100ml) was from Riccarton Main Drain, Addington Brook and Wilsons Stream. The next two highest record of 24,000 CFU/100ml was from Kā Pūtahi Creek at Belfast Road while the third highest (20,000 CFU/100ml) was from the Avon River at Manchester Road site. All of these records were associated with rain. The highest record from the Riccarton Main Drain site (>24,000 CFU/100ml) was associated with a recorded wastewater overflow event.
- The peak record from Dudley Creek (5,500 CFU/100 ml) could have been associated with a wastewater overflow event. The overflow began at 9:30 at 70 Thames Street (5.25 hours duration) and the sample was taken 2.8 km downstream at 9:35. No velocity data were available, however flow at the sampling site was 1.92 m^3/s.
- The Halswell Retention Basin sites were within the range of that recorded at the waterway sites, and the outlet concentrations were generally lower than the inlet.
- Levels were generally higher in the Ōpāwaho/ Heathcote and Huritini/ Halswell catchments.
- Generally, there were higher, one-off values recorded at sites this year compared to last monitoring year.
- Concentrations generally remained stable over time (Tables 4 (a) – (d)). The largest changes were recorded at Curletts Road Stream Upstream of Heathcote River (9% decrease) and Halswell River at Akaroa Highway (9% increase).

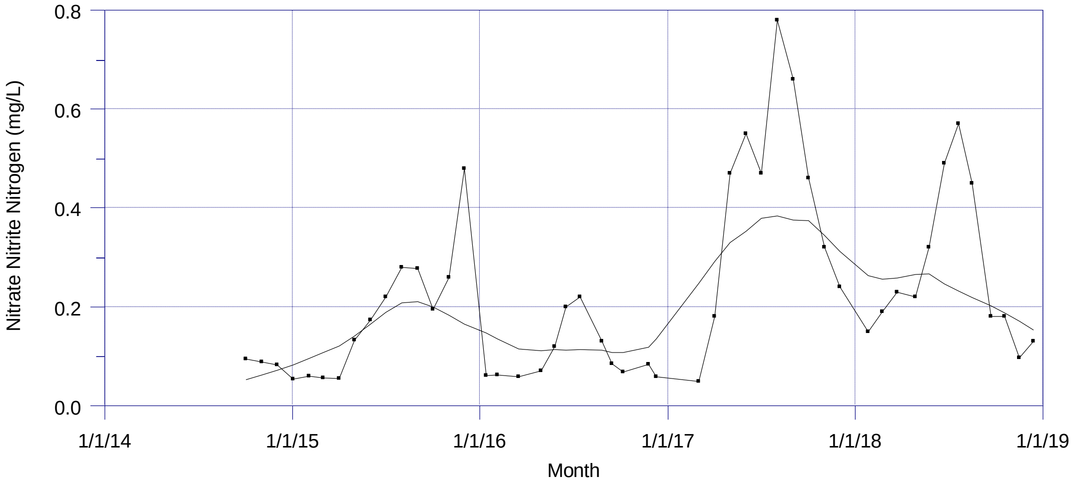

Figure 3. NNN levels at the Ōtūkaikino Creek at Omaka Scout Camp site for the monitoring period October 2014 to December 2018. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A positive (i.e. increasing) trend of 25% was recorded over the sampling period.

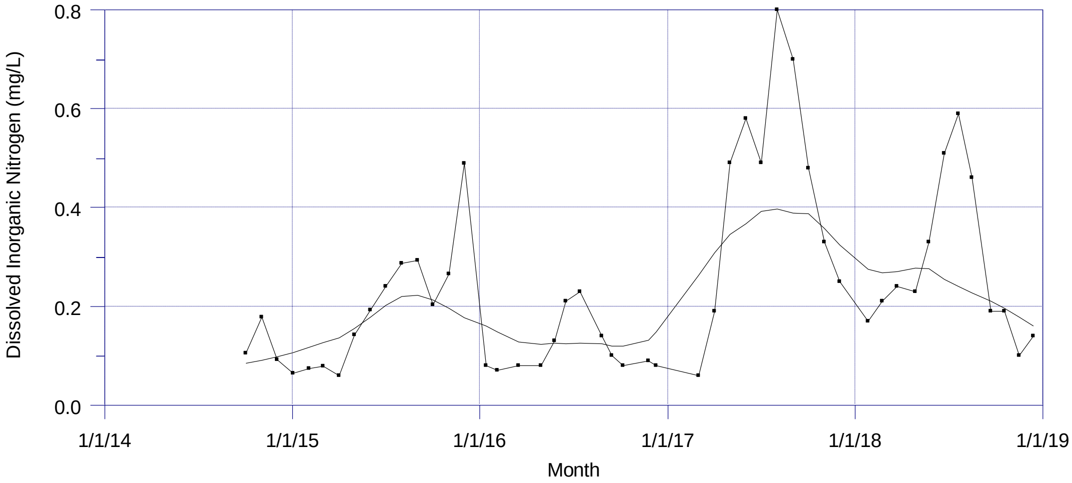

Figure 4. DIN levels at the Ōtūkaikino Creek at Omaka Scout Camp site for the monitoring period October 2014 to December 2018. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A positive (i.e. increasing) trend of 23% was recorded over the sampling period.

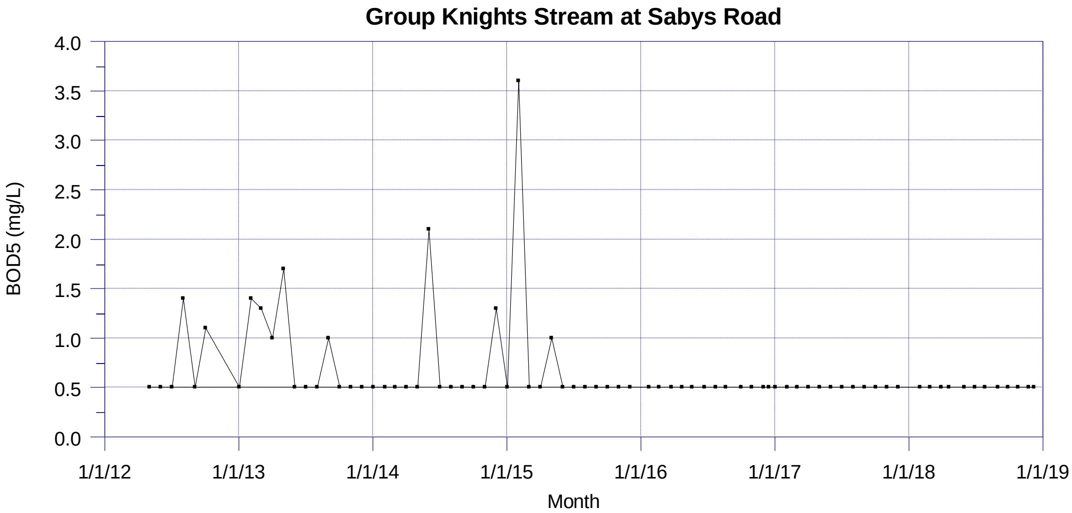

Figure 5. BOD_5 levels at the Knights Stream site for the monitoring period May 2012 to December 2018. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 44% was recorded over the sampling period.

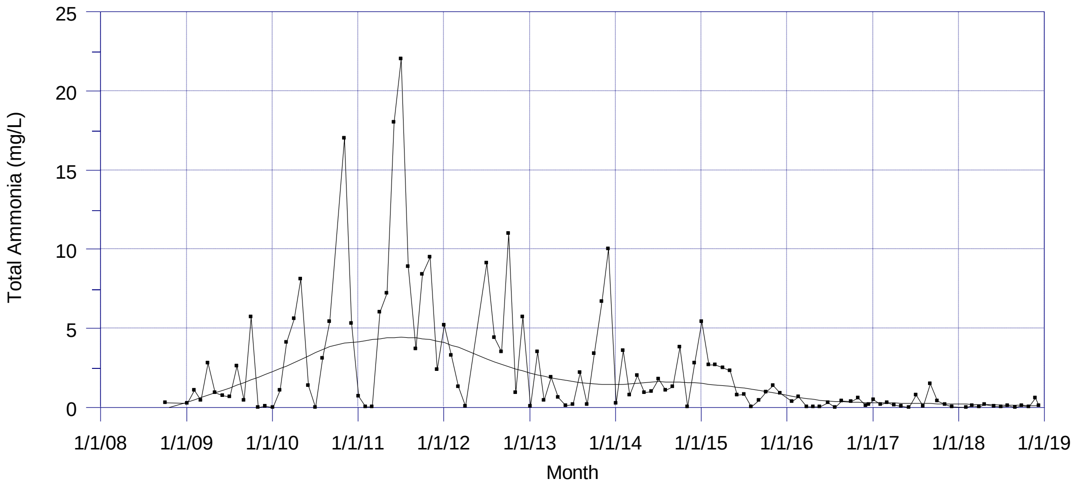

Figure 6. Total ammonia levels at the Halswell Retention Basin Outlet site for the monitoring period May 2012 to December 2018. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 37% was recorded over the sampling period.

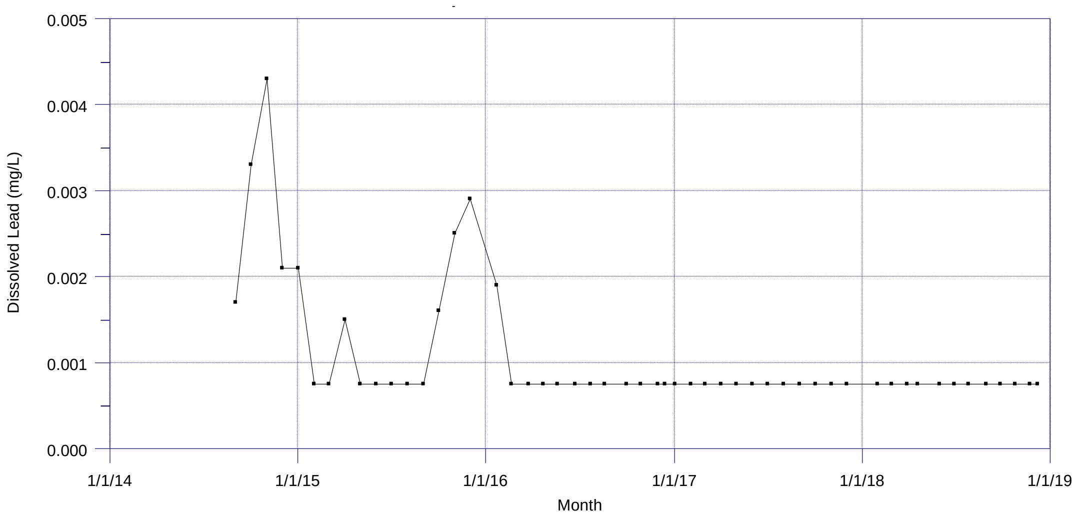

Figure 7. Dissolved lead levels at the Halswell Retention Basin Outlet site for the monitoring period September 2014 to December 2018. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 37% was recorded over the sampling period.

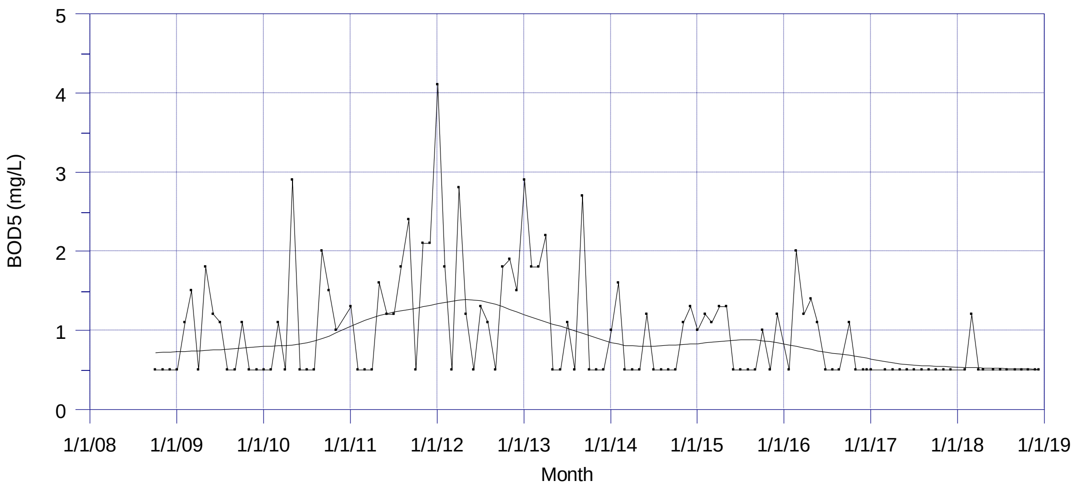

Figure 8. BOD_5 levels at the Nottingham Stream site for the monitoring period May 2012 to December 2018. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 28% was recorded over the sampling period.

Table 3. Number of waterway sites monitored for each parameter (where guideline levels are available), the number of samples analysed and the number of samples and sites (based on medians/95th percentiles, depending on the parameter) not meeting the guideline levels, during the monitoring period of January to December 2018.

Parameter	Guideline	Number of Sites Monitored	Number of Samples Analysed	Number of Samples Not Meeting Guideline	Number of Sites Not Meeting Guidelines
Nitrate Nitrite Nitrogen	<0.444 mg/L	42	504	415 (82.3%)	35
Dissolved Reactive Phosphorus	Varies depending on catchment, from <0.016 mg/L to <0.025 mg/L	42	504	324 (64.3%)	27
Dissolved Inorganic Nitrogen	Varies depending on catchment, from <0.09 mg/L to <1.5 mg/L	42	504	228 (45.2%)	20
Turbidity	<5.6 NTU	37	444	147 (33.1%)	10
Escherichia coli	<550/100ml	42	504	151 (30.0%)	41
Dissolved oxygen	Varies depending on catchment, from >70% to >90%	42	504	140 (27.8%)	9
Dissolved zinc	Varies depending on catchment, from <0.00868 mg/L to <0.146 mg/L	42	504	91 (18.1%)	24
Total Suspended Solids	<25 mg/L	42	504	53 (10.5%)	2 (Heathcote River at Tunnel Road, Heathcote River at Ferrymead Bridge)
Biochemical Oxygen Demand	<2 mg/L	42	504	38 (7.5%)	1 (Curletts Road Stream at Motorway)
Water temperature	Varies depending on catchment, from <20°C to <25°C	42	504	11 (5.4%)	0
pH	6.5 to 8.5	42	504	12 (2.4%)	0
Dissolved copper	Varies depending on catchment, from <0.00152 mg/L to <0.00543 mg/L	42	504	27 (2.2%)	6
Nitrate	Median <3.8 mg/L and/or 95%ile <5.6 mg/L	42	504	10 (2.0%)	1 (Knights Stream)
Dissolved lead	Varies depending on catchment, from <0.00384 mg/L to <0.167 mg/L	42	504	0 (0%)	0
Total ammonia	Varies depending on catchment, from <0.32 mg/L to <1.75 mg/L	42	504	0 (0%)	0
Total	-	42	7,500	1,647 (22.0%)	42 (100%) (for at least one parameter)

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Table 4a. Direction of significant trends ($p \leq 0.05$) for parameters monitored monthly at each of the sites in the Ōtākaro/ Avon River catchment (refer to Appendix C, Table i for sample periods).

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Wairarapa Stream			↓ 15%	↓ 11%				↓ 3%	↑ 1%	↑ 1%	↓ 18%		↓ 2%	↓ 2%	
Waimairi Stream				↓ 10%				↓ 4%		↑ 0%			↓ 2%	↓ 2%	
Avon River at Mona Vale				↓ 11%				↓ 4%		↑ 1%			↓ 2%	↓ 2%	
Avon River at Carlton Mill Corner				↓ 10%				Not Sampled		↑ 1%	↓ 16%	↑ 2%	↓ 4%	↓ 4%	
Riccarton Main Drain				↓ 9%		↑ 3%				↑ 1%			↑ 5%	↑ 5%	
Addington Brook										↑ 1%	↓ 13%				
Avon River at Manchester Street				↓ 7%					↑ 0%	↑ 1%	↓ 12%		↓ 3%	↓ 3%	↓ 4%
Dudley Creek						↓ 1%	↑ 6%			↑ 2%	↓ 9%		↓ 5%	↓ 5%	
Avon River at Dallington Terrace/Gayhurst Road					↑ 0%		↓ 4%	↓ 6%	↑ 1%	↑ 1%	↓ 8%	↓ 6%	↓ 1%	↓ 1%	
Horseshoe Lake Discharge								↓ 3%		↑ 1%	↓ 7%	↓ 3%	↓ 2%	↓ 2%	
Avon River at Avondale Road				↓ 3%				Not Sampled		↑ 1%	↓ 21%		↓ 5%	↓ 5%	
Avon River at Pages/Seaview Bridge			↓ 10%	↓ 2%	↑ 0%	↑ 7%		↓ 4%	↑ 1%	↑ 1%	↓ 11%	↓ 5%	↓ 3%	↓ 3%	↑ 3%
Avon River at Bridge Street				↓ 5%	↑ 0%	↑ 8%			↑ 1%	↑ 1%	↓ 10%	↓ 7%		↓ 3%	↑ 5%

Notes: EC = Electrical Conductivity, TSS = Total Suspended Solids, DO = Dissolved Oxygen, Temp = Temperature; BOD_5 = Biochemical Oxygen Demand, NNN = Nitrate Nitrite Nitrogen and DIN = Dissolved Inorganic Nitrogen. Blank cells indicate no significant upwards or downwards trends. Trends of 0% are due to rounding values of less than one to the nearest whole number.

Table 4b. Direction of significant trends ($p \leq 0.05$) for parameters monitored monthly at each of the sites in the Ōpāwaho/ Heathcote River catchment (refer to Appendix C, Table i for sample periods).

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Heathcote River at Templetons Road				↓ 12%					↓ 2%		↑ 10%				
Haytons Stream at Retention Basin			↑ 9%	↓ 11%			↑ 3%				↓ 5%		↓ 13%	↓ 12%	
Curletts Road Stream at Motorway			↑ 21%	↓ 6%	↑ 0%	↑ 2%	↑ 10%	Not Sampled	↓ 3%	↑ 1%			↓ 23%	↓21%	
Curletts Road Stream Upstream of Heathcote River	↓13%						↓ 8%	↓ 11%			↓ 8%	↓ 8%			↓ 9%
Heathcote River at Rose Street				↓ 7%						↑ 1%	↓ 9%		↓ 2%	↓ 2%	
Cashmere Stream at Sutherlands Road				↓ 20%					↓ 2%	↑ 0%	↓ 28%		↓ 3%	↓ 3%	
Cashmere Stream at Worsleys Road				↓ 6%				↓ 3%			↓ 8%				
Heathcote River at Ferniehurst Street				↓ 4%							↑ 4%				
Heathcote River at Bowenvale Ave				↓ 5%	↑ 0%					↑ 1%	↓ 15%				
Heathcote River at Opawa Road/Clarendon Terrace				↓ 5%			↓ 4%	↓ 6%			↓ 7%	↓ 3%			
Heathcote River at Mackenzie Avenue				↓ 7%				Not Sampled		↑ 1%	↓ 20%				
Heathcote River at Catherine Street				↓ 6%				Not Sampled		↑ 1%	↓ 9%				
Heathcote River at Tunnel Road				↓ 8%	↑ 0%		↓ 3%	↓ 5%		↑ 1%		↓ 10%	↑ 2%		
Heathcote River at Ferrymead Bridge			↑ 16%	↓ 14%					↑ 1%	↑ 1%	↓ 4%	↓ 14%			↑ 3%

Notes: EC = Electrical Conductivity, TSS = Total Suspended Solids, DO = Dissolved Oxygen, Temp = Temperature; BOD_5 = Biochemical Oxygen Demand, NNN = Nitrate Nitrite Nitrogen and DIN = Dissolved Inorganic Nitrogen. Blank cells indicate no significant upwards or downwards trends. Trends of 0% are due to rounding values of less than one to the nearest whole number. No monitoring was undertaken at the Heathcote River at Templeton's Road site from February – June 2015, November 2015 – January 2016, March – December 2016 and January- July 2017, as the site was dry.

Table 4c. Direction of significant trends ($p \leq 0.05$) for parameters monitored monthly at each of the sites in the Huritini/ Halswell River catchment and Linwood Canal (refer to Appendix C, Table i for sample periods).

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Halswell Retention Basin Inlet							↓ 3%	Not Sampled			↓ 9%	↓ 21%	↑ 4%	↓ 11%	
Halswell Retention Basin Outlet		↓37%		↓ 15%		↓ 4%	↓ 16%	Not Sampled	↑ 3%		↓ 18%	↓ 37%		↓ 15%	
Knights Stream at Sabys Road			↓ 9%		↓ 1%						↓ 44%	↓ 7%			
Nottingham Stream at Candy's Road			↑ 9%			↓ 3%		↓ 4%	↑ 1%	↑ 1%	↓ 28%		↓ 6%	↓ 5%	
Halswell River at Akaroa Highway						↓ 1%			↑ 1%	↑ 1%	↓ 15%		↓ 3%	↓ 3%	↑ 9%
Linwood Canal				↓ 4%	↑ 0%	↑ 10%		↓ 4%		↑ 1%	↓ 8%	↓ 3%	↓ 10%	↓ 6%	

Notes: EC = Electrical Conductivity, TSS = Total Suspended Solids, DO = Dissolved Oxygen, Temp = Temperature; BOD_5 = Biochemical Oxygen Demand, NNN = Nitrate Nitrite Nitrogen and DIN = Dissolved Inorganic Nitrogen. Blank cells indicate no significant upwards or downwards trends. Trends of 0% are due to rounding values of less than one to the nearest whole number.

Table 4d. Direction of significant trends (p≤0.05) for parameters monitored monthly at each of the sites in the Pūharakekenui/ Styx and Ōtūkaikino River catchments (refer to Appendix C, Table i for sample periods).

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Styx River at Gardiners Road			↓ 13%	↓ 6%		↓ 1%				↑ 1%	↓ 22%		↓ 6%	↓ 6%	↑ 8%
Smacks Creek at Gardiners Road			↓ 18%	↓ 6%		↓ 1%		↓ 8%		↑ 1%	↓ 12%		↓ 4%	↓ 3%	
Styx River at Main North Road				↓ 2%		↓ 1%		↓ 5%	↓ 1%	↑ 1%	↓ 11%		↓ 5%	↓ 5%	↑ 5%
Kā Pūtahi Creek at Blakes Road						↑ 2%	↑ 3%	↑ 5%		↓ 1%	↓ 10%	↑ 3%			
Kā Pūtahi Creek at Belfast Road				↓ 3%	↑ 0%			↓ 4%	↑ 1%	↑ 1%	↓ 7%		↑ 2%	↑ 2%	
Styx River at Marshland Road Bridge					↑ 0%				↑ 0%	↑ 1%	↓ 12%				↑ 4%
Styx River at Richards Bridge				↓ 4%						↑ 1%	↓ 17%	↑ 2%			↑ 6%
Styx River at Harbour Road Bridge										↑ 1%	↓ 14%		↓ 3%	↓ 2%	↑ 6%
Ōtūkaikino River at Groynes Inlet			↓ 17%	↓ 14%	↓ 0%			↓ 13%	↓ 1%	↑ 1%	↓ 15%	↓ 12%	↓ 7%	↓ 7%	
Ōtūkaikino River at Omaka Scout Camp					↓ 2%	↑ 6%			↓ 2%				↑ 25%	↑ 23%	
Wilsons Stream					↓ 1%	↑ 3%						↑ 12%	↑ 4%	↑ 4%	

Notes: EC = Electrical Conductivity, TSS = Total Suspended Solids, DO = Dissolved Oxygen, Temp = Temperature; BOD5 = Biochemical Oxygen Demand, NNN = Nitrate Nitrite Nitrogen and DIN = Dissolved Inorganic Nitrogen. Blank cells indicate no significant upwards or downwards trends. Trends of 0% are due to rounding values of less than one to the nearest whole number.

Table 4e. Direction of significant trends (p≤0.05) for parameters monitored by the Styx Living Laboratory Trust.

Site	Clarity	pH	EC	Temp
Styx River at Brooklands	↓ 1%	↑ 2%		↑ 1%
Kā Pūtahi Creek at Everglades Golf Course		↑ 2%	↑ 1%	↑ 1%
Kā Pūtahi Creek at Ouruhia Domain		↑ 1%	↑ 1%	↑ 1%
Styx River at Radcliffe Road	↓ 1%	↑ 3%		↑ 1%
Styx River at Styx Mill Conservation Reserve	↑ 0%	↑ 1%	↑ 2%	↑ 1%
Styx River at Willowbank	↓ 1%		↑ 1%	↑ 1%
Smacks Creek Conservation Reserve	↓ 1%			↑ 1%

Notes: EC = Electrical Conductivity. Blank cells indicate no significant upwards or downwards trends. Trends of 0% are due to rounding values of less than one to the nearest whole number.

3.3 Water Quality Index

- 2%, 79% and 19% of sites were recorded as having ‘very poor’, ‘poor’ and ‘fair’ water quality, respectively (Table 5; Figure 11). No site had ‘good’ or ‘very good’ water quality, as guidelines were exceeded on at least one occasion at all sites.
- All catchments except the Ōtūkaikino generally had ‘poor’ water quality.
- The Ōtūkaikino River recorded the best water quality out of all the catchments and the Ōpāwaho/ Heathcote River and Linwood Canal catchments recorded the worst water quality (Table 6).
- The best site for water quality was Wairarapa Stream, followed by Cashmere Stream at Sutherlands Road and then Heathcote River at Bowenvale Avenue.
- The worst site for water quality was Curletts Road Stream at Motorway, followed by both the Curletts Road Stream Upstream of Heathcote River and Heathcote River at Mackenzie Avenue sites, followed by Haytons Stream at Retention Basin.
- The best fitting statistical model was the ‘catchment’ and ‘year’ interaction model, meaning that some catchments, but not all, varied in WQI depending on the year of survey (x^2 =188.90, d.f.=30, p<0.0001; Figure 12). P-values between the interaction model and the catchment only model were identical, therefore model selection was based on AIC[11]:
    - Ōtākaro/ Avon: initially showing an improvement in WQI over time, with the median WQI moving from the ‘poor’ category into the ‘good’ category in 2016 and then back down to the ‘fair’ category in 2017 and ‘poor’ in 2018.
    - Ōpāwaho/ Heathcote: no improvement in WQI over time, with the median WQI always within the ‘poor’ category.

[11] The Akaike Information Criterion (AIC) estimates the relative quality of a statistical model for any given set of data.

  - Huritini/ Halswell: slight improvement in WQI over time, however median WQI has remained in the ‘poor’ category for all years except 2017. The catchment consists of only three sites that may not be a thorough representation of the catchment.
  - Pūharakekenui/ Styx: has recorded no overall improvement in WQI over time, however there were improvements in 2016 (‘good’) and 2017 (‘fair’) categories.
  - Ōtūkaikino: variable WQI scores over the years, with the median WQI moving between the ‘poor’ and ‘very good’ categories. However, this catchment consists of only three sites that may not be a thorough representation of the catchment.
  - Linwood Canal: has recorded no overall improvement in WQI over time, with the median WQI predominantly in the ‘poor’ category.
- Time Trends analysis showed that two sites have recorded significant improvements in WQI over time (Halswell River at Akaroa Highway (Tai Tapu Road) and Cashmere Stream at Sutherlands Road) and one site has recorded a significant decline (Curletts Road Stream at Motorway) (Table 5).

Table 5. Water Quality Index (WQI) scores at each site for the monitoring period of January to December 2018 and Direction of significant trends (p≤0.05) since 2013. Additional water quality categories not represented by sites in 2018 are 'good' (80 – 89.99) and 'very good' (≥90).

Catchment	Site	WQI	Water Quality Category	Change over time
Ōpāwaho/ Heathcote	Curletts Road Stream at Motorway	39.6	Very Poor	↓ 9%
Ōpāwaho/ Heathcote	Heathcote River at MacKenzie Avenue	48.5	Poor	
Ōpāwaho/ Heathcote	Curletts Road Stream Upstream of Heathcote River	48.9	Poor	
Ōpāwaho/ Heathcote	Haytons Stream at Retention Basin	51.4	Poor	
Ōtūkaikino	Wilsons Stream	52.7	Poor	
Pūharakekenui/ Styx	Styx River at Marshland Road Bridge	52.7	Poor	
Ōpāwaho/ Heathcote	Heathcote River at Templetons Road	53.1	Poor	
Pūharakekenui/ Styx	Styx River at Richards Bridge	53.5	Poor	
Ōtākaro/ Avon	Addington Brook	54.5	Poor	
Ōpāwaho/ Heathcote	Heathcote River at Tunnel Road	55.0	Poor	
Pūharakekenui/ Styx	Kā Pūtahi Creek at Belfast Road	55.2	Poor	
Ōtākaro/ Avon	Riccarton Main Drain	57.3	Poor	
Ōtākaro/ Avon	Dudley Creek	57.9	Poor	
Ōtākaro/ Avon	Avon River at Avondale Road Bridge	59.0	Poor	
Ōpāwaho/ Heathcote	Heathcote River at Ferrymead Bridge	59.3	Poor	
Pūharakekenui/ Styx	Kā Pūtahi Creek at Blakes Road	61.0	Poor	
Linwood Canal	Linwood Canal/City Outfall Drain	62.9	Poor	
Ōtākaro/ Avon	Avon River at Bridge Street	63.6	Poor	
Ōpāwaho/ Heathcote	Heathcote River at Catherine Street	64.2	Poor	
Ōtākaro/ Avon	Avon River at Dallington Terrace/Gayhurst Road	64.2	Poor	
Ōtākaro/ Avon	Horseshoe Lake Discharge	64.6	Poor	
Ōpāwaho/ Heathcote	Cashmere Stream at Worsleys Road	64.7	Poor	
Ōpāwaho/ Heathcote	Heathcote River at Ferniehurst Street	65.0	Poor	
Pūharakekenui/ Styx	Styx River at Harbour Road Bridge	65.1	Poor	
Huritini/ Halswell	Nottingham Stream at Candys Road	65.9	Poor	
Ōpāwaho/ Heathcote	Heathcote River at Rose Street	65.9	Poor	
Ōtākaro/ Avon	Avon River at Manchester Street	66.1	Poor	
Huritini/ Halswell	Halswell River at Akaroa Highway (Tai Tapu Road)	66.7	Poor	↑ 3%
Pūharakekenui/ Styx	Smacks Creek at Gardiners Road	66.8	Poor	
Ōtākaro/ Avon	Avon River at Mona Vale	66.9	Poor	
Pūharakekenui/ Styx	Styx River at Main North Road	67.3	Poor	
Ōtākaro/ Avon	Waimairi Stream	67.9	Poor	
Ōtākaro/ Avon	Avon River at Pages/Seaview Bridge	68.4	Poor	
Ōtākaro/ Avon	Avon River at Carlton Mill Corner	69.7	Poor	
Pūharakekenui/ Styx	Styx River at Gardiners Road	70.6	Fair	
Ōpāwaho/ Heathcote	Heathcote River at Opawa Road/Clarendon Terrace	71.1	Fair	

Catchment	Site	WQI	Water Quality Category	Change over time
Huritini/ Halswell	Knights Stream at Sabys Road	72.2	Fair	
Ōtūkaikino	Ōtūkaikino Creek at Omaka Scout Camp	73.1	Fair	
Ōtūkaikino	Ōtūkaikino River at Groynes Inlet	73.2	Fair	
Ōpāwaho/ Heathcote	Heathcote River at Bowenvale Avenue	74.1	Fair	
Ōpāwaho/ Heathcote	Cashmere Stream at Sutherlands Road	76.0	Fair	↑ 3%
Ōtākaro/ Avon	Wairarapa Stream	76.6	Fair	

Table 6. Best and worst catchments and sites for the monitoring period January to December 2018, based on the Water Quality Index (WQI). Red = Ōtākaro/ Avon River catchment, orange = Ōpāwaho/ Heathcote River catchment, blue = Pūharakekenui/ Styx River catchment, green = Ōtūkaikino River catchment, purple = Huritini/ Halswell River catchment and black = Linwood Canal.

Placing	Best Sites		Worst Sites	
	Catchment Scale	Site Scale	Catchment Scale	Site Scale
	Ōtūkaikino River (median WQI = 73)	Wairarapa Stream (WQI = 77)	Ōpāwaho/ Heathcote River (median WQI = 62)	Curletts Road Stream at Motorway (WQI = 40)
	Huritini/ Halswell River (median WQI = 67)	Cashmere Stream at Sutherlands Road (WQI = 76)	Pūharakekenui/ Styx River Linwood Canal (median WQI = 63)	Curletts Road Stream Upstream of Heathcote River Heathcote River at Mackenzie Avenue (WQI = 49)
	Ōtākaro/ Avon River (median WQI = 65)	Heathcote River at Bowenvale Avenue (WQI = 74)		Haytons Stream at Retention Basin (WQI = 51)

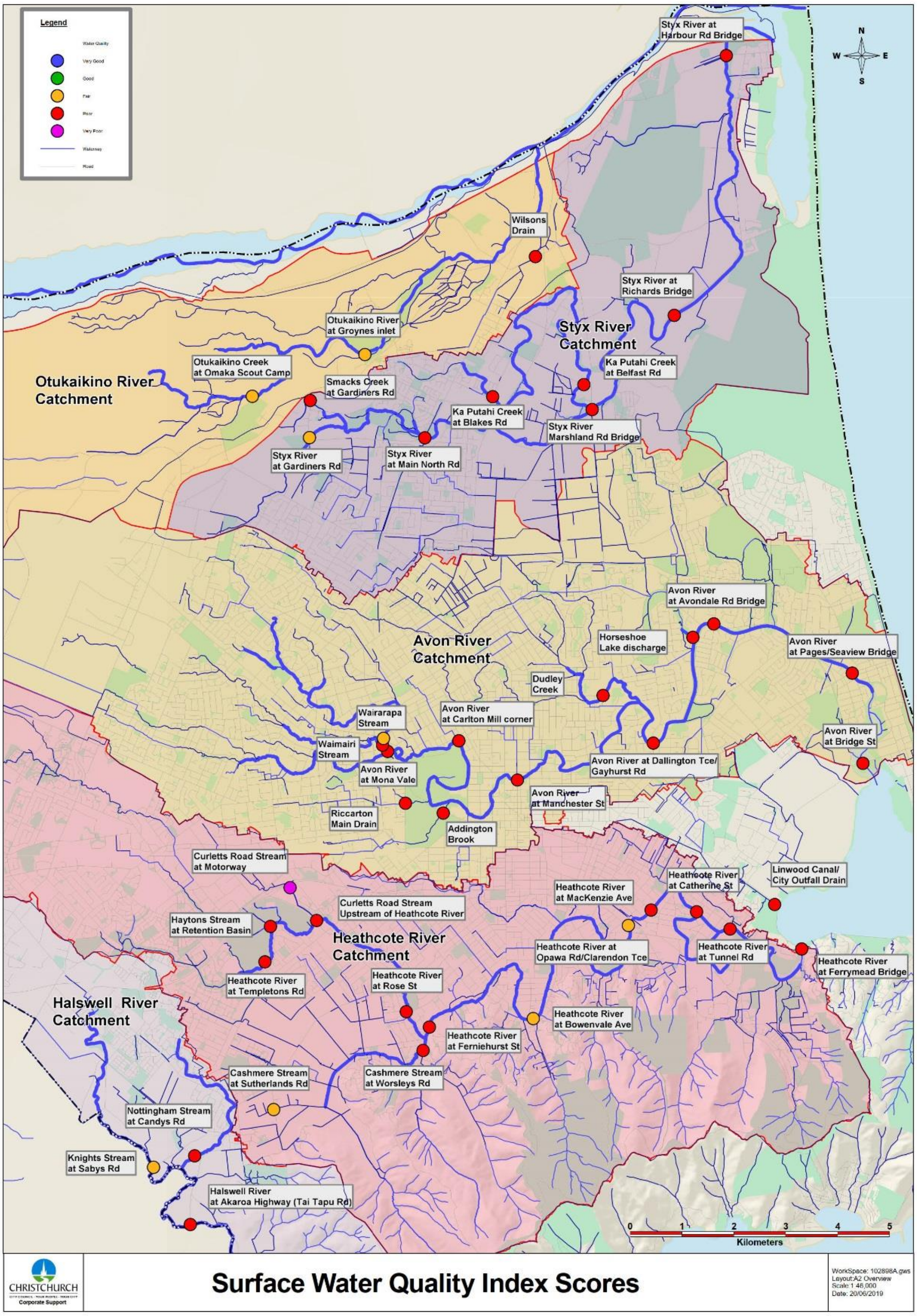

Figure 9. Water Quality Index (WQI) categories for 2018 at the Christchurch City Council water quality monitoring sites. No sites were in the Good or Very Good category.

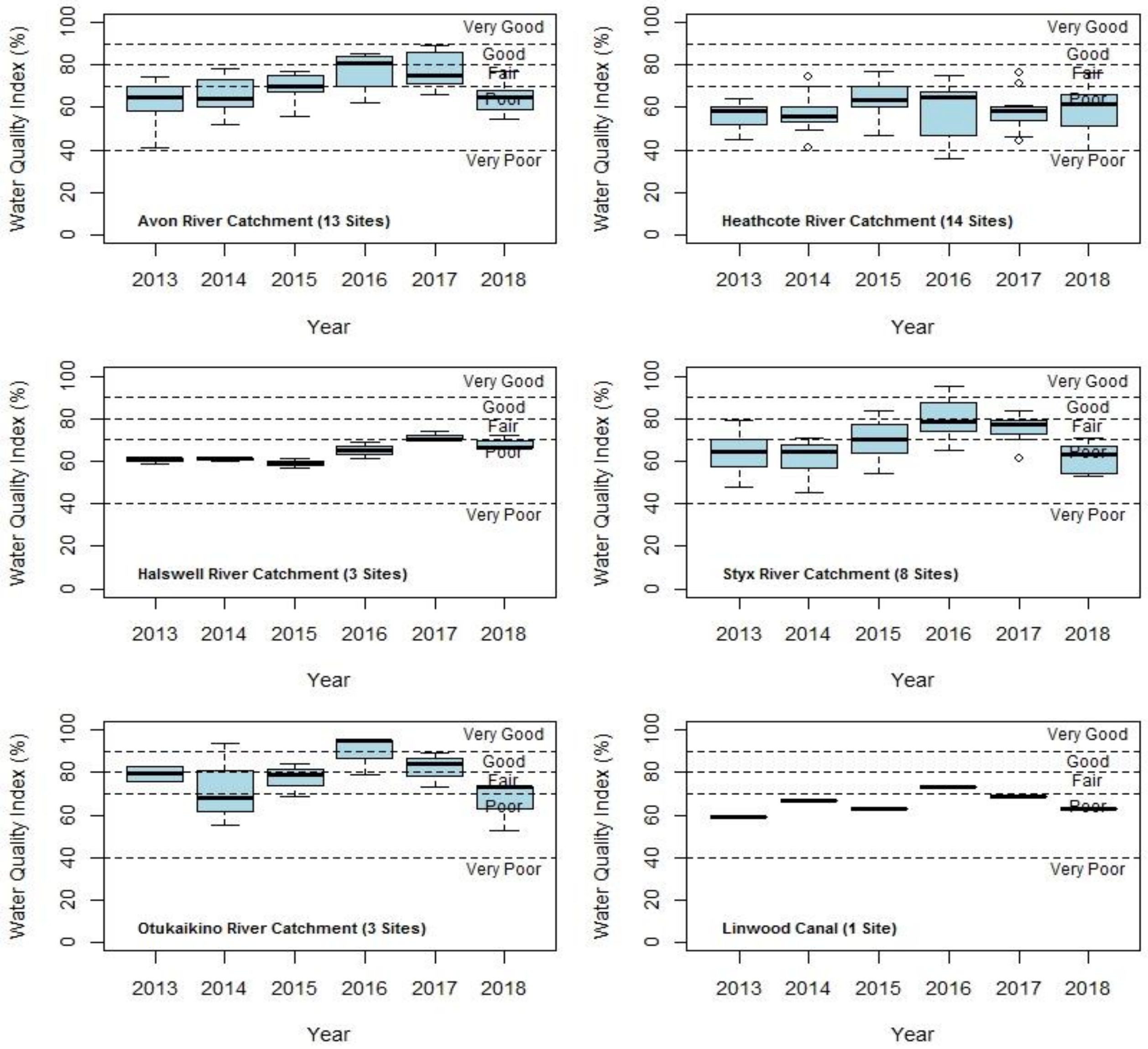

Figure 10. Boxplots of Water Quality Index for each catchment for the 2013 to 2018 monitoring years

4 Discussion

There were a number of parameters within the waterways that were recorded at levels unlikely to cause adverse effects, including dissolved lead, total ammonia and nitrate. However, 22% of samples (1,647 of 7,500 samples) did not meet the guideline levels. The parameters that recorded values well outside the guidelines across most sites included NNN, DIN, DRP and *E. coli*. There were also some parameters that generally recorded levels within the guidelines, but on a number of occasions, or regularly at a small number of sites, recorded concentrations outside the guidelines, including dissolved copper, dissolved zinc, pH, TSS, turbidity, dissolved oxygen and BOD_5.

The concentrations of parameters have mostly remained steady over time (59%), but some improvements in water quality were recorded (26%) and some declines (11%). The following temporal trends of note were recorded:

- A 25% and 23% increase in NNN and DIN respectively at the Ōtūkaikino Creek at Omaka Scout Camp site, due to some high peaks in concentrations during 2017 and 2018. This indicates that there are still some nutrient sources entering the stream from agricultural land use in the upper catchment, however peaks were lower in 2018 than 2017.
- A 44% reduction in BOD_5 at Knights Stream, driven by peak concentrations reducing from 2015. These decreases may be due to riparian planting in the vicinity of the monitoring site a few years ago by ECan. A riffle was also constructed at this location by the CCC in 2016 to allow water flow monitoring, which likely aerates the water, and flushes contaminated water and sediment through the system.
- A 37% reduction in total ammonia and dissolved lead at the Halswell Retention Basin Outlet. The reduction in ammonia was driven by high and peaky concentrations prior to 2016, but particularly in 2010-2011.Post 2016 all lead concentrations have been below the LOD, which lead to the significant reduction. These reductions are most likely due to the significant works undertaken early 2016 to enlarge the basin.
- A 28% reduction in BOD_5 at Nottingham Stream, which is due to the loss of spikes in concentrations from 2017. This may be due to better catchment management practices.

The results of the temporal trends do not indicate that there have been any lasting effects on sediment levels in the water at these monitoring sites due to (1) the 2010 Christchurch earthquake sequence, or (2) the 2017 Port Hills fires and subsequent erosion. However, sediment cover and depth of the streambed may have increased due to these two events, and this is not covered by this water quality monitoring programme, but addressed by other aquatic ecology monitoring undertaken by the CCC. In addition, turbidity levels in the Ōpāwaho/ Heathcote River catchment this year were generally similar to 2017 but higher than the 2016 monitoring year. This may be due to a combination of wetter years in 2017 and 2018 and the significant instream projects happening in the Ōpāwaho/ Heathcote River such as dredging and bank stabilisation works which began in 2018.

Based on the WQI, the majority of sites had 'poor' water quality. The Ōtūkaikino River catchment generally had 'fair' water quality, however all other catchments were generally 'poor'. The Ōtūkaikino River recorded the best overall water quality out of all the catchments, but Wairarapa Stream in the Ōtākaro/ Avon catchment was the best site. The catchment recording the worst water quality was the Ōpāwaho/ Heathcote River, with the four worst sites all being in this catchment. The worst site was Curletts Road Stream at Motorway followed jointly by Curletts Road Stream Upstream of Heathcote River and Heathcote River at Mackenzie Avenue, then Haytons Stream at Retention Basin. There were a number of contaminants of particular concern at the Curletts Road Stream at Motorway (copper, zinc, TSS, DO, BOD_5, DRP), Curletts Road Stream Upstream of Heathcote River (zinc, DO, DRP) and Haytons Stream (zinc, DRP) sites. The WQI for Heathcote River Stream at Mackenzie Avenue site was heavily skewed by an exceptionally high TSS value (2,700 mg/L) which was recorded downstream of dredging works. Removal of this value from the calculation improved the WQI score from 48.5 to 60.0, however it still remained in the ‘poor’ category. The WQI scores of the Halswell River at Akaroa Highway and Cashmere Stream at Sutherlands Road sites have significantly improved over time, while the Curletts Road Stream at Motorway site declined.

The upper Avon, Styx and Otukaikino sites showed a decline in WQI with the top eight sites moving from the ‘good’ to the ‘fair’ category in 2018. This decline is largely due to an increase in the number of parameters exceeding the guideline, particularly zinc, DRP, TSS and *E.coli*. More frequent exceedances can be attributed to the amount of rainfall that fell being higher in 2018 compared to previous years, with 50% of sampling days being affected by rain in the Styx catchment. This highlights the impact stormwater discharges have on surface water environments where higher rainfall may mean more contaminants are mobilised within catchments and discharged into waterways

The six waterway sites located in proximity to main stormwater outfalls did not appear to record differing results compared to the other waterway sites. This could be due to (a) many of the other sites also being located near other outfalls, (b) the monthly monitoring not often being carried out during the early stages of a wet weather event (when the ‘first flush’ of contaminants typically occurs) or (c) stormwater not having any noticeable effects in these locations. The exception to this was Curletts Road Stream at Motorway, which generally recorded worse levels in contaminants (for copper, zinc, dissolved oxygen, BOD_5 and total ammonia) than other waterway sites. Haytons Stream at Retention Basin also recorded higher levels of zinc, total ammonia and DRP compared to the other waterway sites.

The two Halswell Retention Basin sites (Inlet and Outlet) generally recorded greater concentrations of parameters than the waterway sites. In particular, the basin recorded high levels of copper, zinc, pH, TSS, BOD_5, total ammonia and DRP. The same pattern was observed in the 2017 data. This is to be expected given the predominantly industrial stormwater input into the basins and that the waterways are subjected to dilution from baseflow. The outlet generally recorded lower levels than the inlet. Lower levels at the outlet might be due to the treatment ability of the basin, but as these samples were taken at the same time, it may just be a reflection that peak contaminant levels had not reached the outlet yet. Of note, pH levels were very high at the outlet and much higher than the inlet, indicating that the basin processes are causing basic conditions. These monitoring results for the basin are similar to those recorded in previous years (e.g., Margetts & Marshall, 2015; Margetts & Marshall, 2016; Marshall & Burrell, 2017; Margetts & Marshall, 2018).

The results of this year’s monitoring are largely consistent with those recorded in previous years (Dewson, 2012; Dewson, 2013; Whyte, 2013a; Whyte, 2013b; Whyte, 2014a; Whyte, 2014b; Margetts, 2014a; Margetts & Marshall, 2015; Margetts & Marshall, 2016, Marshall & Burrell, 2017; Margetts & Marshall, 2018). This indicates that many of Christchurch’s waterways are both historically and currently subjected to contamination, from stormwater, wastewater and other inputs (e.g. agriculture, waterfowl faeces and industrial discharges). These parameters may be having short-term and long-term adverse effects on biota (i.e. DIN, copper, zinc, TSS/turbidity, dissolved oxygen and BOD_5), may encourage the proliferation of aquatic plants and/or algae (i.e. NNN and DRP), may indicate human health risks from contact recreation (i.e. *E. coli*) and may affect water clarity/aesthetics (TSS/turbidity). These results support the international Urban Stream Syndrome (Walsh et al., 2005), whereby lower water quality is recorded internationally in urban (particularly industrial) areas (e.g. Ōtākaro/ Avon and Ōpāwaho/ Heathcote River catchments) and generally better water quality is recorded in rural areas (e.g. Ōtūkaikino River catchment).

The sites and parameters of concern in this report should be the focus of improved catchment management practices in Christchurch. Such practices currently being encouraged by CCC include better treatment and source control of stormwater contaminants, and redirection of trade waste (e.g. vehicle wash-down water) to the waste water network, instead of the stormwater system. CCC are currently constructing a number of stormwater basins for the purpose of flood mitigation and stormwater treatment, with a large number being in the Heathcote catchment. Water quality improvements are anticipated, however will most likely be noticed over time rather than immediately. Water quality across the city should improve over time with the instigation of the impending Comprehensive Stormwater Network Discharge Consent (CSNDC) where improvements to the environmental monitoring programme and new conditions around stormwater discharges will be imposed, as well as the implementation of new regional and national policy. Increasing public perception of water quality issues and community education should also result in improvements across the city.

5 Recommendations

- Haytons Stream and Curletts Road Stream should remain as priority areas for improved contaminant source control and stormwater treatment:
  - CCC and ECan are currently working with landowners to reduce contaminants entering stormwater systems or waterways directly. Industrial site audits are proving a good avenue for targeting key contaminant sources and increasing education around stormwater.
  - CCC has committed to new or upgraded stormwater treatment facilities in both of these catchments, with construction currently underway. Dedicated wet-weather stormwater sampling is recommended to assess the effectiveness of these new and upgraded facilities.
- Investigations into the sources of particularly poor water quality should be carried out for the following waterways:
  - Wilsons Stream (NNN, DIN, DRP and *E. coli*), based on this year's monitoring.
  - Kā Pūtahi Creek (ammonia, DRP and *E. coli*), based on this and previous year's monitoring.
  - Styx River at Marshland Road Bridge and Styx River at Richards Bridge (TSS/turbidity), based on this year's monitoring.
  - Cashmere Stream at Worsleys Road (turbidity), based on this and previous year's monitoring. This is particularly important given the high concentration of kākahi/freshwater mussels recently surveyed in Cashmere Stream (Marshall 2019, *unpublished data*).
- Catchment management practices in the Ōtūkaikino River have been a focus for the Christchurch – West Melon Zone Committee following the CCC reports of

declining water quality and ecological health in recent years (Noakes & Blakely, 2017; Margetts & Marshall, 2018):

  - It was recommended to the Zone Committee in 2018 that a catchment management plan should be developed, however there are limited resources available to develop this plan and the focus at this stage is on immediate actions that can be taken prior to a catchment plan being implemented. ECan and CCC are working with landowners, rūnanga and other agencies with an interest in the river (e.g. Fish and Game and the University of Canterbury) to gather and share scientific information and identify and rectify poor practice that may be impacting on the river. Riparian planting is also a focus, with significant planting already carried out in this catchment by the CCC and landowners and more planned in coming years.
  - This report and the previous report on 2017 data identified a large increase in NNN at the Omaka Scout Camp site (46% in 2017, 25% in 2018) since monitoring began in October 2014. The potential causes for this and the DIN increase should be further investigated.
- Catchment management improvements should also focus on the middle tributaries of the Avon River (Addington Brook, Dudley Creek and Horseshoe Lake), as these sites showed poor water quality compared to other sites in the catchment (zinc, conductivity, TSS/turbidity, DO, BOD_5, total ammonia, DRP and *E. coli*), but particularly for DRP and *E. coli*. Environment Canterbury have developed a catchment management plan for Addington Brook and future work is proposed for stormwater treatment. Naturalisation works have been undertaken in Dudley Creek and No.1 Drain and monitoring of these sites is recommended to quantify changes.
- Investigations should be carried out to identify how to reduce faecal contamination of all waterways across the city:
  - Faecal source tracking has indicated that waterfowl are a major source of faecal contamination during dry and wet weather (Moriarty & Gilpin, 2015), but waterfowl control within the city may be unpopular with some people. With the increase in waterfowl, particularly with increased numbers in the vacant land within the red zone, and the public interest in swimmable rivers, the need for control is increasing.
- Determination of more cost-effective and robust methods for wet weather sampling of waterways:
  - The current grab sampling techniques are limited by the ability to (a) predict when the 'First Flush' will be and (b) to get out on site at the right time to catch the 'First Flush' (e.g. sometimes this is at night). This is shown in many of the past monitoring reports, where it has been difficult to achieve the wet weather event criteria and this report where insufficient data has been captured due to the lack of suitable rain events.
  - CCC is currently investigating the use of Thermo Scientific™ Nalgene™ Storm Water Sampler bottles to undertake sampling. NIWA has also recently completed an Envirolink research programme on potential passive sampling techniques, including these devices, which recommends more robust and cost-effective methods for monitoring wet weather events than grab sampling. New wet weather monitoring methods will be implemented in 2020 as the report recommendations highlight more effective ways of sampling rain events.
  - Many of the contaminants of concern in this report are sourced from stormwater (e.g. copper, zinc and sediment). The current monitoring programme has enabled CCC to describe the state of the environment and identify areas of poor water quality. However, the majority of monthly samples are not taken during rain events, so they do not specifically measure acute stormwater impacts, only

chronic effects. More detailed and site specific wet weather event monitoring is being proposed as part of water quality investigations within the CSNDC.

6 Conclusions

Christchurch City waterways generally recorded a WQI of ‘poor’ this monitoring year. The Ōpāwaho/ Heathcote River catchment recorded the poorest water quality, and the worst site was Curletts Road Stream at Motorway, followed jointly by Curletts Road Stream Upstream of Heathcote River and Heathcote River at Mackenzie Avenue. The particularly poor result for the Heathcote River at Mackenzie Avenue site was due to major instream work suspending extremely high levels of sediment. The Ōtūkaikino River catchment recorded the best water quality, and the best site was Wairarapa Stream. Generally, there was little difference in catchment WQI between 2013 and 2018. The WQI of the Halswell River at Akaroa Highway and Cashmere Stream at Sutherlands Road sites significantly improved over time, while the Curletts Road Stream at Motorway site declined. The contaminants of most concern were nitrogen, phosphorus and *E. coli*, as well as dissolved copper, dissolved zinc, pH, TSS, turbidity, dissolved oxygen and BOD_5 at certain sites. The concentrations of parameters have mostly remained steady over time, with some improvements and few declines in water quality recorded. The results of this year’s monitoring are largely consistent with those recorded in previous years.

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Appendix A: Laboratory Methods and Limits of Detection

Table i. Laboratory methods used over time to calculate parameter concentrations. N/A = Not Applicable.

Group	Parameter	Limit of Detection	Date	Analysis Method
Metals	Total copper	<0.001 mg/L	1 July 2018 - current day	APHA 3125 B modified, (Varian7900 ICP- MS). Digestion APHA 3030 E
		Varies between <0.001- <0.005 mg/L	5 May 2016 - 30 June 2018	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters. Digestion APHA 3030 E
		Varies between <0.001- <0.005 mg/L	Sampling instigation – 4 May 2016	
	Dissolved copper	<0.0001 mg/L	October 2016 - current day	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters
		<0.002 mg/L	December 2008 – September 2016	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters
		<0.004 mg/L	2007 - November 2008)	Graphite furnace (GFAA - graphite furnace atomic absorption, Varian) using acid washed GF/F filters
	Total lead	<0.001 mg/L	1 July 2018 - current day	APHA 3125 B modified (Varian7900 ICP- MS). Digestion APHA 3030 E
		Varies between <0.004 - <0.0015 mg/L	Sampling instigation - 30 June 2018	APHA 3125 B modified (Varian7900 ICP- MS). Digestion APHA 3030 E
	Dissolved lead	<0.0001 mg/L	October 2016 - current day	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters
		<0.0015 mg/L	December 2008 - September 2016	APHA 3125 B modified (Varian7900 ICP- MS), using nylon 0.45um filters. Digestion APHA 3030 E
		<0.006 mg/L	2007 - November 2008	APHA 3125 B modified (Varian7900 ICP- MS), using nylon 0.45um filters. Digestion APHA 3030 E
	Total zinc	<0.005 mg/L	1 July 2018 - current day	APHA 3125 B modified, (Varian7900 ICP- MS). Digestion APHA 3030 E
		<0.001 mg/L	5 May 2016 – 30 June 2018	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters
		<0.001 mg/L	March 2009 – 4 May 2016	ICPOES (Inductively coupled optical emission spectrometer, Perkin Elmer) using acid washed GF/F filters
		<0.006 mg/L	Sampling instigation - February 2009	ICPOES (Inductively coupled optical emission spectrometer, Perkin Elmer) using acid washed GF/F filters
	Dissolved zinc	<0.0005 mg/L	October 2016 - current day	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters
		<0.001 mg/L	5 May 2016 – September 2016	APHA 3125 B modified, (Varian7900 ICP- MS) using nylon 0.45um filters

Group	Parameter	Limit of Detection	Date	Analysis Method
		<0.001 mg/L	March 2009 – 4 May 2016	ICPOES (Inductively coupled optical emission spectrometer, Perkin Elmer) using acid washed GF/F filters
		<0.006 mg/L	Sampling instigation - February 2009	ICPOES (Inductively coupled optical emission spectrometer, Perkin Elmer) using acid washed GF/F filters
	Total arsenic	<0.001 mg/L	1 July 2018 - current day	APHA 3125 B modified, (Varian7900 ICP- MS). Digestion APHA 3030 E
		<0.001 mg/L	October 2015 - 30 June 2018	ICPMS APHA 3125B
		<0.002 mg/L	Sampling instigation - September 2015	GFAA APHA 3120B
Nutrients	Total nitrogen	<0.010mg/L	1 July 2018 - current day	APHA 4500-N C (persulphate digestion and continuous flow analyser)
		<0.01 mg/L	10 July 2014 - 30 June 2018	APHA 4500-N C 22nd Ed. 2012 (persulphate digestion and continuous flow analyser)
		<0.05 mg/L	4 March 2009 - 9 July 2014	
		<1.0 mg/L	Sampling instigation - 3 March 2009	
	Nitrate nitrogen	0.002 mg/L	1 July 2018 - current day	4500-NO3 F, Automated Cadmium Reduction Method
		<0.003 mg/L	9 September 2014 - 30 June 2018	APHA 4500-NO3 F (Continuous Flow Autoanalyser)
		<0.05 mg/L	Sampling instigation - 8 September 2014	APHA 4500-NO3 H (Hydrazine Reduction Discrete Analyser)
	Nitrite nitrogen	<0.001 mg/L	1 July 2018 - current day	APHA 4500-NO3 F (continuous flow analyser)
		<0.001 mg/L	9 September 2014 - 30 June 2018	APHA 4500-NO3 F 22nd Ed. 2012 (cadmium reduction and continuous flow analyser)
		<0.005 mg/L	Sampling instigation - 8 September 2014	APHA 4500-NO2 B (Discrete Analyser)
	Nitrate Nitrite Nitrogen (NNN)	<0.002mg/L	1 July 2018 - current day	APHA 4500-NO3 E (Continuous Flow Autoanalyser)
		<0.01 mg/L	27 July 2011 - 30 June 2018	APHA 4500-NO3 E (Continuous Flow Autoanalyser)
		<0.05 mg/L	3 April 2009 - 26 July 2011	APHA 4500-NO3 E (Continuous Flow Autoanalyser)
		<0.05 mg/L	Sampling instigation – 2 April 2009	Nitrate + Nitrite
	Dissolved Inorganic Nitrogen (DIN)	<0.007 mg/L	1 July 2018 - current day	Total ammonia + Nitrite-Nitrate-Nitrogen
		<0.02 mg/L	Sampling instigation - 30 June 2018	Total ammonia + Nitrite-Nitrate-Nitrogen
	Total ammonia	<0.005 mg/L	4 September 2014 - current day	APHA 4500-NH3 G (Continuous Flow Autoanalyser)

Group	Parameter	Limit of Detection	Date	Analysis Method
	(ammoniacal nitrogen)	<0.01 mg/L	sampling instigation - 3 September 2014	4500-NH3 F (Discrete Analyser)
	Total phosphorus	<0.001 mg/L	1 July 2018 - current day	APHA 4500-P J (persulphate digestion and continuous flow analyser)
		<0.003 mg/L	10 July 2014 - 30 June 2018	APHA 4500-P J 22nd Ed. 2012 (persulphate digestion and continuous flow analyser)
		<0.02 mg/L	17 November 2009 - 09 July 2014	APHA 4500-P J (Discrete Analyser)
		<0.06 mg/L	Sampling instigation - 16 November 2009	APHA 4500-P J (Discrete Analyser)
	Dissolved Reactive Phosphorus (DRP)	<0.001 mg/L	1 July 2018 - current day	APHA 4500-P F (Continuous Flow Autoanalyser)
		<0.003 mg/L	22 December 2010 - 30 June 2018	APHA 4500-P F (Continuous Flow Autoanalyser)
		<0.02 mg/L	1 December 2010 - 21 December 2010	4500-P E (Discrete Analyser)
		<0.003 mg/L	17 November 2009 - 30 November 2010	4500-P E (Discrete Analyser)
		<0.01 mg/L	Sampling instigation - 16 November 2009	4500-P E (Discrete Analyser)
Bacteria	*Escherichia coli*	<1 and >24,000 MPN/100ml	1 July 2018 - current day	Colilert APHA 4500 9223 B
		Varies depending on required dilution	Sampling instigation - 30 June 2018	Colilert APHA 4500 9223 B
	Enterococci	<10 and >24,000 MPN/100ml	sampling instigation - current day	Enterolert APHA 9230 D
Clarity	Total Suspended Solids (TSS)	<1 mg/L	1 July 2018 - current day	APHA 2540 D
		<3 mg/L	September 2010 - 30 June 2018	APHA 2540 D
		<5 mg/L	Sampling instigation - August 2010	APHA 2540 D
	Turbidity	<0.1 NTU	28 August 2018 – current day	TL230 ISO 7027 (concurrent testing)
		<0.1 NTU	Sampling instigation - current day	APHA 2130 B, (turbidity meter Hach 2100AN) (concurrent testing)
Other	Dissolved Oxygen (DO)	N/A	1 July 2018 - current day	APHA 4500-O G, YSI Pro ODO meter

Group	Parameter	Limit of Detection	Date	Analysis Method
		N/A	Sampling instigation - 30 June 2018	APHA 4500-O G
	Biochemical Oxygen Demand (BOD_5)	<1.0 mg/L	Sampling instigation- current day	APHA 5210 B
	Total water hardness	N/A	Sampling instigation- current day	APHA 2340 B calculation from calcium and magnesium measured by APHA 3125 B modified (Varian7900 ICP- MS,) using nylon 0.45um filters
	Conductivity	N/A	Sampling instigation- current day	APHA 2510 B
	pH	N/A	Sampling instigation- current day	APHA 4500-H+ B
	Water temperature	N/A	Sampling instigation- current day	APHA 2550 B.YSI Pro ODO meter
	TPH[11]	<0.3 mg/L	Sampling instigation- current day	Extraction DCM (GC-FID)

[11] Analysed by Watercare Laboratory (IANZ accredited)

Christchurch City Council

Appendix B: Metal Hardness Modified Trigger Values

8.1 Ōtākaro/ Avon, Ōpāwaho/ Heathcote, Pūharakekenui/ Styx, Ōtūkaikino and Huritini/ Halswell River Catchments

1. Introduction

The Australian and New Zealand guidelines for fresh and marine water quality (ANZECC, 2000) provides a set of default guideline trigger values for metals, with which to compare measured contaminant concentrations. These trigger values represent concentrations below which there is considered to be a low risk of adverse biological effects (ANZECC, 2000). The guidelines also provide a process for modifying the given trigger values for local environmental conditions. If measured concentrations of toxicants are below default trigger values, then there is a low risk of adverse effects. However, if measured concentrations exceed these guidelines, then it is possible to consider site specific factors that may modify the trigger values, to gain a better understanding of whether a real risk exists. If measured concentrations also exceed modified trigger values, then the next step would be to directly assess biological effects.

Christchurch City Council has measured concentrations of metals (total cadmium, total copper, total lead, total zinc) in water samples from 33 river monitoring sites across the city since 2008. Measured concentrations vary widely across the monitoring sites, and there are several sites where values often exceed guideline trigger values. In fresh waters, the hardness, pH and alkalinity of the water can alter the toxicity of metals and hence the risk of adverse biological effects (ANZECC, 2000). The default guideline trigger values for metals assume that water is soft (with a hardness value of between 0 and 59 mg/L as CaCO3), but as water hardness increases, the toxicity of some metals decreases and therefore the trigger value may increase, without increasing the risk of adverse biological effects.

To make an informed assessment of the real risks associated with exceeding the default trigger values, additional monitoring for water hardness has been included at sites within each catchment for the purpose of calculating appropriate hardness modified trigger values (HMTV) for Christchurch rivers using the water hardness dependent algorithms provided in the ANZECC (2000) guidelines.

2. Sites and sampling regime

Water samples are collected monthly at sites across the five main catchments within Christchurch City (Avon, Heathcote, Styx, Halswell, Otukaikino). These samples are analysed at the Christchurch City Council laboratory for a range of physical and chemical characteristics, including temperature, nutrients, microbiological indicators and metals. Since December 2010, samples from the eight sites listed in Table 1 have also been analysed for water hardness measured in mg/L as $CaCO_3$. Routine water quality monitoring was disrupted on several occasions during 2011, by the significant earthquakes experienced in the city. Despite this, each of the sites had between 9 and 12 water hardness measures recorded by March 2012 and the results were relatively consistent over time for each site.

Table 1. Sampling sites for water hardness investigation (December 2010 to March 2012)

Site Description	Easting	Northing	Number of water hardness samples
Otukaikino at Groynes Inlet	2477878	5750484	11
Styx River at Gardiners Road	2476786	5748821	12
Styx River at Marshland Road bridge	2482356	5749417	12
Avon River at Mona Vale	2478279	5742653	9
Avon River at Gayhurst Road	2483549	5742827	9
Heathcote River at Templetons Road	2475913	5738516	12
Heathcote at Opawa Road/Clarendon Terrace	2483072	5739226	12
Halswell River at Akaroa Highway	2474427	5733346	9

3. Results

3.1. Water Hardness by catchment

Sites on the Styx and Otukaikino rivers had median hardness values within the 'soft' water category, the Avon and Halswell river sites were within the 'moderate' hardness category and the Heathcote sites had 'moderate' to 'hard' water (Figure 1). For the Heathcote River, the Templetons Road site had a number of low hardness outlier values, but median water hardness was higher at the upstream site (Templetons Road) than the downstream site (Opawa Road).

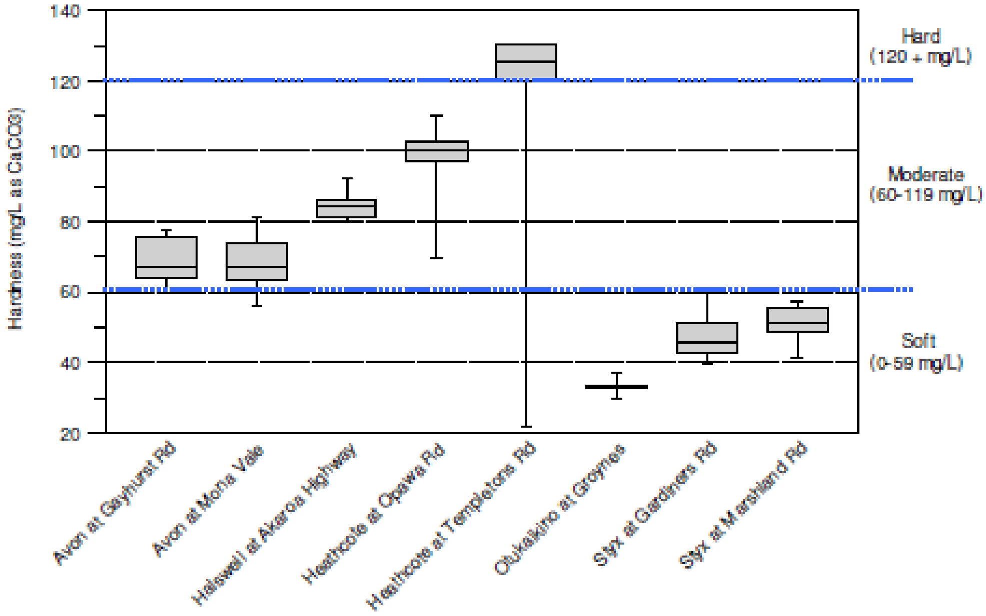

Figure 1 Box plots displaying median (and upper, lower quartiles, max and min) water hardness values for monitoring sites on the Avon, Heathcote, Halswell, Styx and Otukaikino rivers between December 2010 and March 2012.

3.2. Hardness Modified Trigger Values (HMTV)

Hardness modified trigger values (HMTV) are greater than default trigger values in each of the rivers in Christchurch (Table 1). This is because the default values assume that water is in the 'soft' category and this provides trigger values to conservatively protect aquatic ecosystems values in the absence of further information to refine these values.

Table 2 Default and HMTV for metals in the Avon, Heathcote, Halswell, Styx and Otukaikino rivers, based on 99, 95 and 90% levels of species protection as described by ANZECC (2000).

		Default trigger values (µg/L) (ANZECC, 2000)			Hardness modified trigger values (µg/L)		
Level of species protection		**99%**	**95%**	**90%**	**99%**	**95%**	**90%**
Avon	Cadmium	0.06	0.20	0.40	0.12	0.41	0.82
	Copper	1.00	1.40	1.80	1.98	2.77	3.56
	Lead	1.00	3.40	5.60	2.77	9.43	15.54
	Zinc	2.40	8.00	15.00	4.75	15.84	29.70
Heathcote	Cadmium	0.06	0.20	0.40	0.19	0.64	1.27
	Copper	1.00	1.40	1.80	3.02	4.22	5.43
	Lead	1.00	3.40	5.60	5.21	17.71	29.16
	Zinc	2.40	8.00	15.00	7.24	24.14	45.26
Halswell	Cadmium	0.06	0.20	0.40	0.15	0.50	1.00
	Copper	1.00	1.40	1.80	2.40	3.36	4.32
	Lead	1.00	3.40	5.60	3.70	12.57	20.71
	Zinc	2.40	8.00	15.00	5.76	19.19	35.99
Styx	Cadmium	0.06	0.20	0.40	0.09	0.31	0.62
	Copper	1.00	1.40	1.80	1.52	2.12	2.73
	Lead	1.00	3.40	5.60	1.86	6.34	10.44
	Zinc	2.40	8.00	15.00	3.64	12.14	22.76
Otukaikino	Cadmium	0.06	0.20	0.40	0.07	0.22	0.44
	Copper	1.00	1.40	1.80	1.08	1.52	1.95
	Lead	1.00	3.40	5.60	1.13	3.84	6.32
	Zinc	2.40	8.00	15.00	2.60	8.68	16.27

4. References

ANZECC (Australian and New Zealand Environment and Conservation Council), 2000. Australian and New Zealand guidelines for fresh and marine water quality.

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8.2 Linwood Canal

Linwood Canal Hardness Modified Trigger Values for Metals

1. Introduction

The Australian and New Zealand guidelines for fresh and marine water quality (ANZECC, 2000) provides a set of default guideline trigger values for dissolved metals. If measured concentrations of toxicants are below default trigger values, then there is considered to be a low risk of adverse effects. The guidelines also provide a process for modifying the given trigger values for local environmental conditions, namely hardness, which can affect the toxicity of metals and therefore increase the risk of adverse biological effects (ANZECC, 2000). The default guideline trigger values for metals assume that water is soft (with a hardness value of between 0 and 59 mg/L as CaCO3). However, as water hardness increases, the toxicity of some metals decreases and therefore the trigger value may increase without increasing the risk of adverse biological effects. Hardness Modified Trigger Values (HMTV) for dissolved metals for the Avon, Heathcote, Halswell, Styx and Otukaikino Rivers have previously been calculated by the Christchurch City Council (Dewson, 2012) and these are the guidelines used in reporting. It is considered that hardness values are unlikely to change over the years, so these values should only need to be re-assessed approximately every five years. However, no values have previously been calculated for the Linwood Canal (City Outfall Drain), which is in its own catchment. This memorandum therefore outlines hardness modified values for this waterway, which have also been calculated based on the water hardness algorithms provided in the ANZECC guidelines (ANZECC, 2000).

2. Methods

Linwood Canal at Humphreys Drive (2485954E, 5739637N) has been sampled monthly for a variety of water quality parameters since January 2007. However, water hardness has only been monitored (measured in mg/L as CaCO3) since September 2014. One full year of data has now be collected to enable the calculation of Hardness Modified Trigger Values for metals. Dissolved copper, lead and zinc trigger values were calculated, given these are the primary metals of concern, which are commonly compared against guidelines levels.

Boxplots of the water hardness data were created in IBM® SPSS Statistics 20, to show the median and interquartile range. Statistical outliers were not removed, as values were assumed to be 'real', providing useful information on variations in the concentrations recorded. The dark line in the boxplots represents the median, and the bottom and top lines of the box represent the 25th and 75th percentiles (the interquartile range), respectively. The T-bars that extend from the box approximate the location of 95% of the data. Circles represent statistical outliers and stars represent extreme outliers.

To calculate the HMTV for metals for Linwood Canal, 90% species protection was chosen. This waterway is not classified under the proposed Land and Water Regional Plan (Environment Canterbury, 2012), but is considered to best fit the 'spring-fed – plains – urban' classification, which relates to 90% species protection under this plan. The algorithms in the ANZECC (2000) guidelines were then used to calculate the final trigger values.

3. Results

Median water hardness at Linwood Canal fell within the 'extremely hard' category (greater than 400 mg/L) of the ANZECC (2000) guidelines (Table 1 & Figure 1). Therefore, HMTV for copper, lead and zinc were calcluated to be 0.0175 mg/L, 0.168 mg/L and 0.146 mg/L, respectively (Table 2).

Christchurch City Council

Table 1. Summary of the monitoring data for water hardness (mg/L) in Linwood Canal from September 2014 - August 2015.

Sample Size	Median	Mean	Standard Error of the Mean	Minimum	Maximum
12	435	738	206	160	2500

Table 3. Calculations of Hardness Modified Trigger Values for copper, lead and zinc for Linwood Canal, using 90% species protection and the ANZECC (2000) algorithms. HMTV = Hardness Modified Trigger Value; TV = Trigger Value; H = Hardness.

Copper	Lead	Zinc
$HMTV = TV(H/30)^{0.85}$	$HMTV = TV(H/30)^{1.27}$	$HMTV = TV(H/30)^{0.85}$
$= 1.8 \times (435/30)^{0.85}$	$= 5.6 \times (435/30)^{1.27}$	$= 15 \times (435/30)^{0.85}$
= 17.5 µg/L	= 167 µg/L	= 146 µg/L
= 0.0175 mg/L	= 0.167 mg/L	= 0.146 mg/L

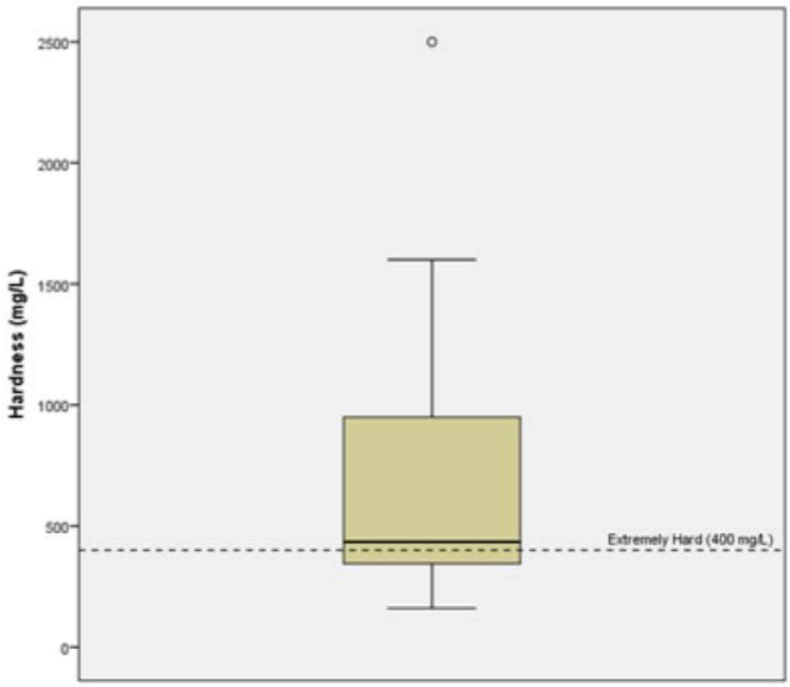

Figure 1. Box plot of water hardness for Linwood Canal for the monitoring period September 2014 - August 2015

3. References

ANZECC (Australian and New Zealand Environment and Conservation Council, ANZECC, and Agriculture and Resource Management Council of Australia and New Zealand, ARMCANZ), 2000. Australian and New Zealand guidelines for fresh and marine water quality. Volume 1: The guidelines. ANZECC & ARMCANZ, Artarmon, New South Wales.

Dewson, Z. (2012). Hardness modified trigger values for river water quality. Christchurch City Council, Christchurch. TRIM No. 13/333219.

Environment Canterbury (2012). Proposed Canterbury Land and Water Regional Plan - Volume 1. Environment Canterbury, Christchurch.

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11th September 2015

Appendix C: Sampling Instigation at Each Site

Table i. Summary of the date of first monthly sampling at the 44 water quality monitoring sites. Dissolved metals were monitored from 2011, unless otherwise specified.

Catchment	Site Description	Monitoring Instigated
Ōtākaro/ Avon	Wairarapa Stream	January 2007[12]
	Waimairi Stream	January 2007[12]
	Avon River at Mona Vale	January 2007[12]
	Avon River at Carlton Mill Corner	October 2008[13]
	Riccarton Main Drain	October 2008
	Addington Brook	October 2008
	Avon River at Manchester Street	July 2008[14]
	Dudley Creek	October 2008
	Avon River at Dallington Terrace/Gayhurst Road[8]	January 2007
	Horseshoe Lake Discharge	October 2008
	Avon River at Avondale Road	October 2008[13]
	Avon River at Pages/Seaview Bridge	January 2007
	Avon River at Bridge Street	January 2007[12]
Ōpāwaho/ Heathcote	Heathcote River at Templetons Road	January 2007[15]
	Haytons Stream at Retention Basin	April 2007[16]
	Curletts Road Stream Upstream of Heathcote River	October 2008
	Curletts Road Stream at Motorway	October 2008[13]
	Heathcote River at Rose Street	June 2008[17]
	Cashmere Stream at Sutherlands Road	December 2010
	Cashmere Stream at Worsleys Road	January 2007
	Heathcote River at Ferniehurst Street	July 2008[16,18]
	Heathcote River at Bowenvale Avenue	January 2007
	Heathcote River at Opawa Road/Clarendon Terrace	January 2007
	Heathcote River at Mackenzie Avenue	October 2008[13]
	Heathcote River at Catherine Street	October 2008[13]
	Heathcote River at Tunnel Road	January 2007
	Heathcote River at Ferrymead Bridge	January 2007
Pūharakekenui/ Styx	Smacks Creek at Gardiners Road	January 2007[15]
	Styx River at Gardiners Road	January 2007[15]
	Styx River at Main North Road	January 2007[15]
	Kā Pūtahi at Blakes Road	January 2007[15]
	Kā Pūtahi at Belfast Road	January 2007[15]
	Styx River at Marshland Road Bridge	January 2007[15]
	Styx River at Richards Bridge	October 2008
	Styx River at Harbour Road Bridge	January 2008
Huritini/ Halswell	Halswell Retention Basin Inlet	April 2007[16,13]
	Halswell Retention Basin Outlet	April 2007[13,16,19]
	Knights Stream at Sabys Road	May 2012
	Nottingham Stream at Candys Road	October 2008
	Halswell River at Akaroa Highway	October 2008
Ōtūkaikino	Ōtūkaikino Creek at Omaka Scout Camp	October 2014
	Ōtūkaikino River at Groynes Inlet	October 2008
	Wilsons Drain at Main North Road	November 2013
Linwood	Linwood Canal	January 2007[12]

[12] Dissolved oxygen monitored from June 2007
[13] Dissolved metals monitored from September 2014
[14] Dissolved oxygen monitored from October 2008
[15] Dissolved oxygen monitored from March 2007
[16] Dissolved oxygen, total ammonia, conductivity, *E. coli*, nitrogen parameters, pH, DRP and water temperature monitored from October 2008
[17] Dissolved oxygen, BOD_5, conductivity, nitrate, pH, TSS and water temperature monitored from August 2008. Total ammonia, *E. coli*, nitrogen parameters (excluding nitrate) and DRP monitored from October 2008
[18] BOD_5 and TSS monitored from October 2008
[19] BOD_5 monitored from April 2008

Appendix D: Monthly Monitoring Graphs

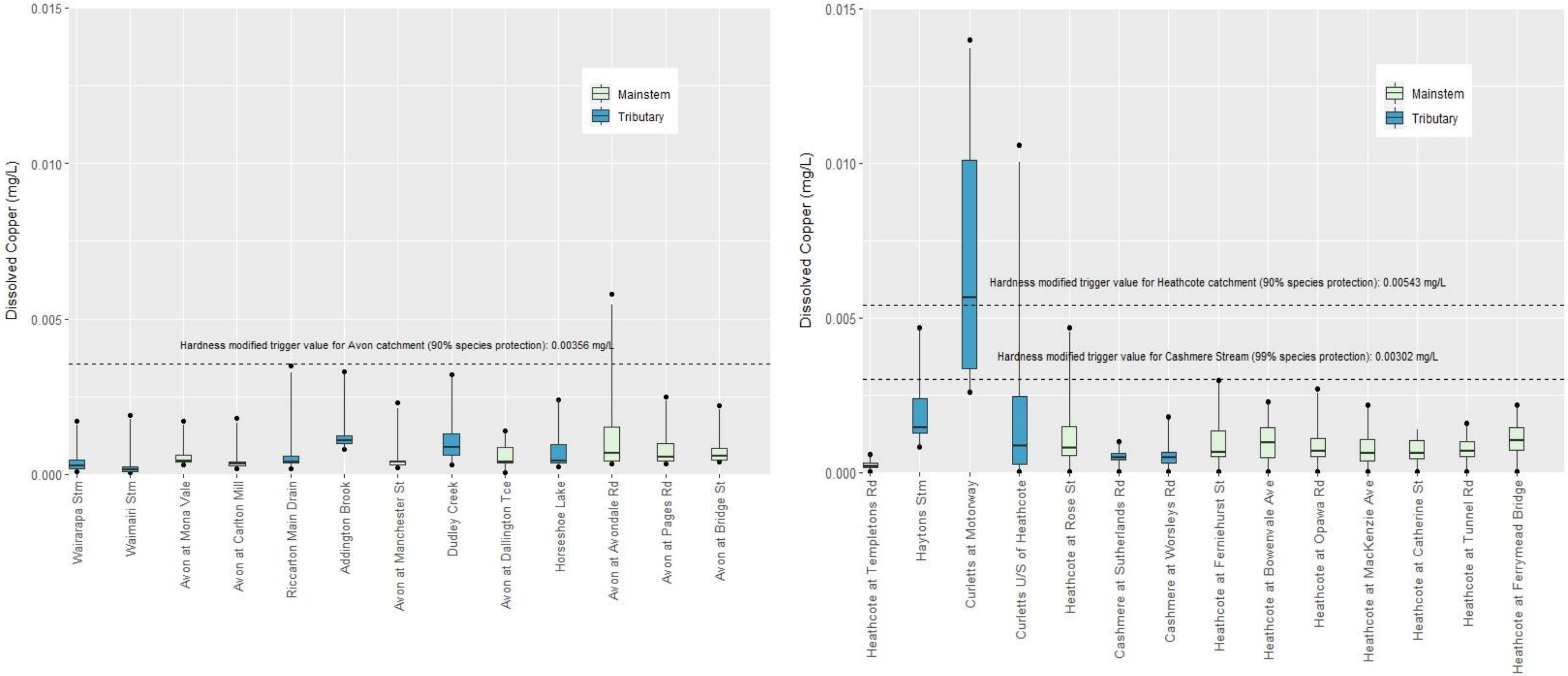


Figure i (a). Dissolved copper levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger values (Environment Canterbury, 2017), which have been modified to account for water hardness (Hardness Modified Trigger Value = HMTV), as per the ANZECC (2000) guidelines methodology. The Laboratory Limit of Detection for these two catchments was 0.0001 mg/L – analysed as half this value (0.00005 mg/L) to allow statistics to be undertaken.

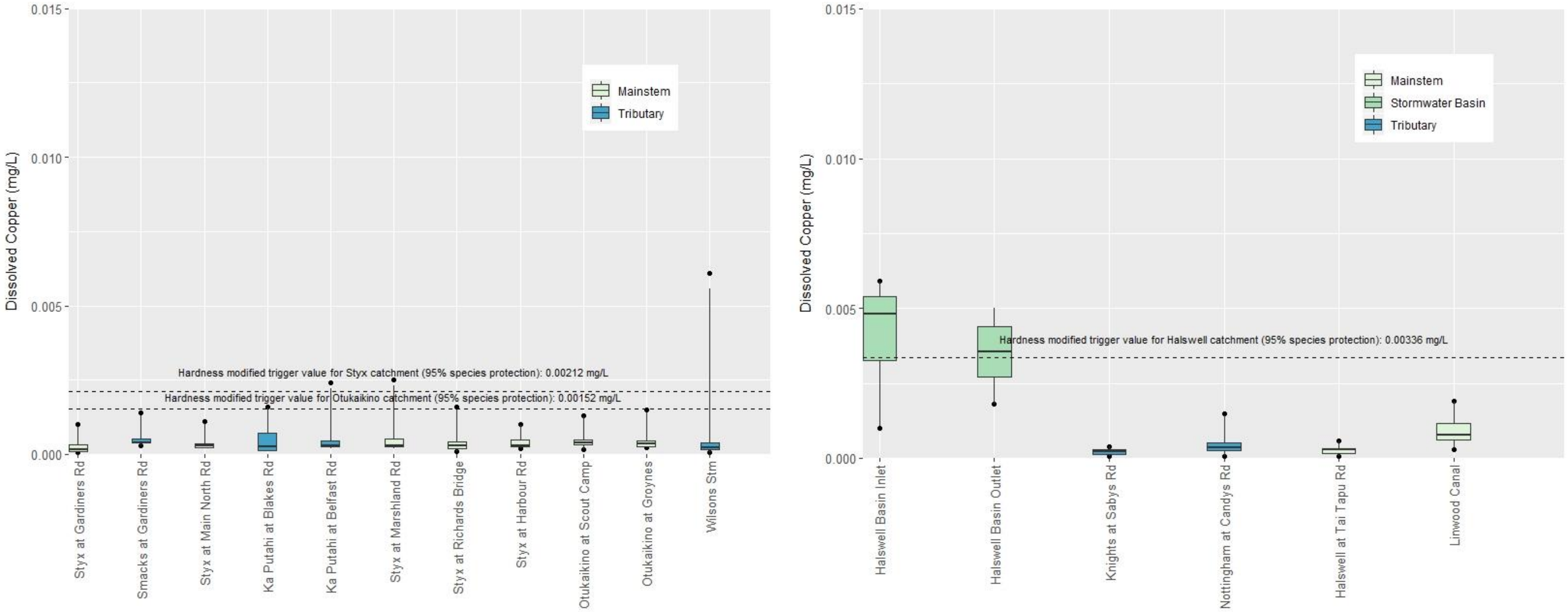


Figure i (b). Dissolved copper levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger values (Environment Canterbury, 2017), which have been modified to account for water hardness (Hardness Modified Trigger Value = HMTV), as per the ANZECC (2000) guidelines methodology. The 90% species protection HMTV for Linwood Canal (0.167 mg/L) is not visible because they are off the scale. The Laboratory Limit of Detection was 0.0001 mg/L (analysed as half this value (0.00005 mg/L) to allow statistics to be undertaken).

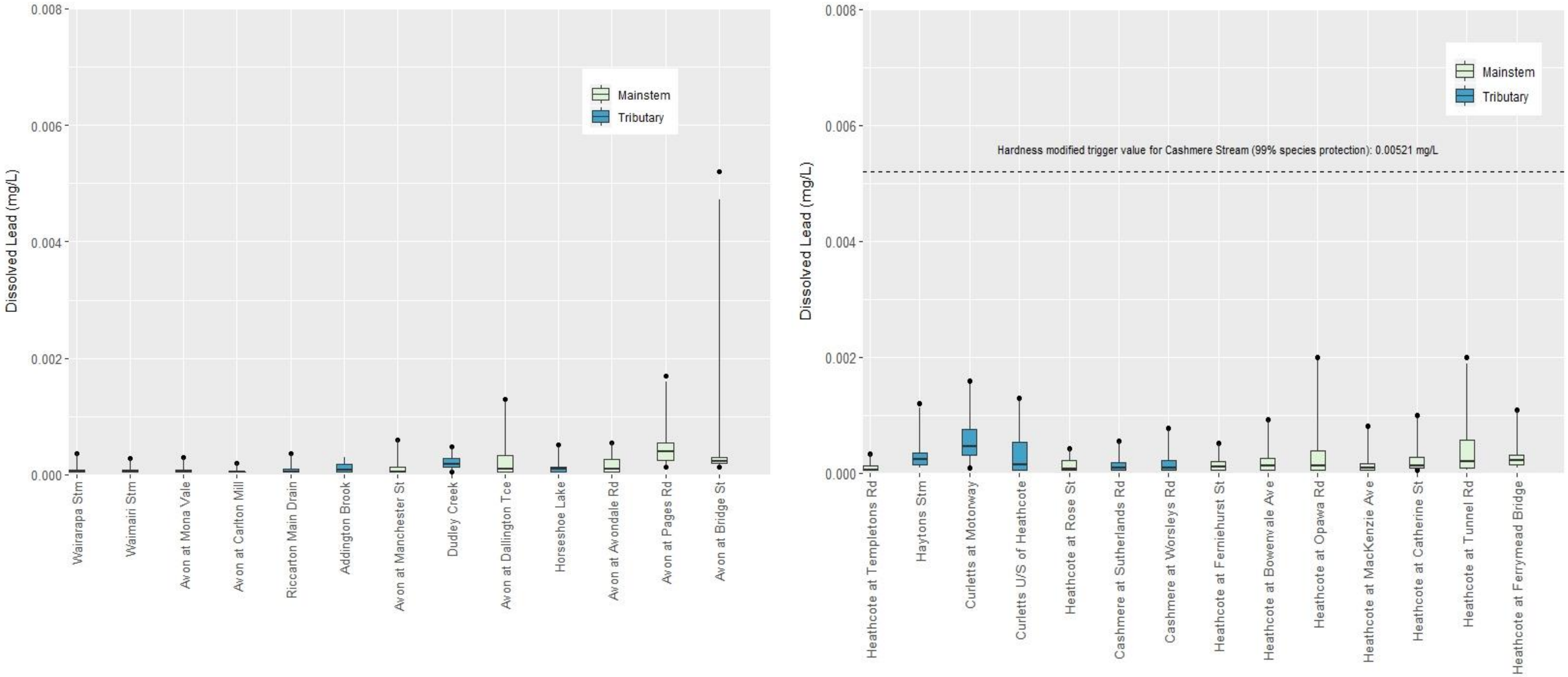


Figure ii (a). Dissolved lead levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed line represents the Land and Water Regional Plan trigger value (Environment Canterbury, 2017), which has been modified to account for water hardness (Hardness Modified Trigger Value = HMTV), as per the ANZECC (2000) guidelines methodology. The 90% protection HMTV for the Ōtākaro/ Avon River (0.01554 mg/L) and the Ōpāwaho/ Heathcote River (0.02916 mg/L) are not shown as they are off the scale. The Laboratory Limit of Detection was 0.0001 mg/L – analysed as half this value (0.00005 mg/L) to allow statistics to be undertaken.

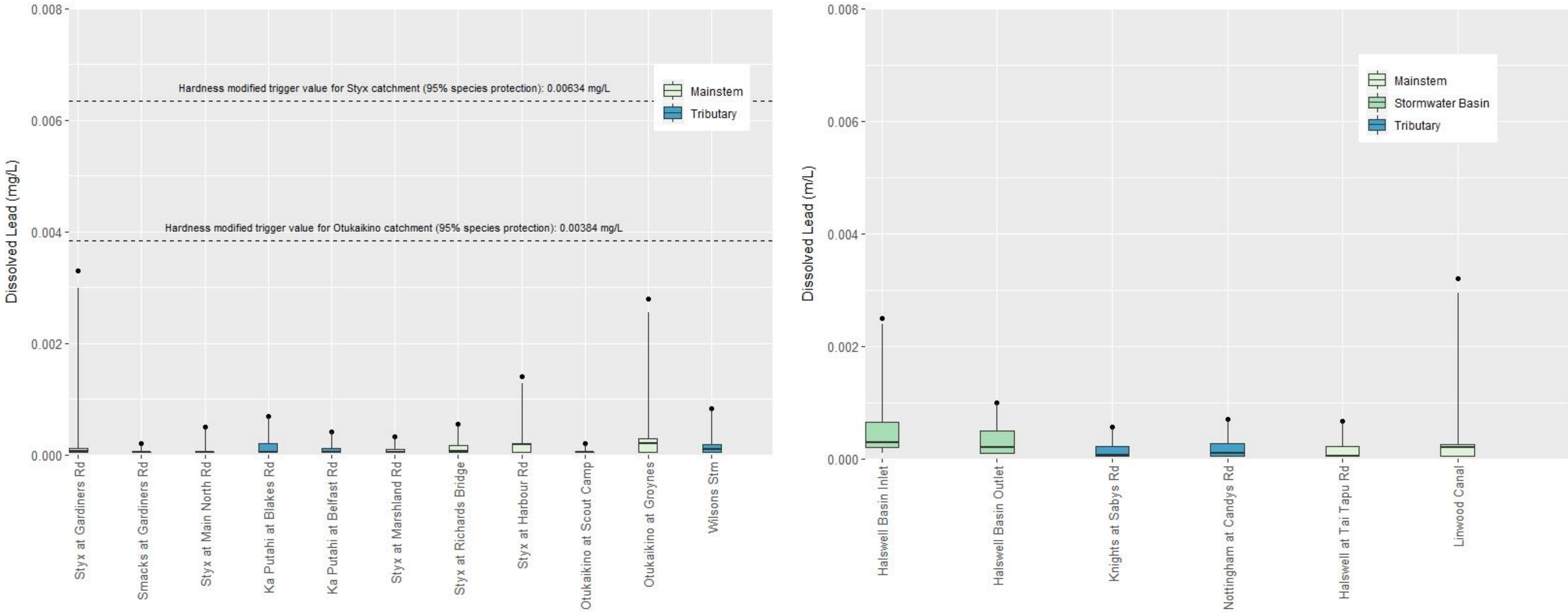


Figure ii (b). Dissolved lead levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value (Environment Canterbury, 2017), which has been modified to account for water hardness (Hardness Modified Trigger Value = HMTV), as per the ANZECC (2000) guidelines methodology. The 95% protection HMTV for Huritini/ Halswell River (0.01257 mg/L) and 90% protection HMTV for Linwood Canal (0.167 mg/L) are not visible because they are off the scale. The Laboratory Limit of Detection was 0.0015 mg/L – analysed as half this value (0.00075 mg/L) to allow statistics to be undertaken.

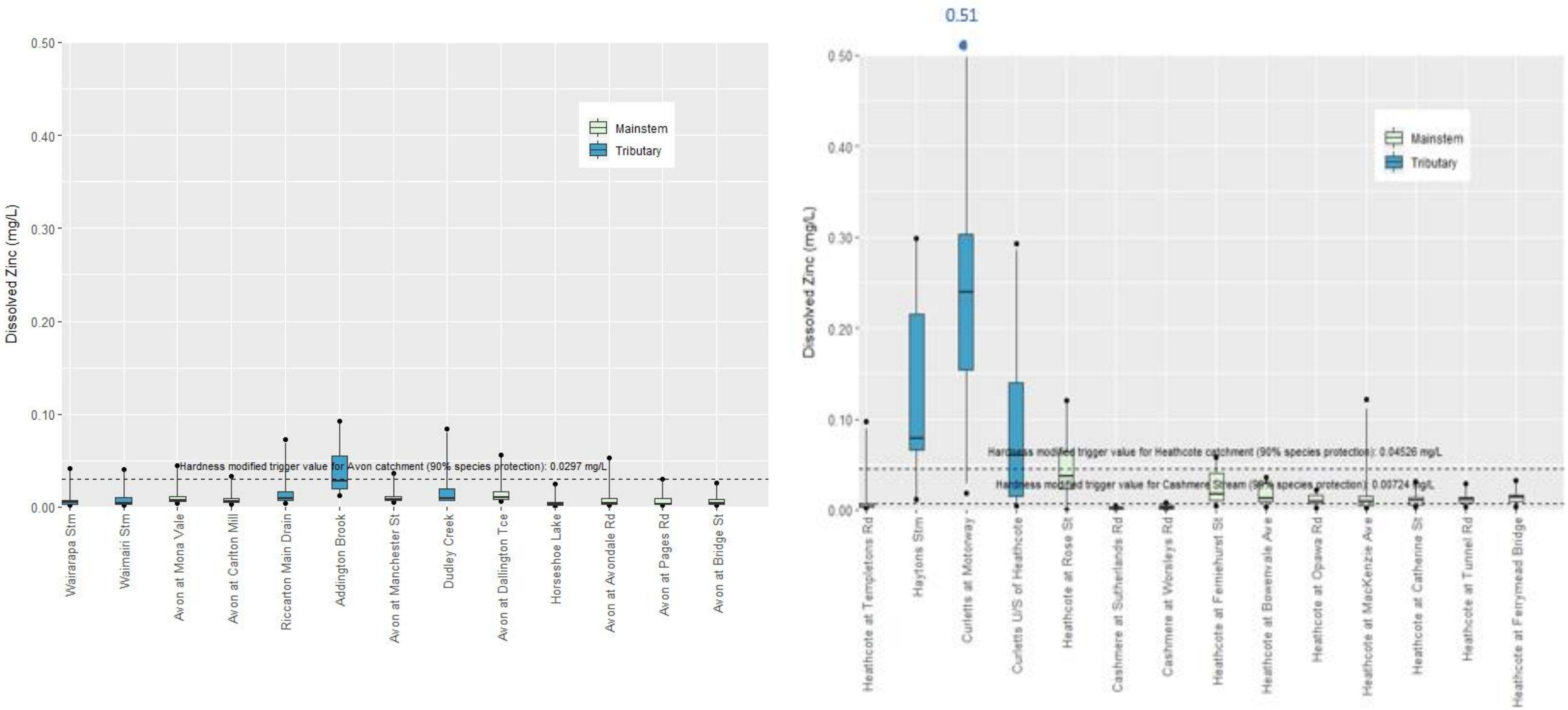


Figure iii (a). Dissolved zinc levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger values (Environment Canterbury, 2017), which have been modified to account for water hardness (Hardness Modified Trigger Value = HMTV), as per the ANZECC (2000) guidelines methodology. The Laboratory Limit of Detection was 0.0005 mg/L – analysed as half this value (0.00025 mg/L) to allow statistics to be undertaken.

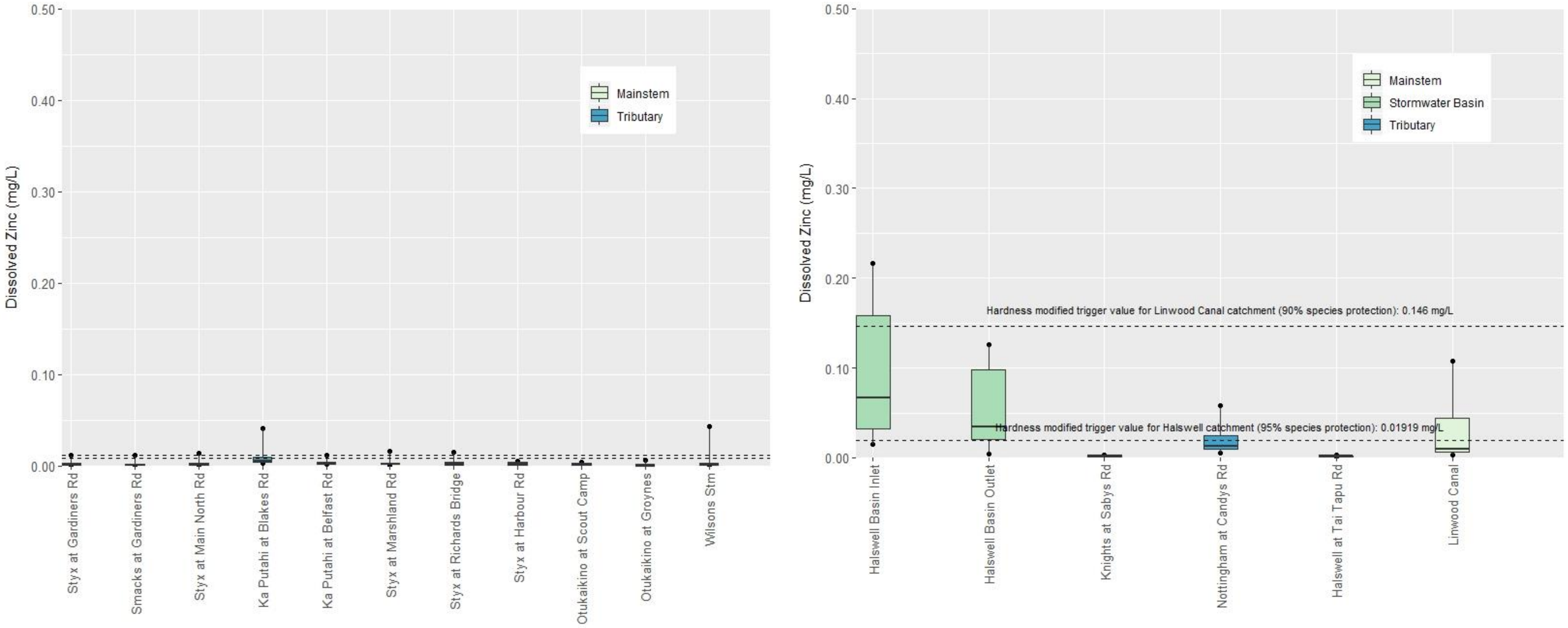


Figure iii (b). Dissolved zinc levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger values (Environment Canterbury, 2017), which have been modified to account for water hardness (Hardness Modified Trigger Value = HMTV), as per the ANZECC (2000) guidelines methodology. On the left graph, the upper dashed line represents the 95% species protection for Pūharakekenui/ Styx River catchment (0.01214 mg/L), while the lower represents the 95% species protection for Ōtūkaikino River catchment (0.00868 mg/L). The 90% protection HMTV for Linwood Canal (0.146 mg/L) is not visible because it is off the scale. The Laboratory Limit of Detection was 0.0005 mg/L – analysed as half this value (0.00025 mg/L) to allow statistics to be undertaken.

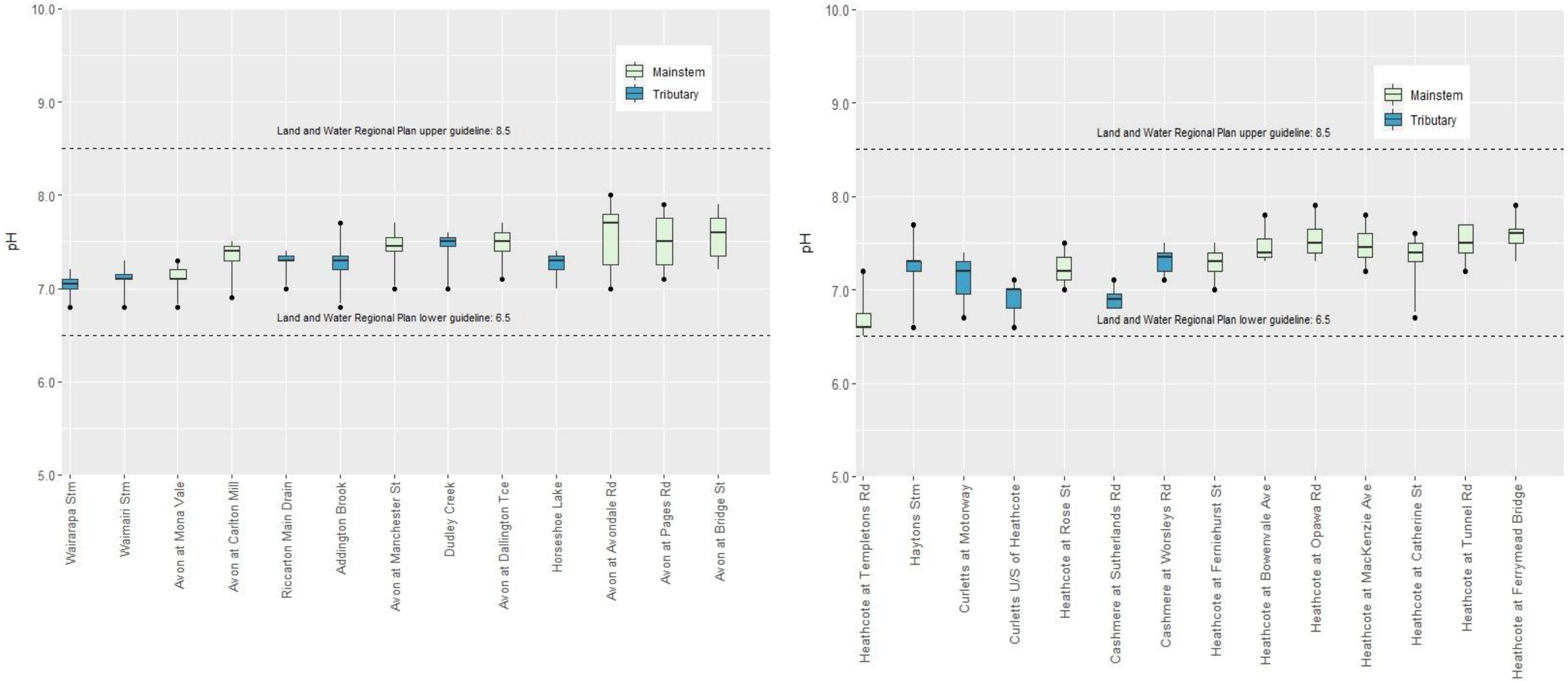


Figure iv (a). pH levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018.Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan lower (6.5) and upper (8.5) limits (Environment Canterbury, 2017).

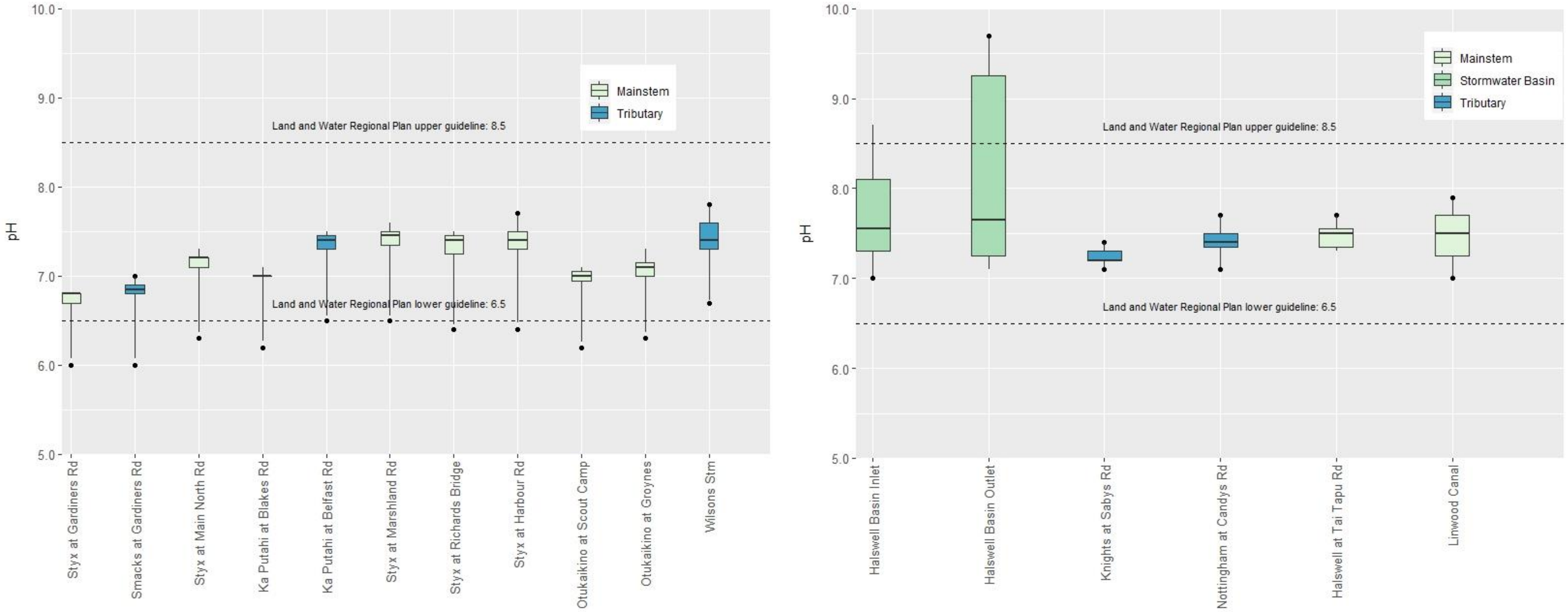


Figure iv (b). pH levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan lower (6.5) and upper (8.5) limits (Environment Canterbury, 2017).

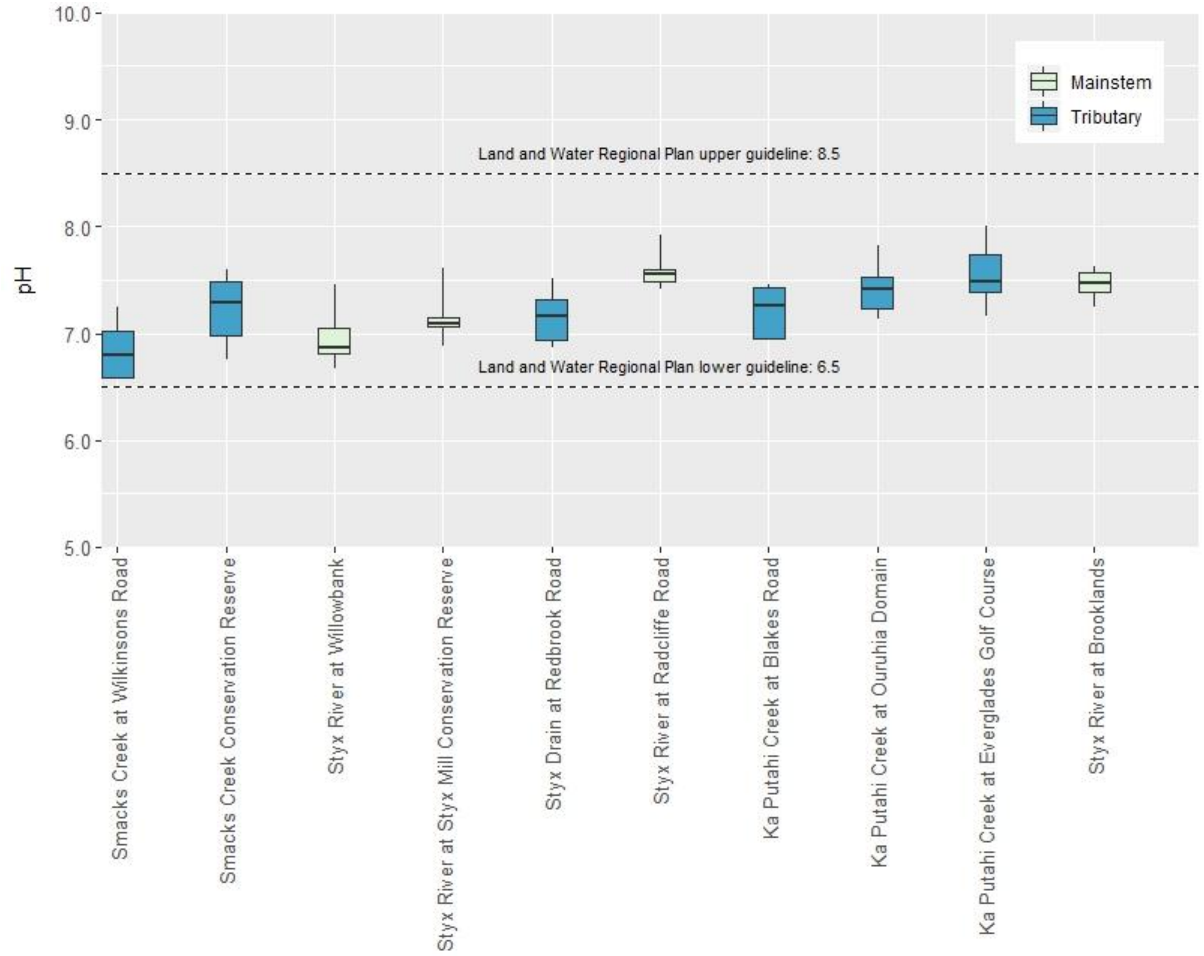


Figure iv (c). pH levels in water samples taken from the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust volunteers for the monitoring period January to December 2018 (n = 4 – 11 samples per site). Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan lower (6.5) and upper (8.5) limits (Environment Canterbury, 2017).

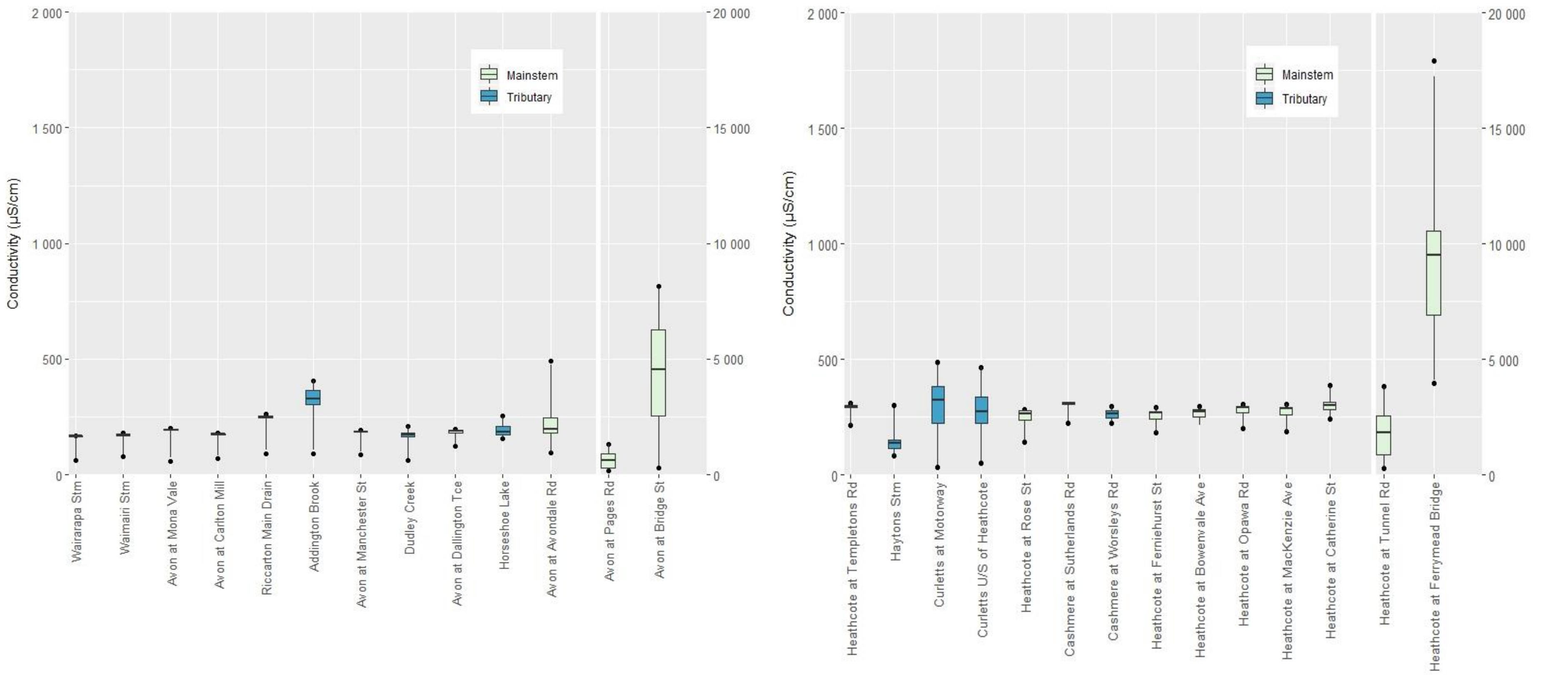


Figure v (a). Conductivity levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). All conductivity graphs have the same scale presented on the primary (left) axis. Given the large differences in values within the catchments, some sites are presented with an alternate scale on the secondary (right) axis. Scale change is marked with a vertical, thick white line.

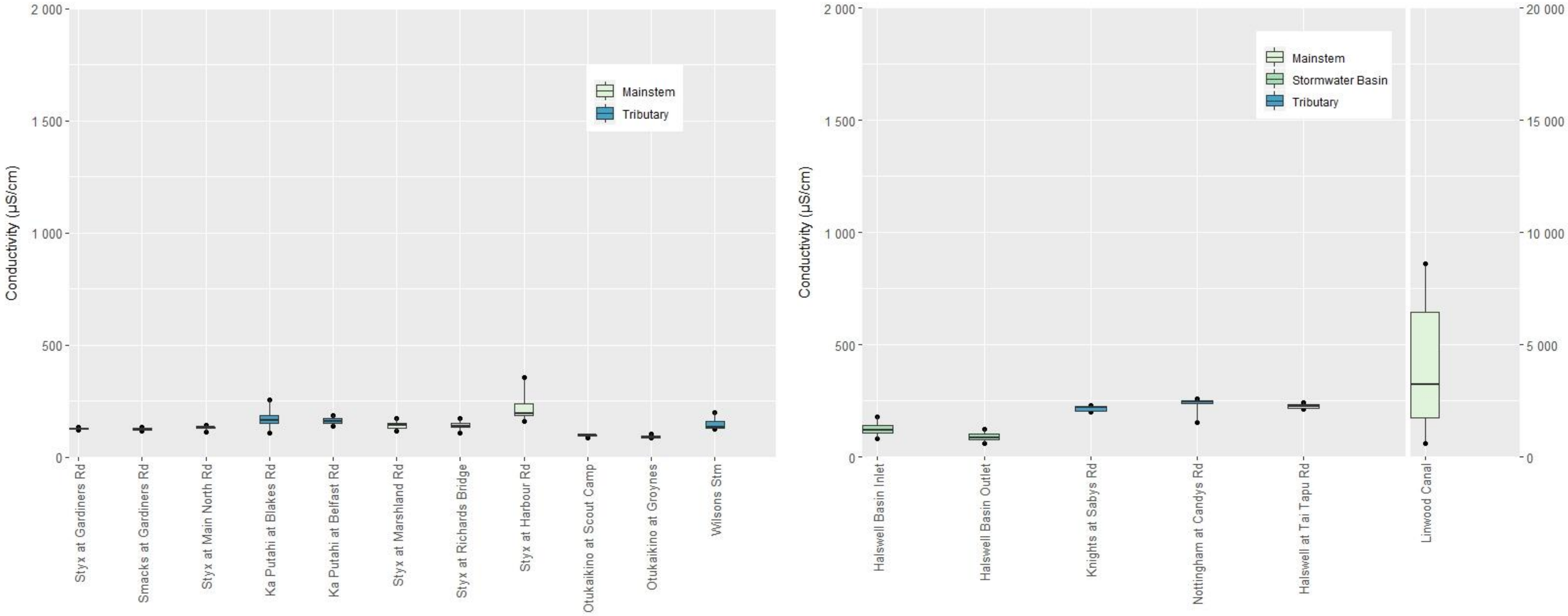


Figure v (b). Conductivity levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). All conductivity graphs have the same scale presented on the primary (left) axis. Given the large differences in values within the catchments, some sites are presented with an alternate scale on the secondary (right) axis. Scale change is marked with a vertical, thick white line.

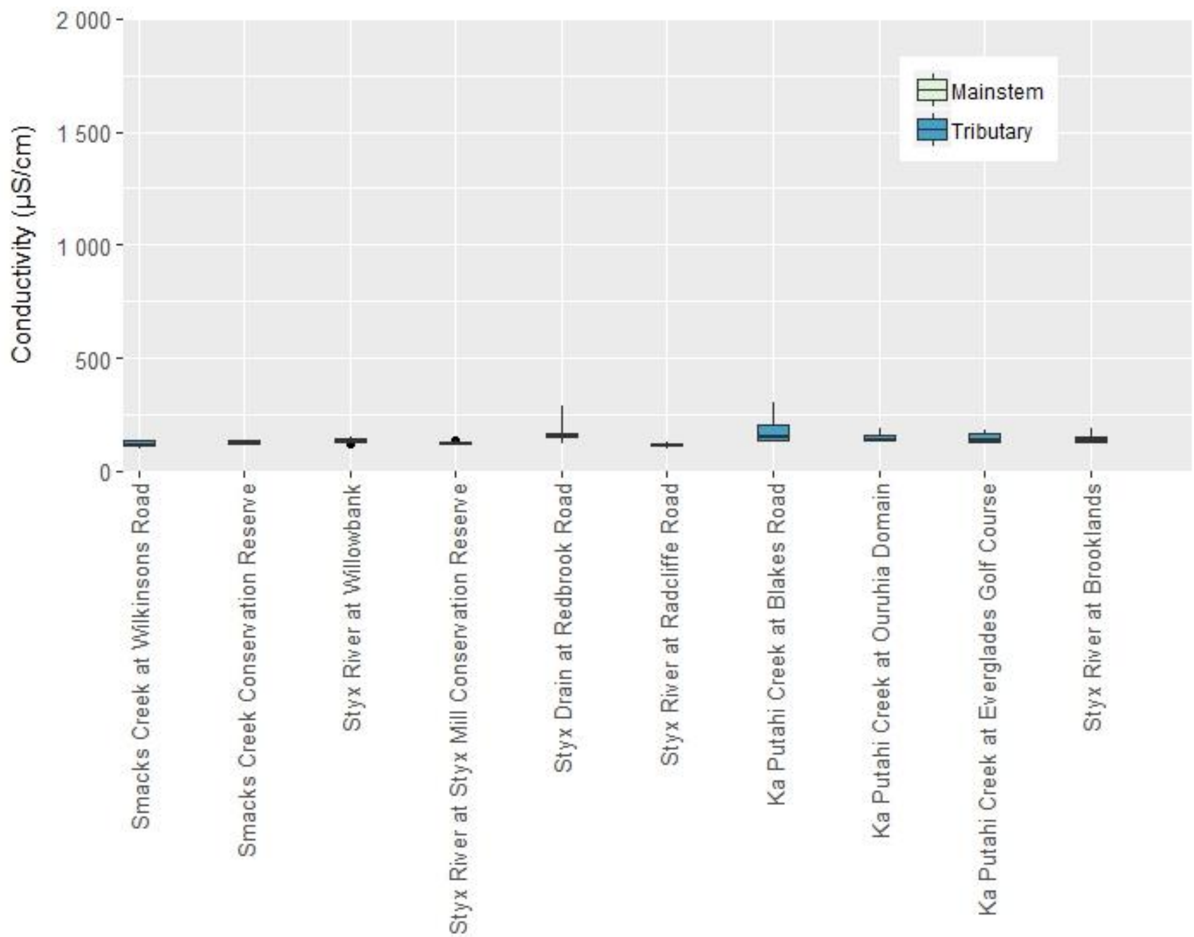


Figure v (c). Conductivity levels in water samples taken from the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust volunteers for the monitoring period January to December 2018 (n = 4 – 11 samples per site). Sites are ordered from upstream to downstream (left to right).

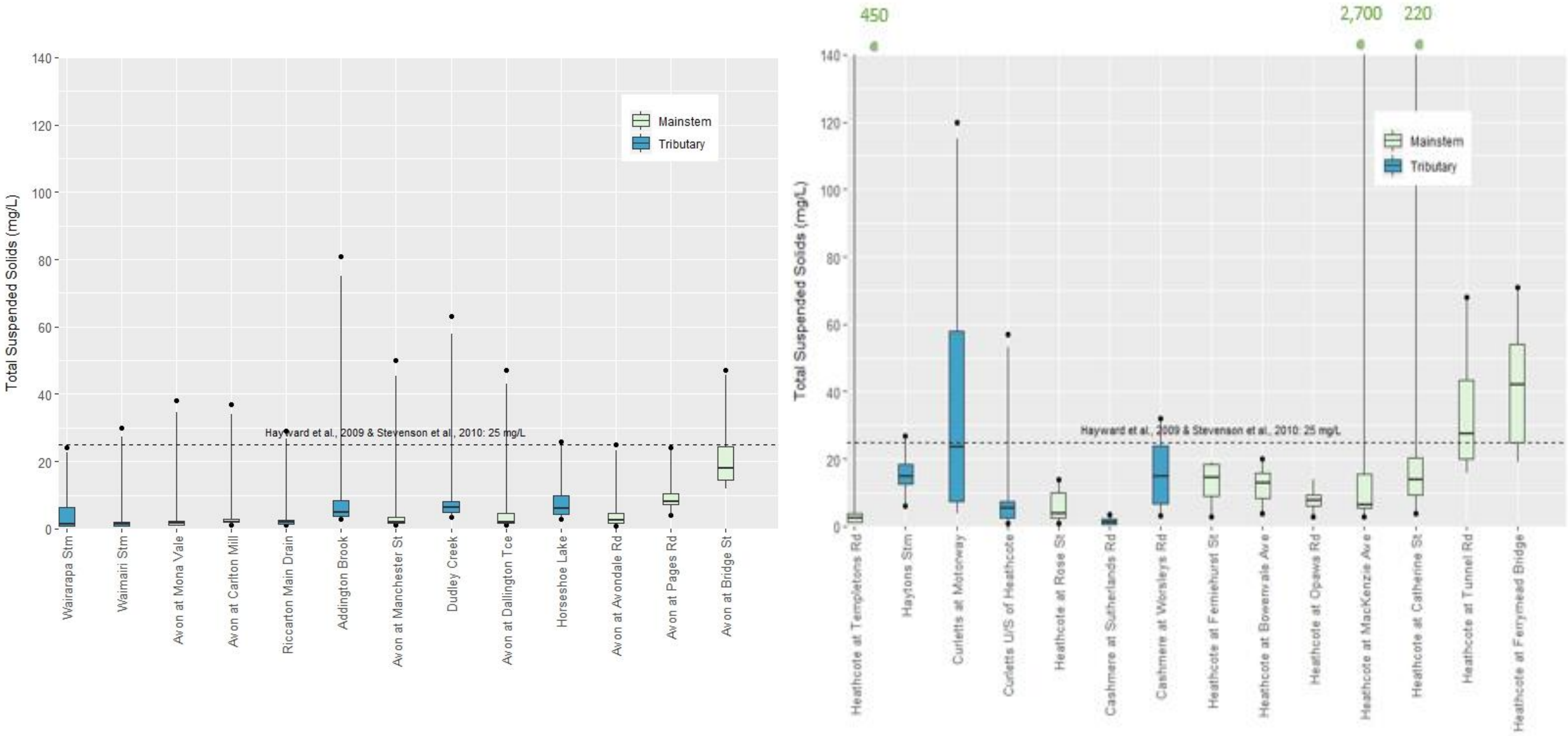


Figure vi (a). Total Suspended Solid (TSS) levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the guideline value of 25 mg/L. The Laboratory Limit of Detection was 3.0 mg/L – analysed as half this value (1.5 mg/L) to allow statistics to be undertaken.

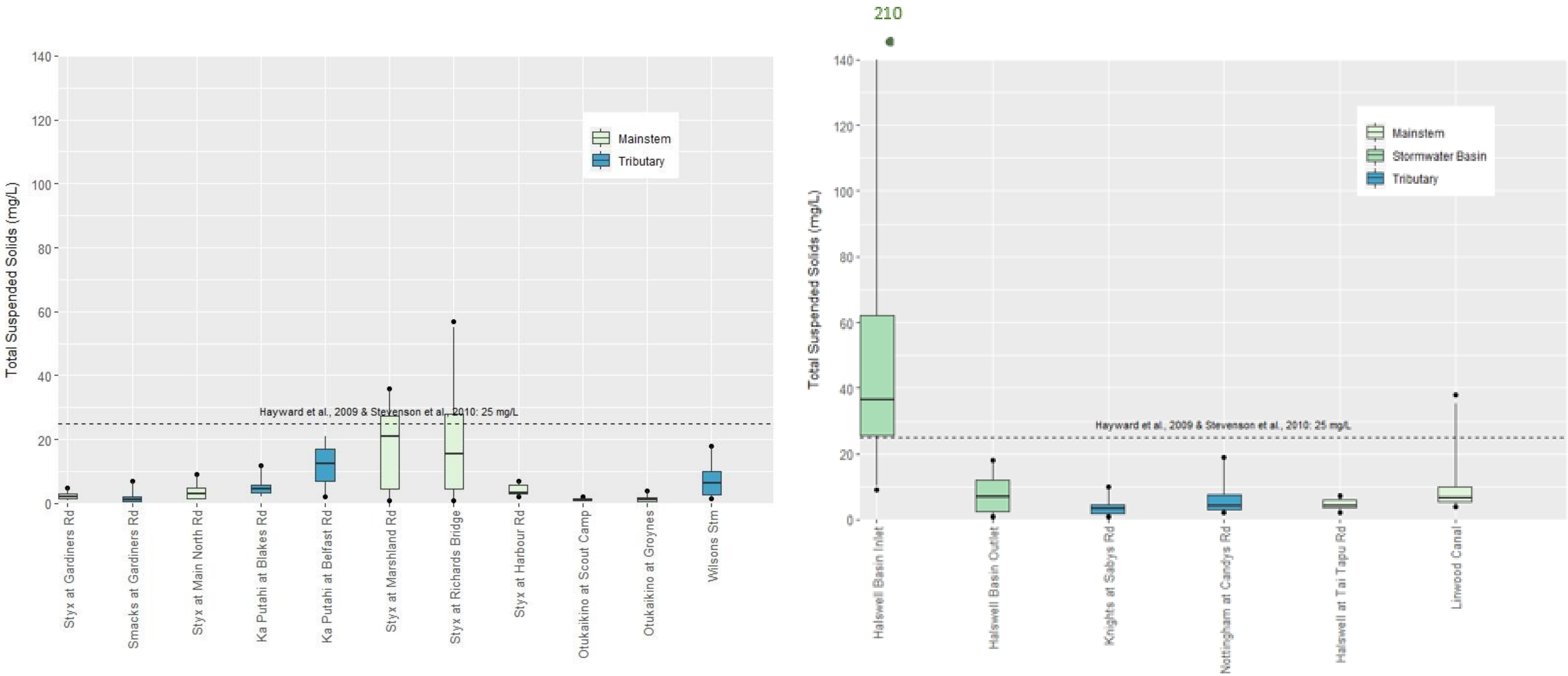


Figure vi (b). Total Suspended Solid (TSS) levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the guideline value of 25 mg/L. The Laboratory Limit of Detection was 3.0 mg/L – analysed as half this value (1.5 mg/L) to allow statistics to be undertaken.

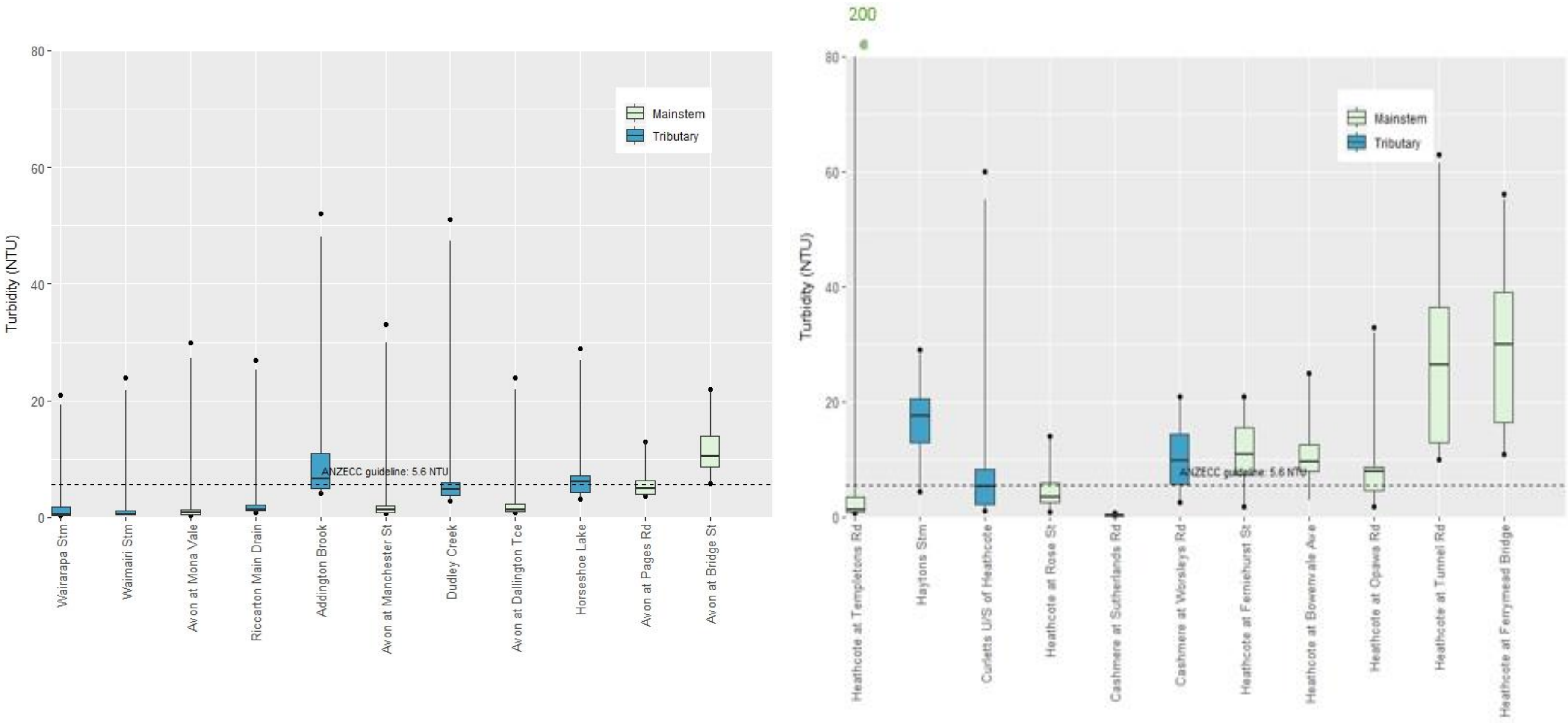


Figure vii (a) .Turbidity levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. The following sites were not measured for this parameter: Avon River at Carlton Mill Corner, Avon River at Avondale Road Bridge, Curletts Road Stream at Motorway, Heathcote River at Catherine Street and Heathcote River at Mackenzie Avenue. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the ANZECC (2000) guideline value of 5.6 Nephelometric Turbidity Units (NTU).

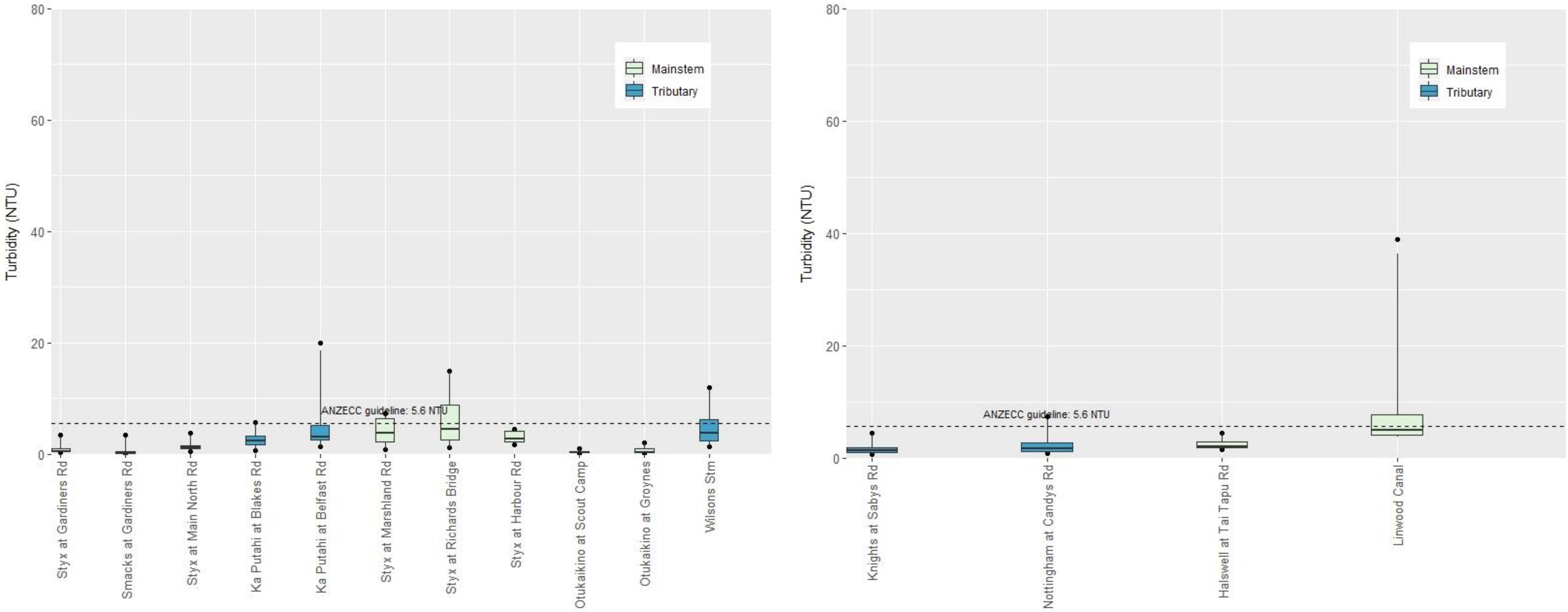


Figure vii (b). Turbidity levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. The following sites were not measured for this parameter: Halswell Retention Basin Inlet and Halswell Retention Basin Outlet. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the ANZECC (2000) guideline value of 5.6 Nephelometric Turbidity Units (NTU).

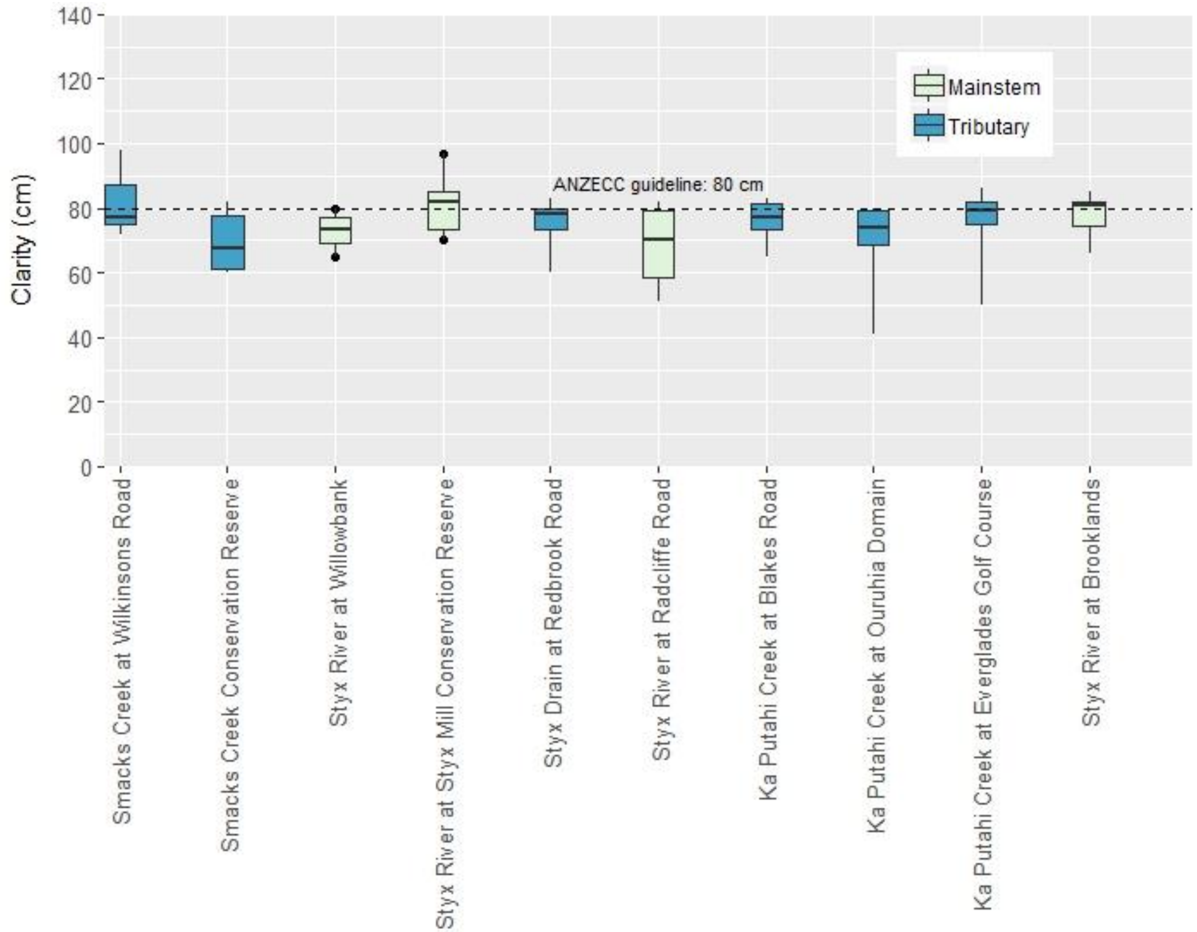
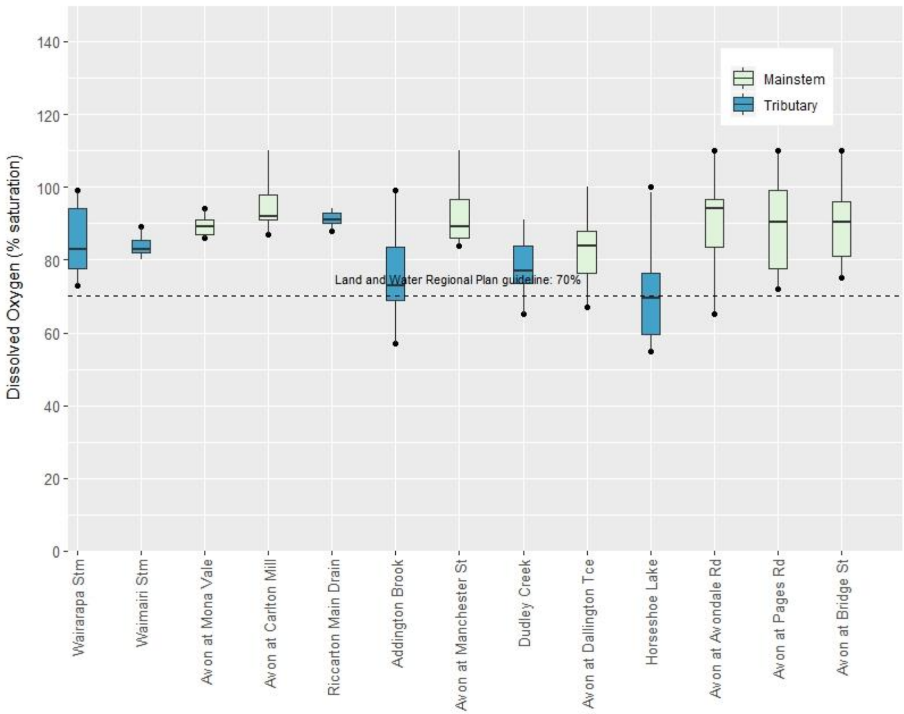


Figure viii. Water clarity levels in water samples taken from the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust volunteers for the monitoring period January to December 2018 (n = 4 – 11 samples per site). Sites are ordered from upstream to downstream (left to right). The dashed line represents the ANZECC (2000) guideline value of 80 cm.



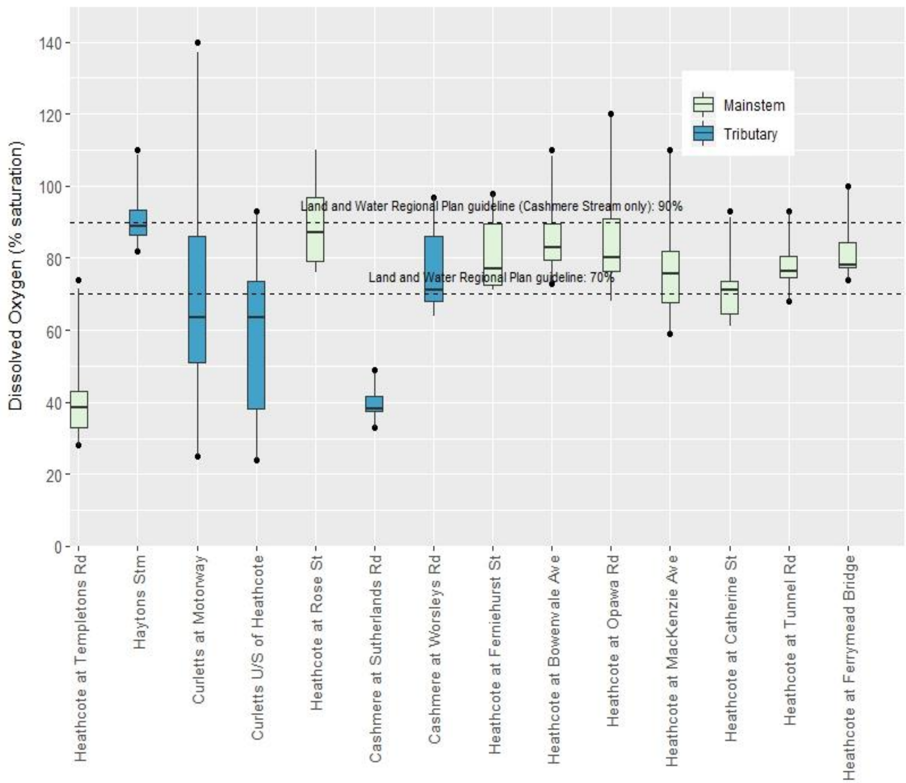


Figure ix (a). Dissolved oxygen levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The lower and upper dashed lines represent the Land and Water Regional Plan minimum guideline value for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (70%), and Banks Peninsula waterways (90%; Cashmere Stream only), respectively (Environment Canterbury, 2017).

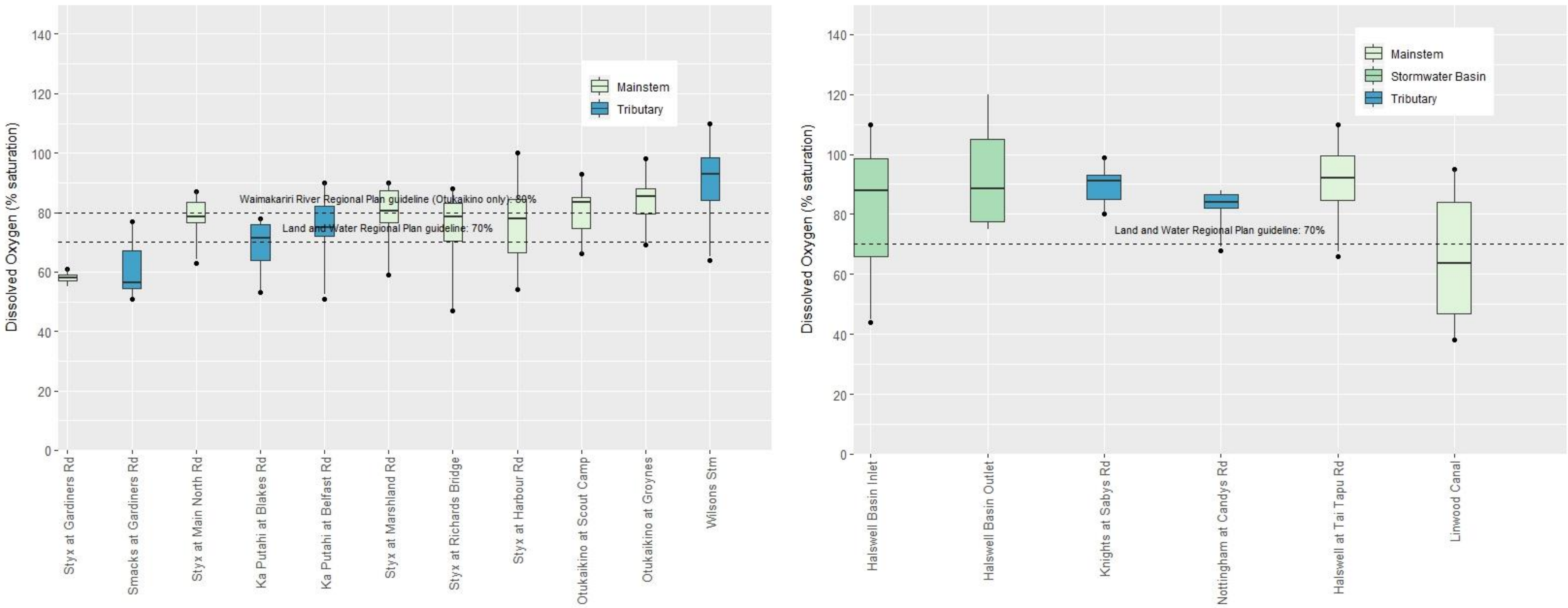


Figure ix (b). Dissolved oxygen levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The lower dashed line represents the Land and Water Regional Plan minimum guideline value for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (70%, Environment Canterbury, 2017). The upper dotted line represents the Waimakariri River Regional Plan minimum guideline value for all Ōtūkaikino sites (80%, Environment Canterbury, 2011).

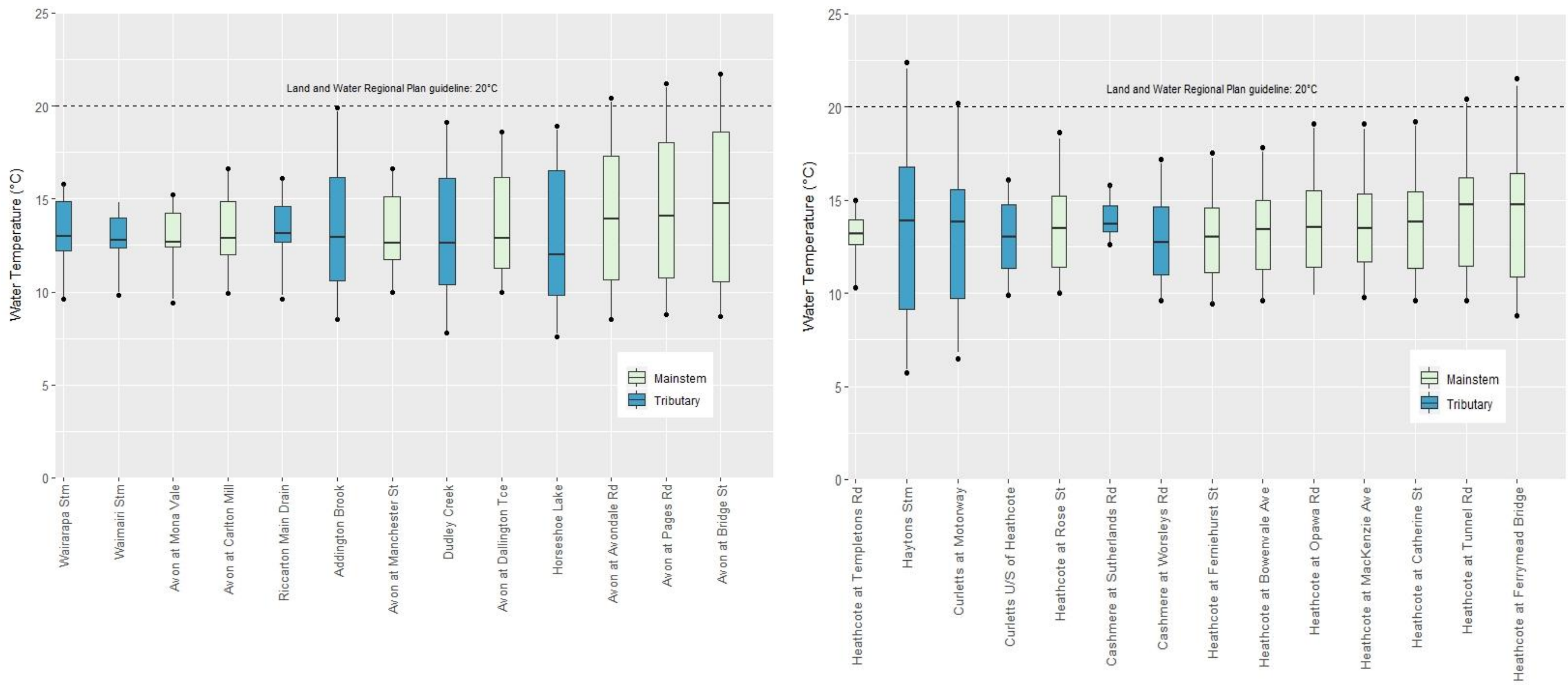


Figure x (a). Temperature of the water at the time of sampling at the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed line represents the Land and Water Regional Plan maximum guideline value (20ºC, Environment Canterbury, 2017).

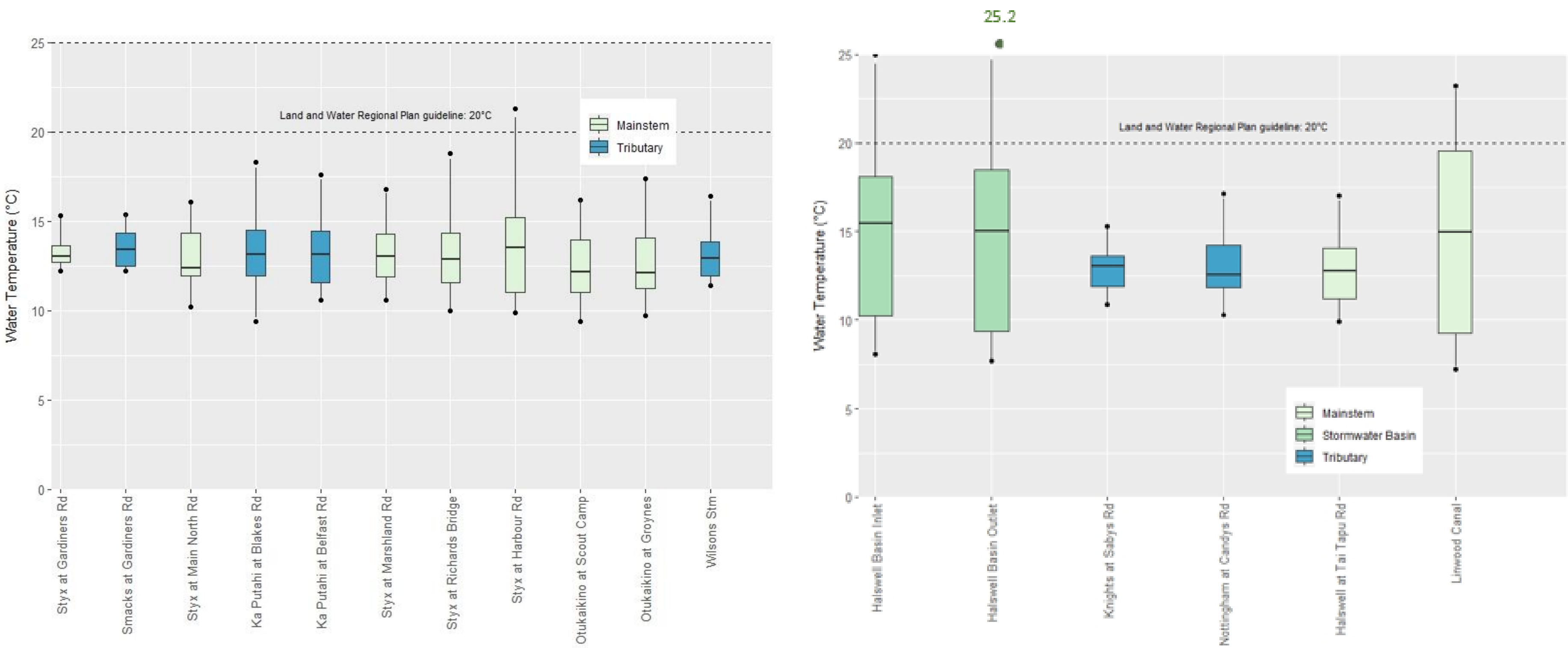


Figure x (b). Temperature of the water at the time of sampling at the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan maximum guideline value (20ºC, Environment Canterbury, 2017). The Waimakariri River Regional Plan maximum guideline value for all Ōtūkaikino sites is 25ºC (Environment Canterbury, 2011).

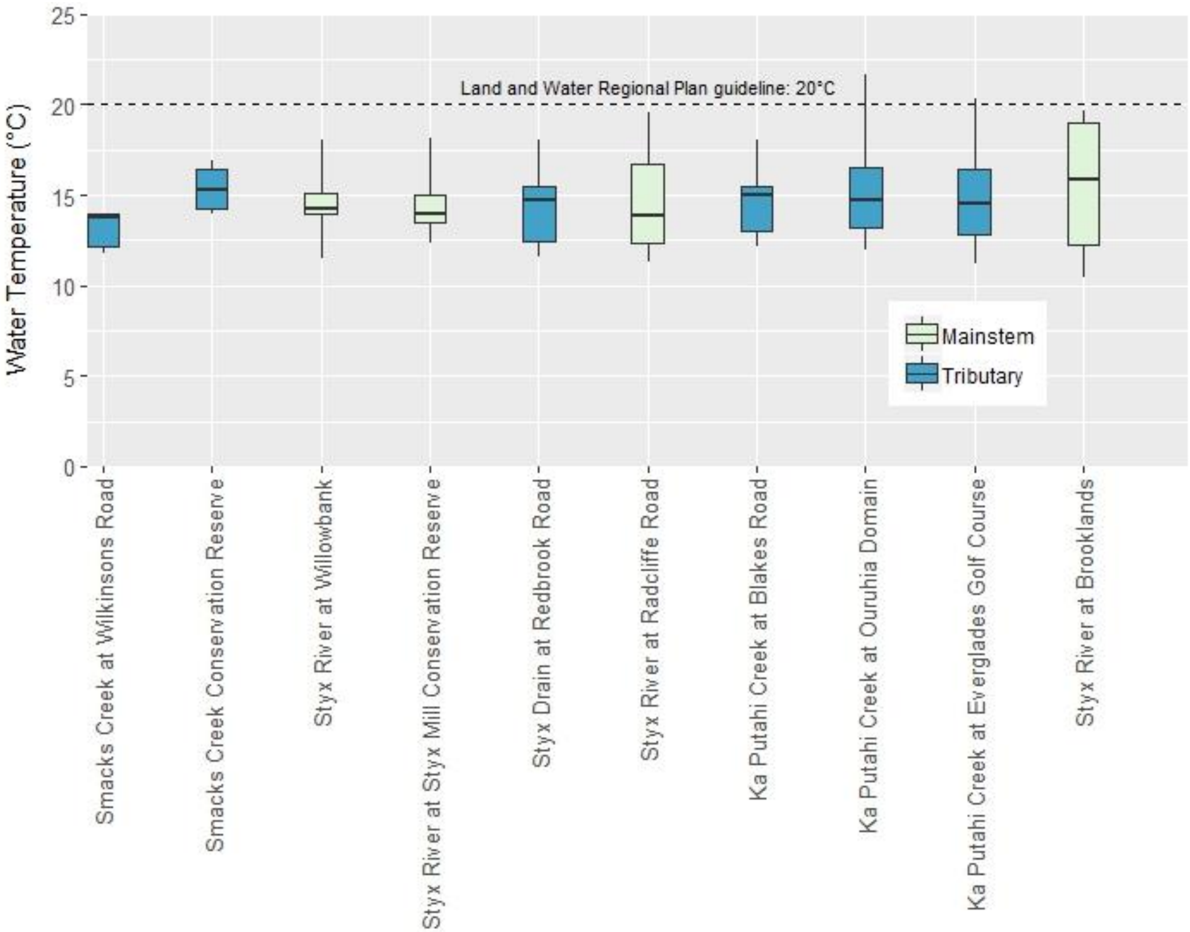


Figure x (c). Temperature of the water at the time of sampling by the Styx Living Laboratory Trust volunteers for the monitoring period January to December 2018 (n = 4 – 11 samples per site). Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan maximum guideline value (20 ºC, Environment Canterbury, 2017).

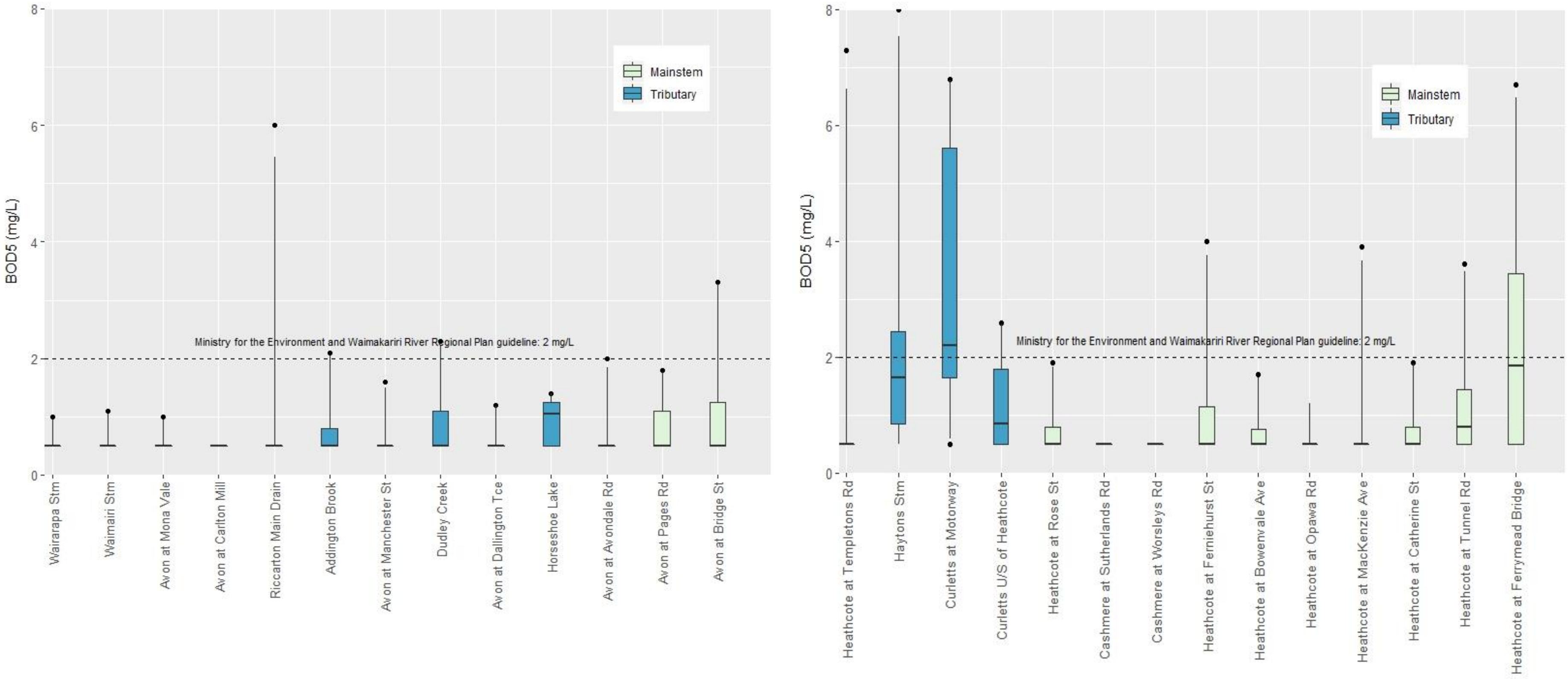
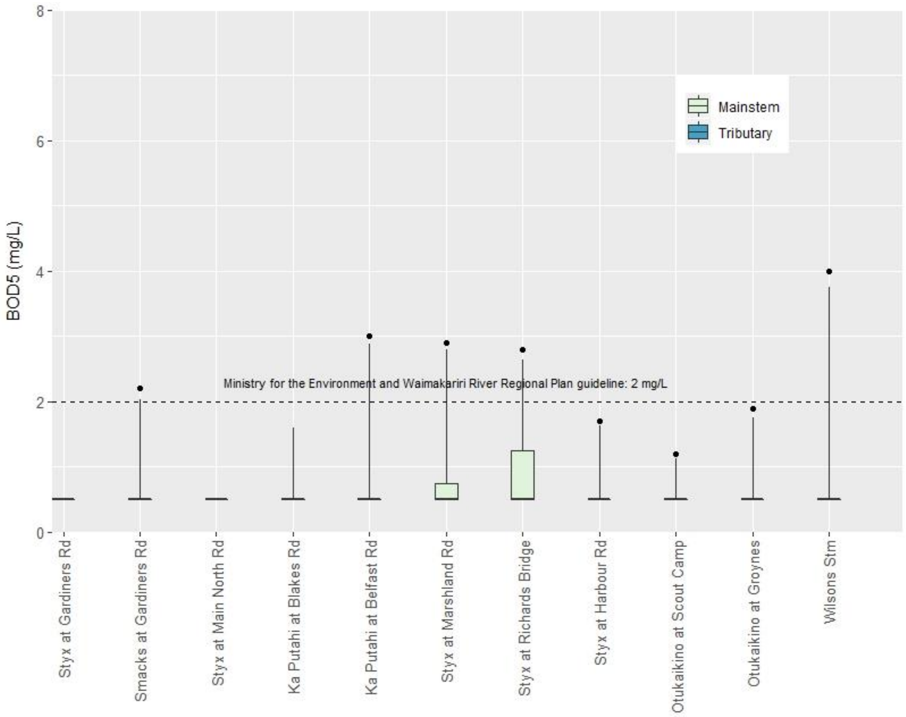


Figure xi (a). Biochemical Oxygen Demand (BOD_5) levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent both the Ministry for the Environment and Waimakariri River Regional Plan guideline value (2 mg/L; Ministry for the Environment, 1992; Environment Canterbury, 2011). The Laboratory Limit of Detection was 1.0 mg/L, analysed as half this value (0.5 mg/L) to allow statistics to be undertaken.



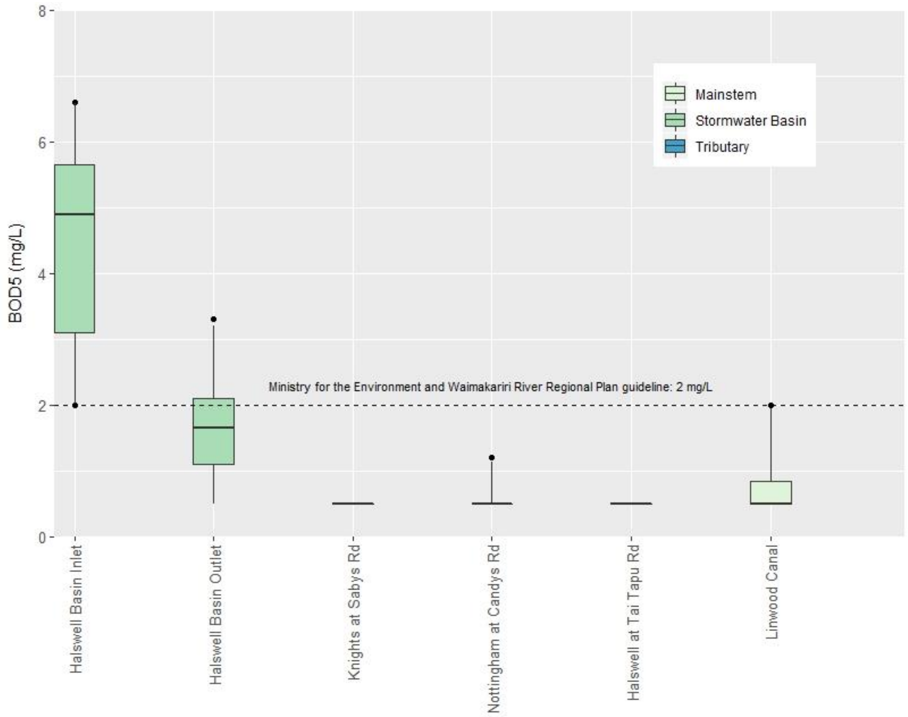


Figure xi (b). Biochemical Oxygen Demand (BOD_5) levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent both the Waimakariri River Regional Plan and Ministry for the Environment guideline value (2 mg/L; Ministry for the Environment, 1992; Environment Canterbury, 2011). The Laboratory Limit of Detection was 1.0 mg/L, analysed as half this value (0.5 mg/L) to allow statistics to be undertaken.

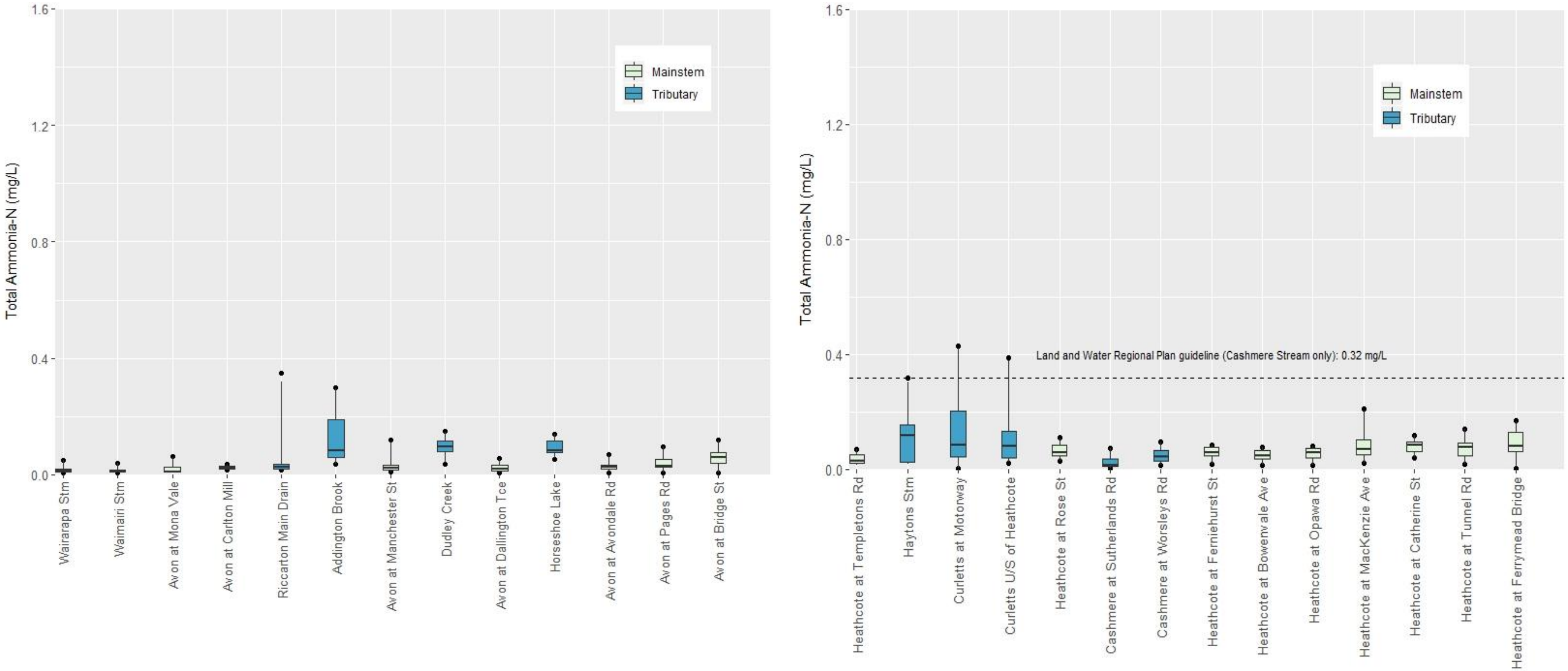


Figure xii (a). Total ammonia levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The Land and Water Regional Plan guideline value of 1.88 mg/L (Environment Canterbury, 2017), which has been adjusted in accordance with median pH levels for the monitoring period of 7.3 for both the Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments, is not presented on the graph as it is off the scale. The dashed line represents the Land and Water Regional Plan maximum guideline value for Banks Peninsula waterways (0.32 mg/L, Cashmere Stream only; Environment Canterbury, 2017). The Laboratory Limit of Detection was 0.005 mg/L – analysed as half this value (0.0025 mg/L) to allow statistics to be undertaken.

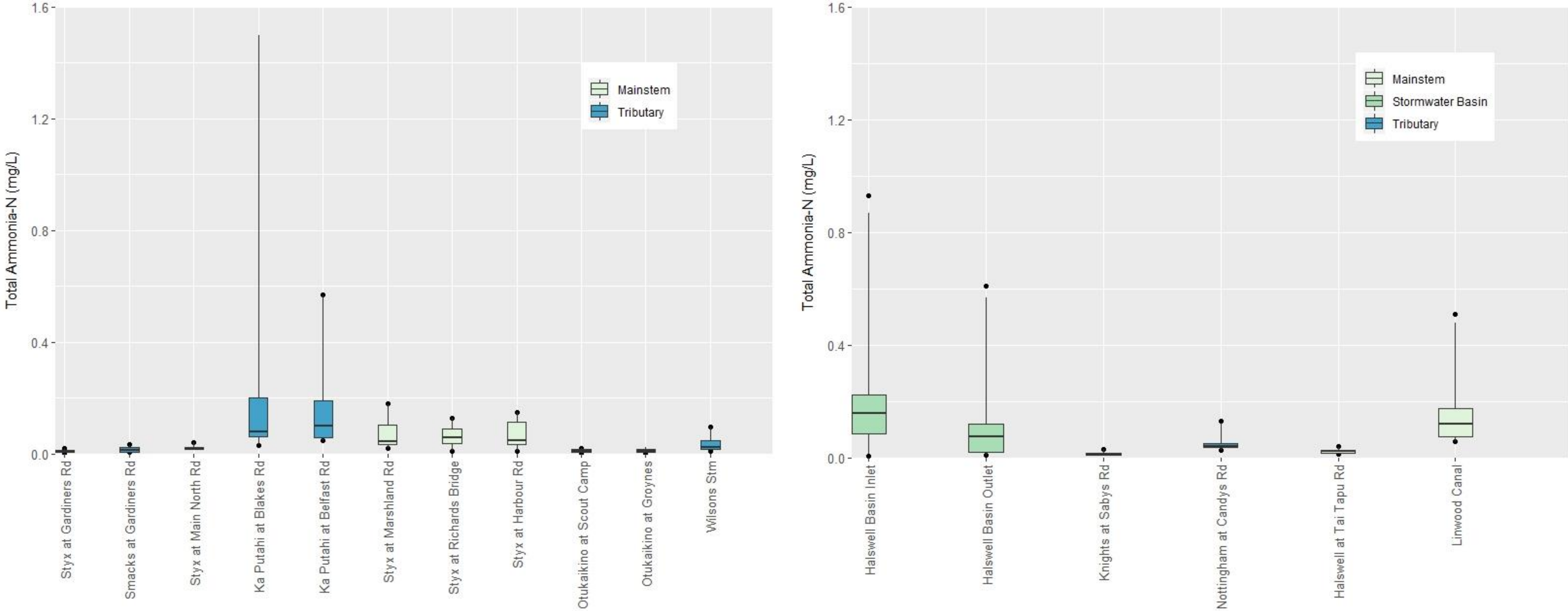


Figure xii (b). Total ammonia levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The Land and Water Regional Plan guideline values (Pūharakekenui/ Styx catchment: 1.99 mg/L, Ōtūkaikino catchment: 2.09 mg/L, Huritini/ Halswell catchment: 1.75 mg/L, Linwood Canal: 1.61 mg/L,; Environment Canterbury, 2017), adjusted in accordance with median pH levels for the monitoring period (Pūharakekenui/ Styx catchment: 7.2, Ōtūkaikino catchment: 7.1, Huritini/ Halswell catchment: 7.4, Linwood Canal: 7.5), are not presented on the graph as they are off the scale. The Laboratory Limit of Detection was 0.005 mg/L – analysed as half this value (0.0025 mg/L) to allow statistics to be undertaken.

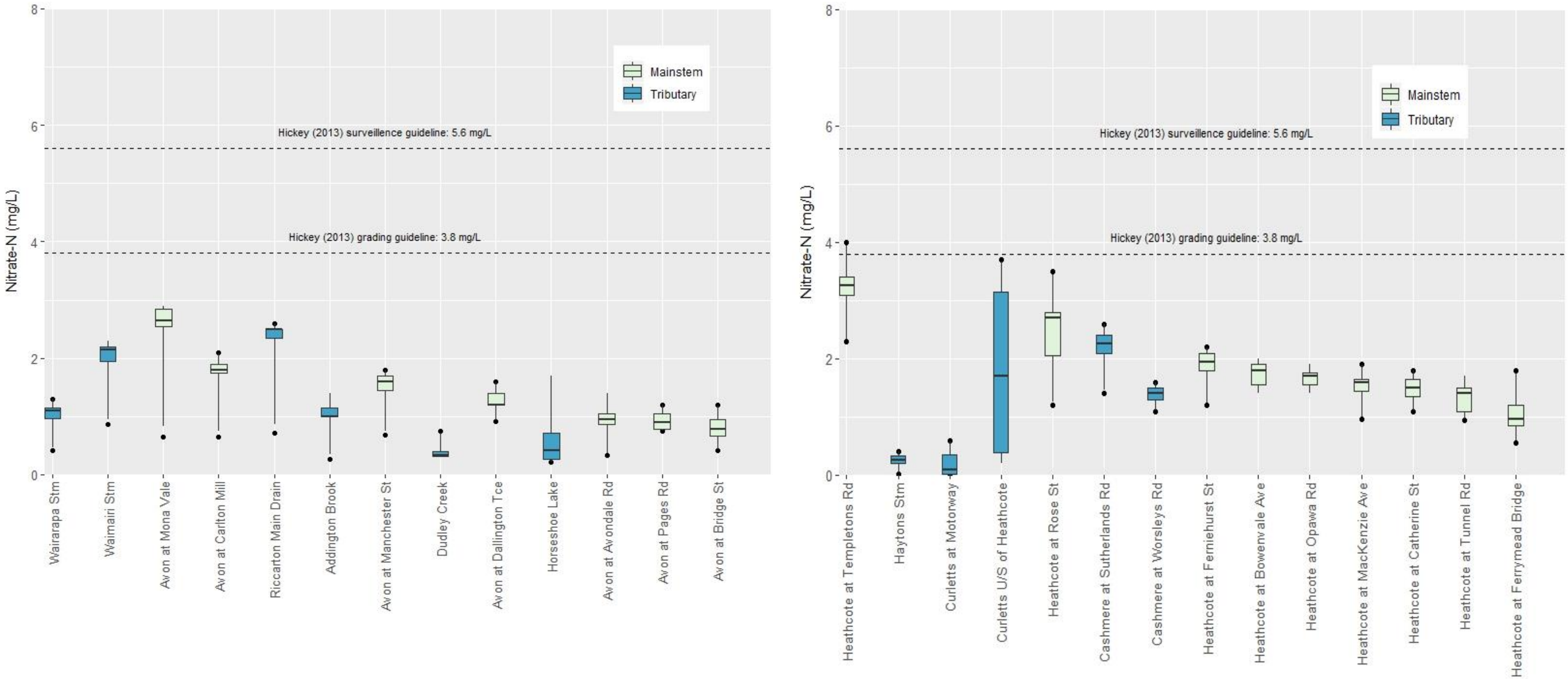
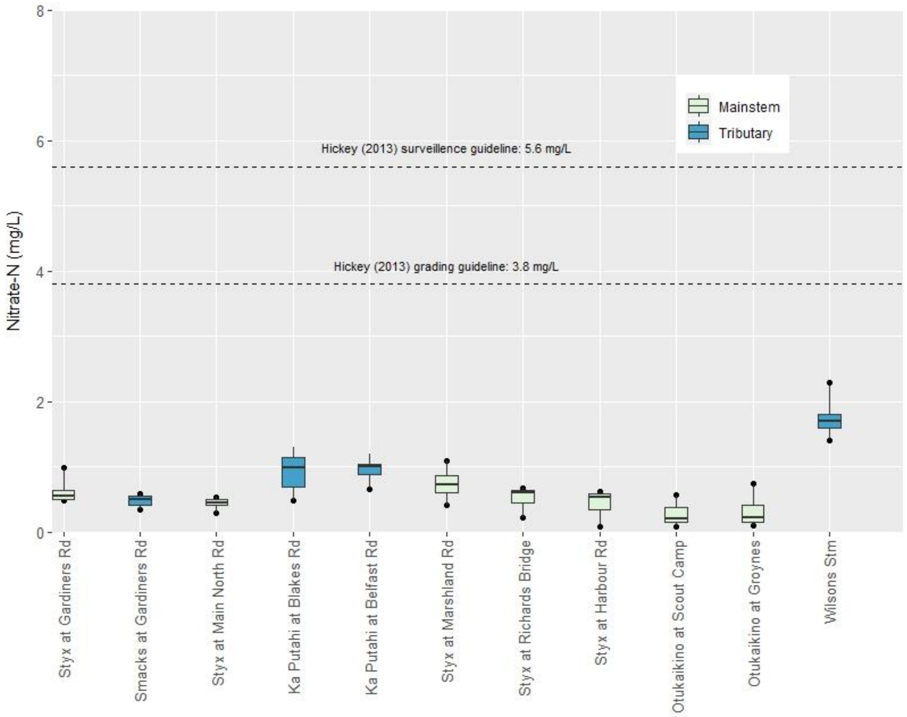


Figure xiii (a). Nitrate-nitrogen levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed and solid lines represent the Hickey (2013) grading (3.8 mg/L) and surveillance (5.6 mg/L) guideline levels, respectively. The Laboratory Limit of Detection was 0.05 mg/L – analysed as half this value (0.025 mg/L) to allow statistics to be undertaken.



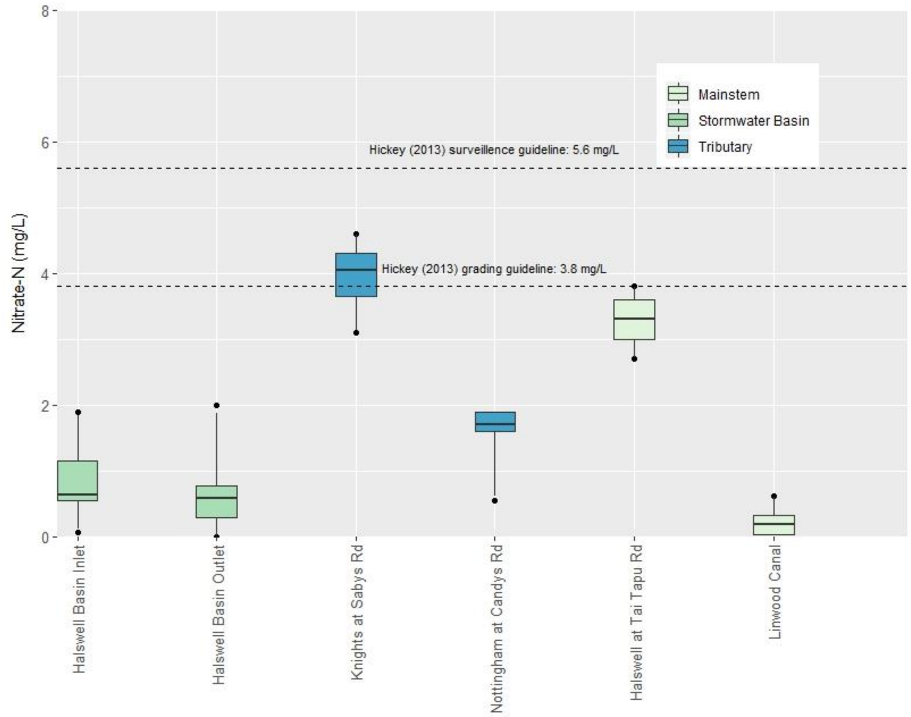


Figure xiii (b). Nitrate levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino Rivers (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018.Sites are ordered from upstream to downstream (left to right). The dashed and solid lines represent the Hickey (2013) grading (3.8 mg/L) and surveillance (5.6 mg/L) guideline levels, respectively. The Laboratory Limit of Detection was 0.05 mg/L – analysed as half this value (0.025 mg/L) to allow statistics to be undertaken.

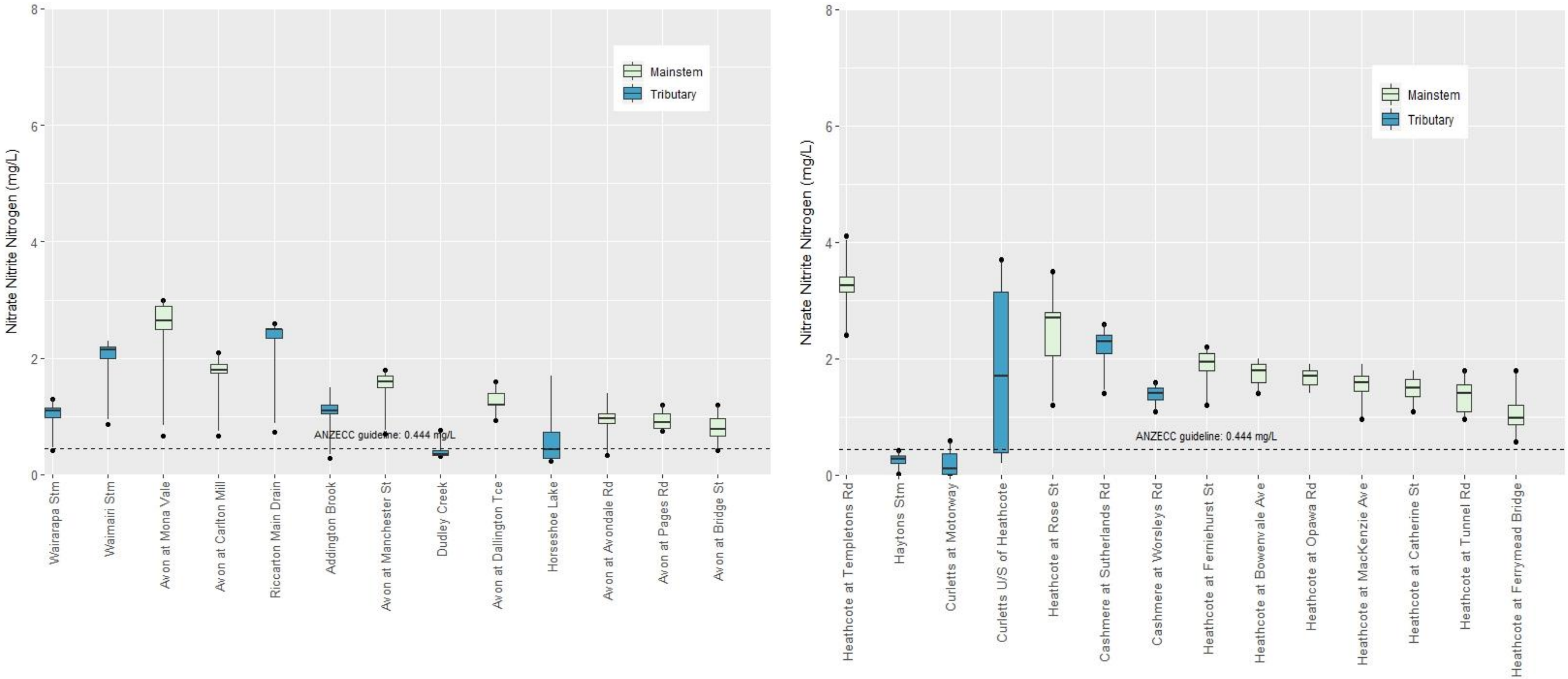


Figure xiv (a). Nitrate Nitrite Nitrogen (NNN) in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018.Sites are ordered from upstream to downstream (left to right). The dashed lines represent the ANZECC water quality guideline (0.444 mg/L; ANZECC, 2000). The Laboratory Limit of Detection was 0.005 mg/L – analysed as half this value (0.0025 mg/L) to allow statistics to be undertaken.

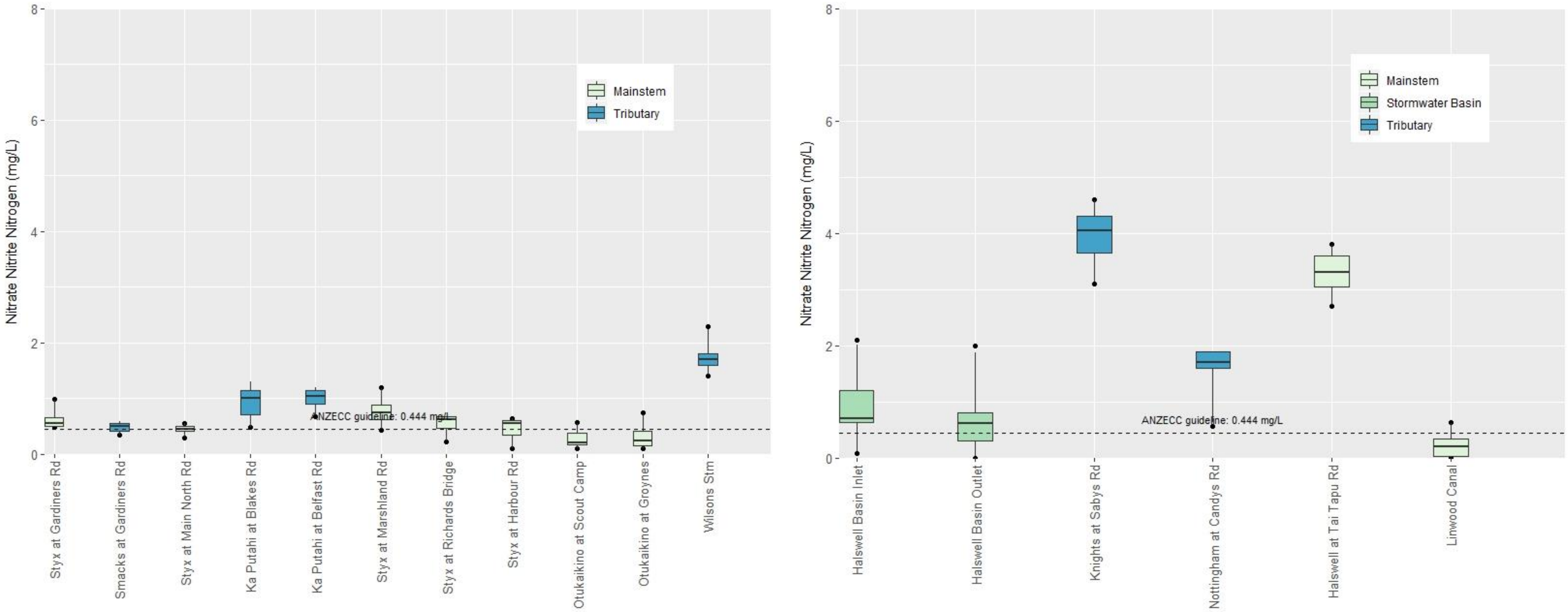


Figure xiv (b). Nitrate Nitrite Nitrogen (NNN) levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the ANZECC water quality guideline (0.444 mg/L; ANZECC, 2000). The Laboratory Limit of Detection was 0.005 mg/L – analysed as half this value (0.0025 mg/L) to allow statistics to be undertaken.

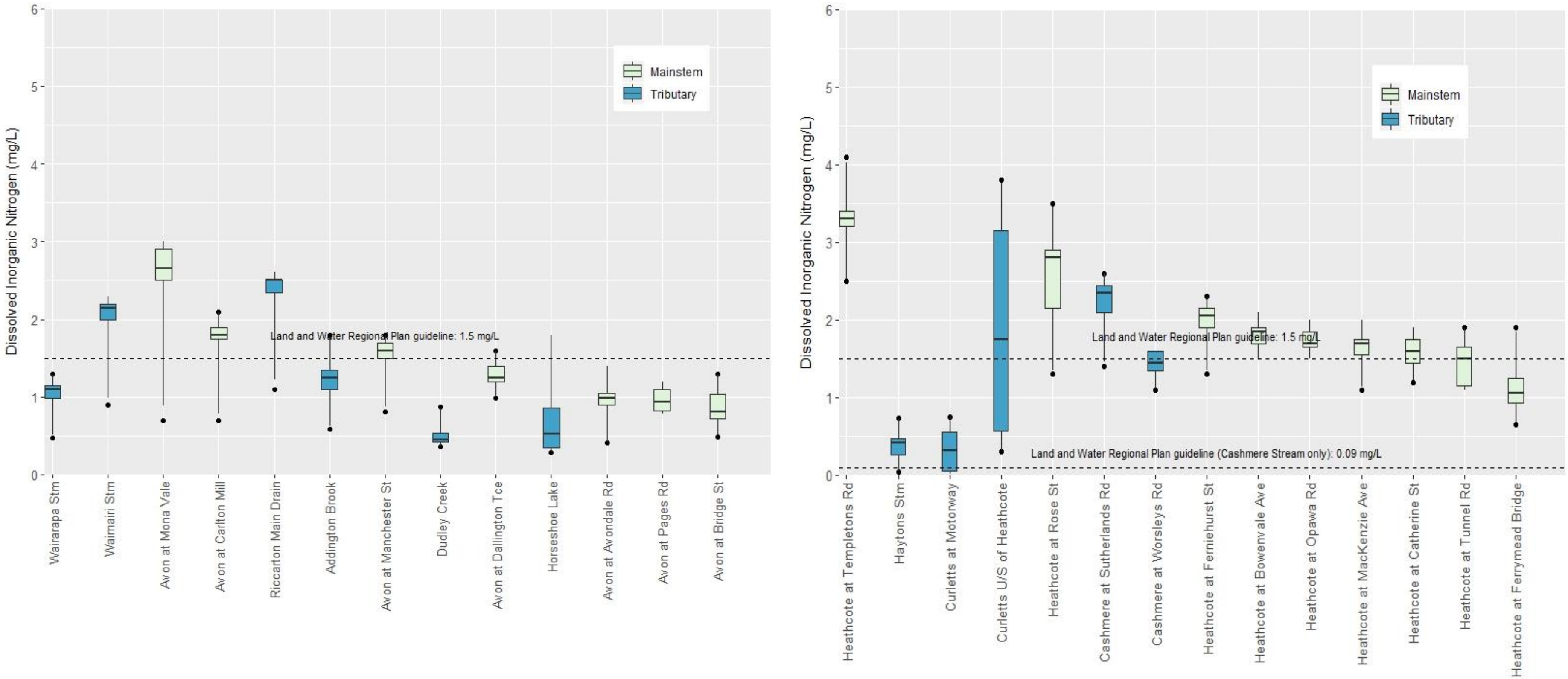


Figure xv (a). Dissolved Inorganic Nitrogen (DIN) levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018.Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value of 1.5 mg/L for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways, and 0.09 mg/L for Banks Peninsula waterways (Cashmere Stream only), respectively (Environment Canterbury, 2017).

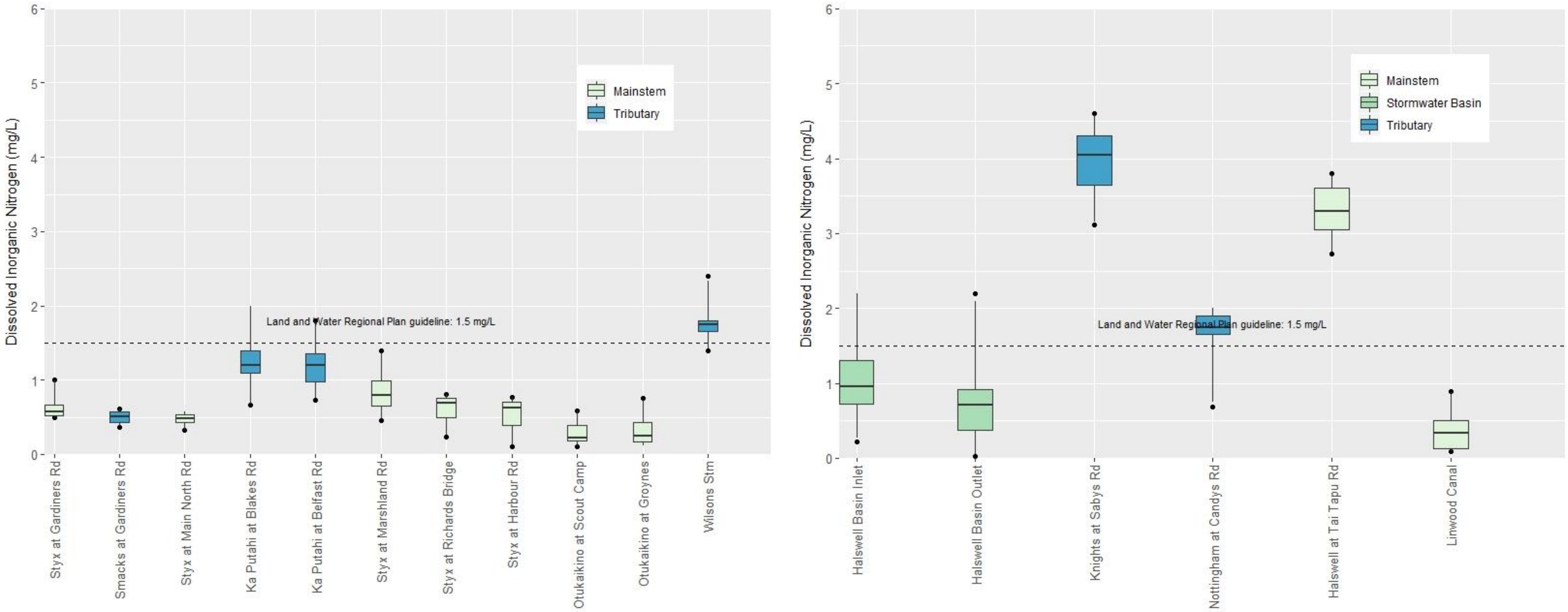


Figure xv (b). Dissolved Inorganic Nitrogen (DIN) levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways of 1.5 mg/L (Environment Canterbury, 2017). The Laboratory Limit of Detection was 0.02 mg/L – analysed as half this value (0.01 mg/L) to allow statistics to be undertaken.

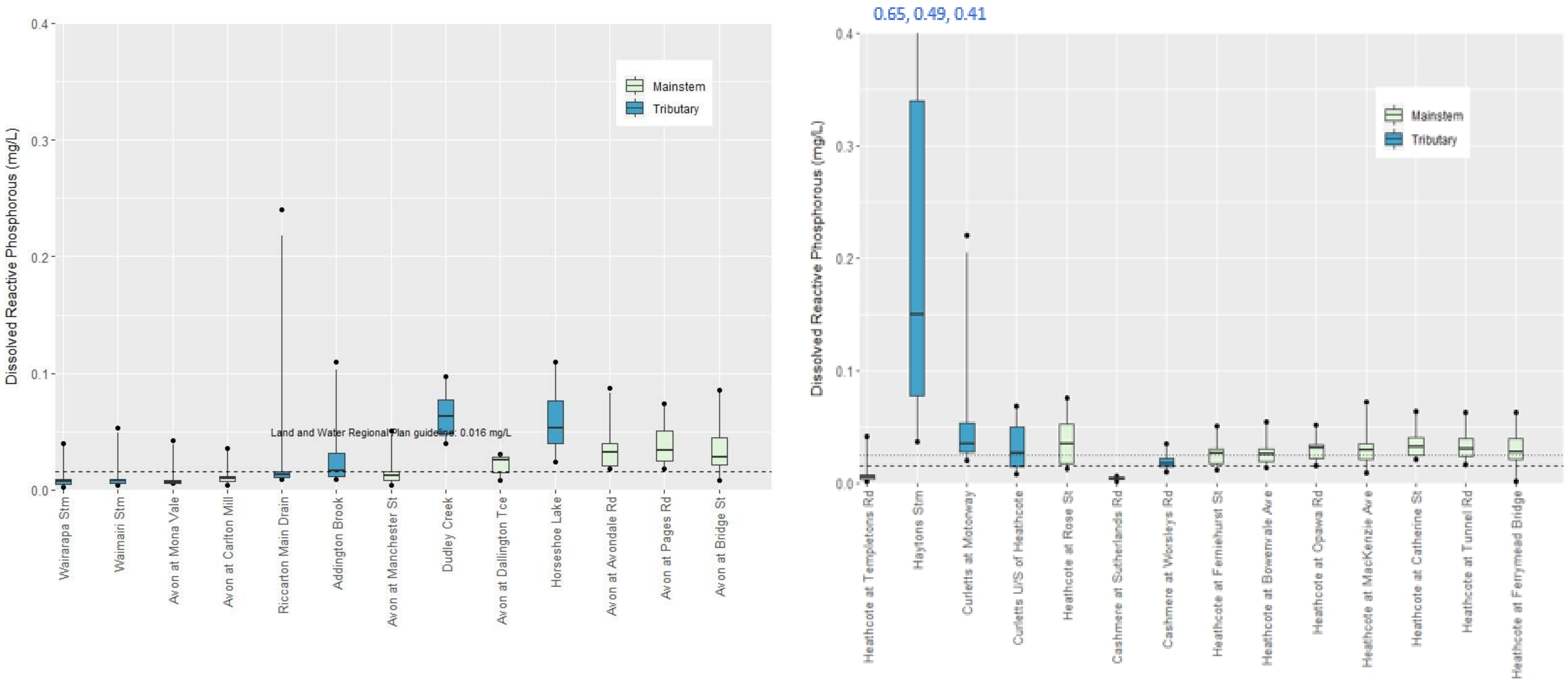


Figure xvi (a). Dissolved Reactive Phosphorus (DRP) levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value of 0.016 mg/L for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways, and the dotted line (right graph only), represents the Land and Water Regional Plan trigger value of 0.025 mg/L for Banks Peninsula waterways (Cashmere Stream only), (Environment Canterbury, 2017). The Laboratory Limit of Detection was 0.003 mg/L, analysed as half this value (0.0015 mg/L) to allow statistics to be undertaken.

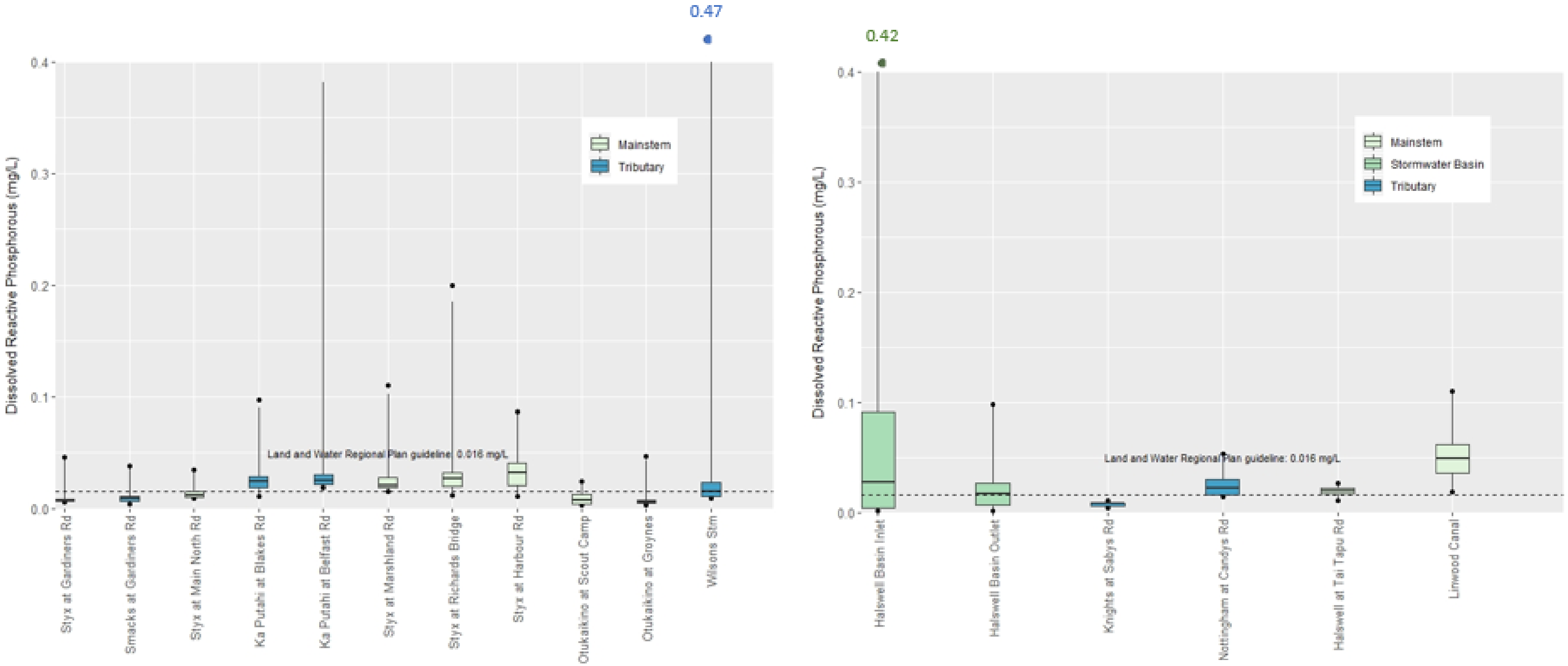


Figure xvi (b). Dissolved Reactive Phosphorus (DRP) levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018.Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value of 0.016 mg/L for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (Environment Canterbury, 2017). The Laboratory Limit of Detection was 0.003 mg/L, analysed as half this value (0.0015 mg/L) to allow statistics to be undertaken.

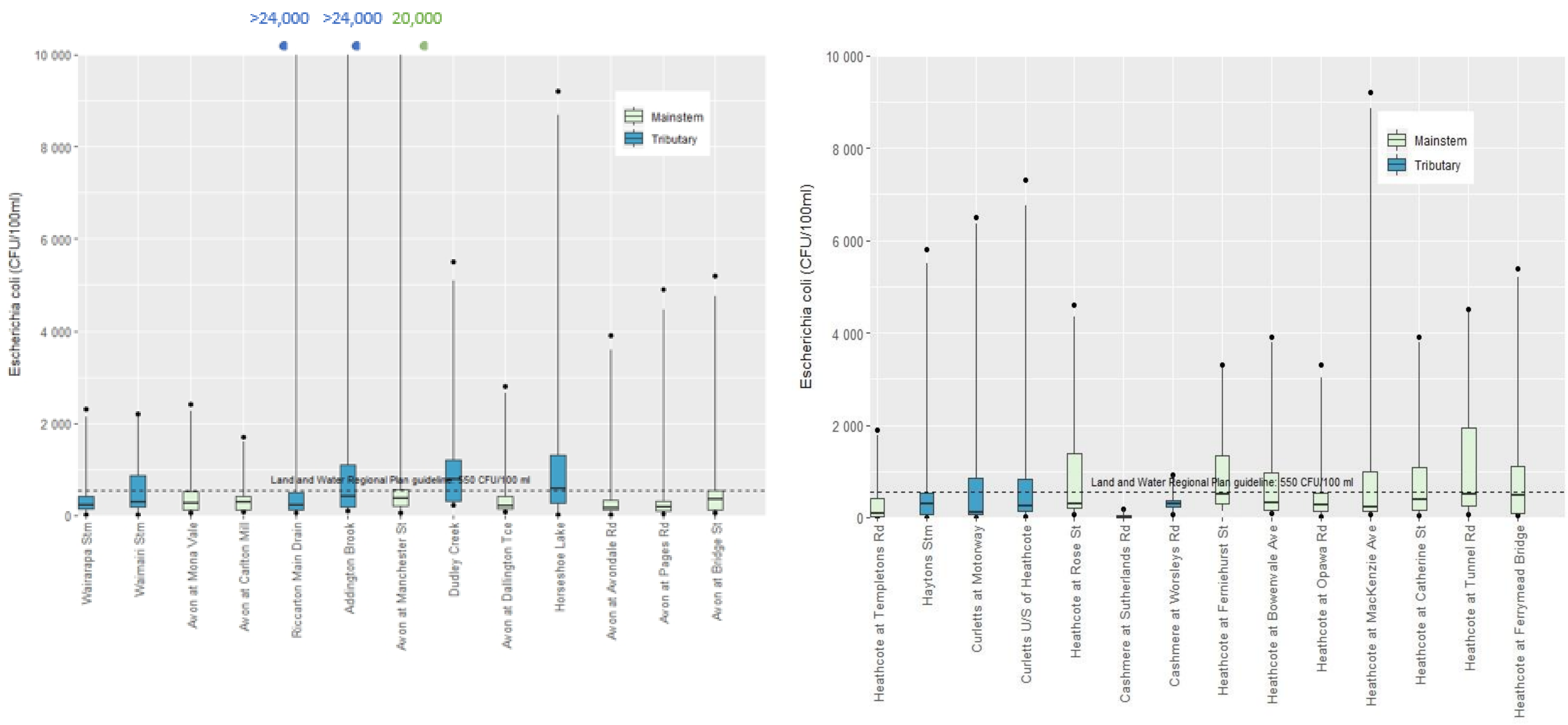
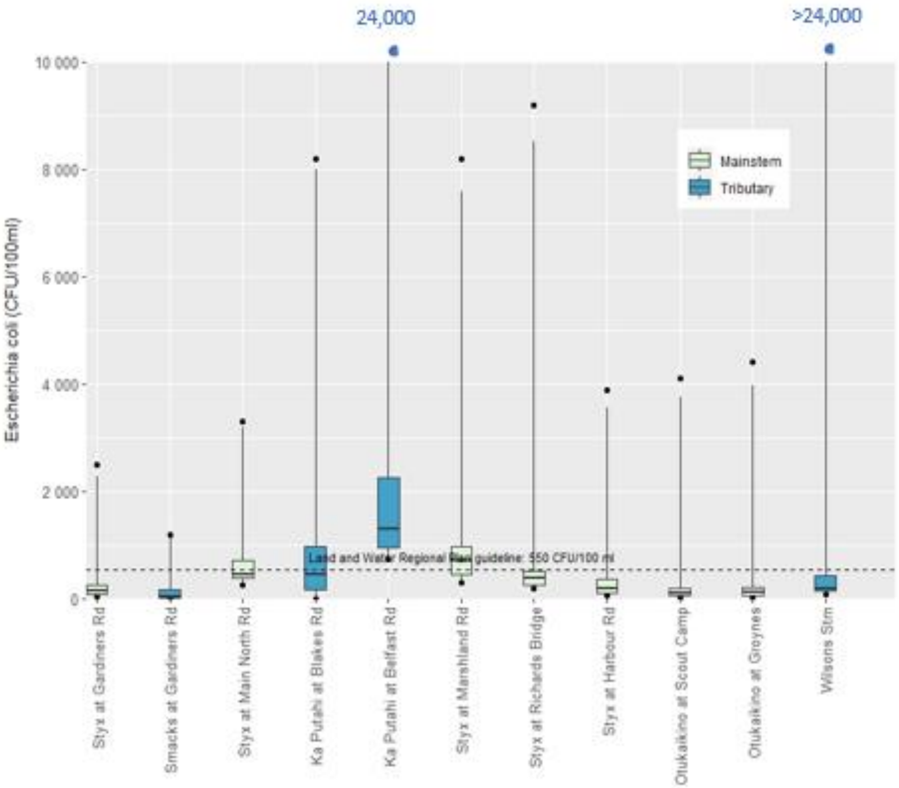


Figure xvii (a). *Escherichia coli* levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2018.Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value of 550 CFU/100ml for 95% of samples for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (Environment Canterbury, 2017). The Laboratory Limit of Detection varied depending on the necessary dilution of the sample, but all were analysed as half this value to allow statistics to be undertaken.



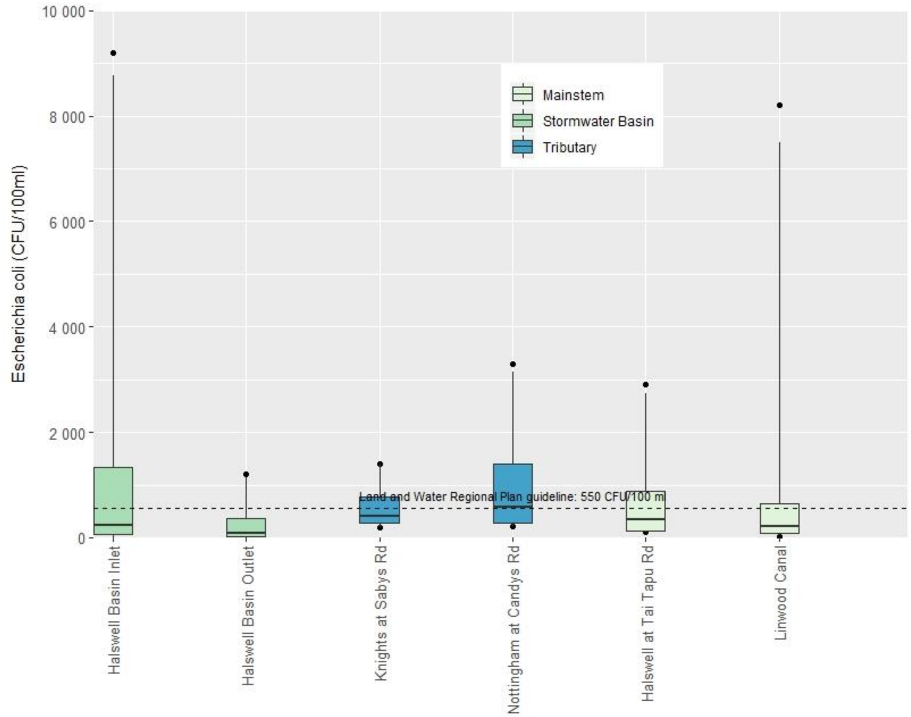


Figure xvii (b). *Escherichia coli* levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2018. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan trigger value of 550 CFU/100ml for 95% of samples for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (Environment Canterbury, 2017). The Laboratory Limit of Detection varied depending on the necessary dilution of the sample, but all were analysed as half this value to allow statistics to be undertaken.