Christchurch City Council

Surface Water Quality Monitoring Report for Christchurch City Waterways: January – December 2019

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Executive Summary

- This report summarises the results of the Christchurch City Council (CCC) surface water quality monitoring for the period January to December 2019, 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 was conducted at four of the eight monthly sampling sites in the Pūharakekenui/ Styx River catchment, and at seven of the thirteen monthly sampling sites in the Ōtākaro/ Avon River catchment. The Pūharakekenui/ Styx River sampling was due to be collected in 2018; however, unfavourable weather meant that only one suitable event occurred, and the final sample was not collected until 2019.
- Results of community monitoring at eleven 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 for monthly samples 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 7,440 of these allowing the assessment of each waterway site against relevant guideline levels. There were several parameters that were recorded at concentrations unlikely to cause adverse effects, including dissolved lead, total ammonia and pH. However, 20% of all samples did not meet the guideline level, with 98% of sites not meeting the guideline for at least one parameter. The contaminants of most concern were nitrogen, phosphorus, *E. coli*, dissolved zinc, and dissolved copper, as well as turbidity, dissolved oxygen and TSS at certain sites. The concentrations of all parameters have mostly remained steady over time, with some improvements and declines in water quality.
- Most waterways recorded a Water Quality Index (WQI) of 'poor'. The Ōpāwaho/ Heathcote catchment recorded the poorest water quality of all the catchments overall. Changes in catchment WQI between 2013 and 2018 were variable. The site with the lowest WQI was Curletts at Motorway, followed by Heathcote at Tunnel Rd site, and then the Haytons Stm and Heathcote at Ferrymead Bridge sites. The Ōtūkaikino River catchment recorded the best WQI of all the catchments, and the site with the highest WQI was Styx at Main North Rd in the Pūharakekenui/ Styx River 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 causing 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 2019 to December 2019. 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).

In December 2019, the CCC was granted a new stormwater consent for the City and Banks Peninsula, the Comprehensive Stormwater Network Discharge Consent (CSNDC; CRC190445). The IGSC, South-West SMP and Styx SMP have therefore now been surrendered. Monitoring under the CSNDC did not begin until January 2020 and therefore next year's report will be the first under this consent.

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 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 in strongly tidal areas, where sampling is undertaken at low tide (± 30 minutes)[2].

The results of community monitoring at 11 sites in the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust (SLLT)[3] are also presented in this report (Table 1). The Styx River catchment was due to be monitored during two wet weather occasions in 2018; however, a lack of suitable rain events meant that sampling extended into 2019. The Avon River catchment was monitored during two wet weather occasions in 2019. The results of both wet weather monitoring rounds are presented in this report.

[1] Avon at Carlton Mill, Avon at Avondale Rd, Heathcote at Catherine St, Heathcote at Mackenzie Ave, Haytons Stm, Curletts at Motorway
[2] Avon at Bridge St, Avon at Pages Rd, Heathcote at Ferrymead Bridge, Heathcote at Tunnel Rd and Linwood Canal
[3] More information about this community group, including their monitoring programme, can be found at https://www.thestyx.org.nz/styx-living-laboratory-trust

Table 1. Christchurch City Council water quality monitoring sites required under the three 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 (Tai Tapu Road)	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] Proposed Plan Change 7 to the LWRP proposes that these locations are classified as 'spring-fed - plains'. As such these sites are treated as spring-fed - plains' in this report.
[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[7]
	N/A	Styx River at Willowbank	1567218	5187641	N/A	Unclassified[7]
	N/A	Styx River at Styx Mill Conservation Reserve	1567918	5187613	N/A	Unclassified[7]
	N/A	Styx Drain at Redbrook Road	1568628	5069246	N/A	Unclassified[7]
	N/A	Rhodes Drain at Hawkins Rd	1571548	5187060	N/A	Unclassified[7]
	N/A	Horner's Drain at Hawkins Rd	1571569	5187095	N/A	Unclassified[7]
	N/A	Styx River at Radcliffe Road	1571720	5187413	N/A	Unclassified[7]
	N/A	Kā Pūtahi Creek at Blakes Road	1570925	5068237	N/A	Unclassified[7]
	N/A	Kā Pūtahi Creek at Ouruhia Domain	1571771	5190129	N/A	Unclassified[7]
	N/A	Kā Pūtahi Creek at Everglades Golf Course	1571798	5189270	N/A	Unclassified[7]
	N/A	Styx River at Brooklands	1575110	5193308	N/A	Unclassified[7]

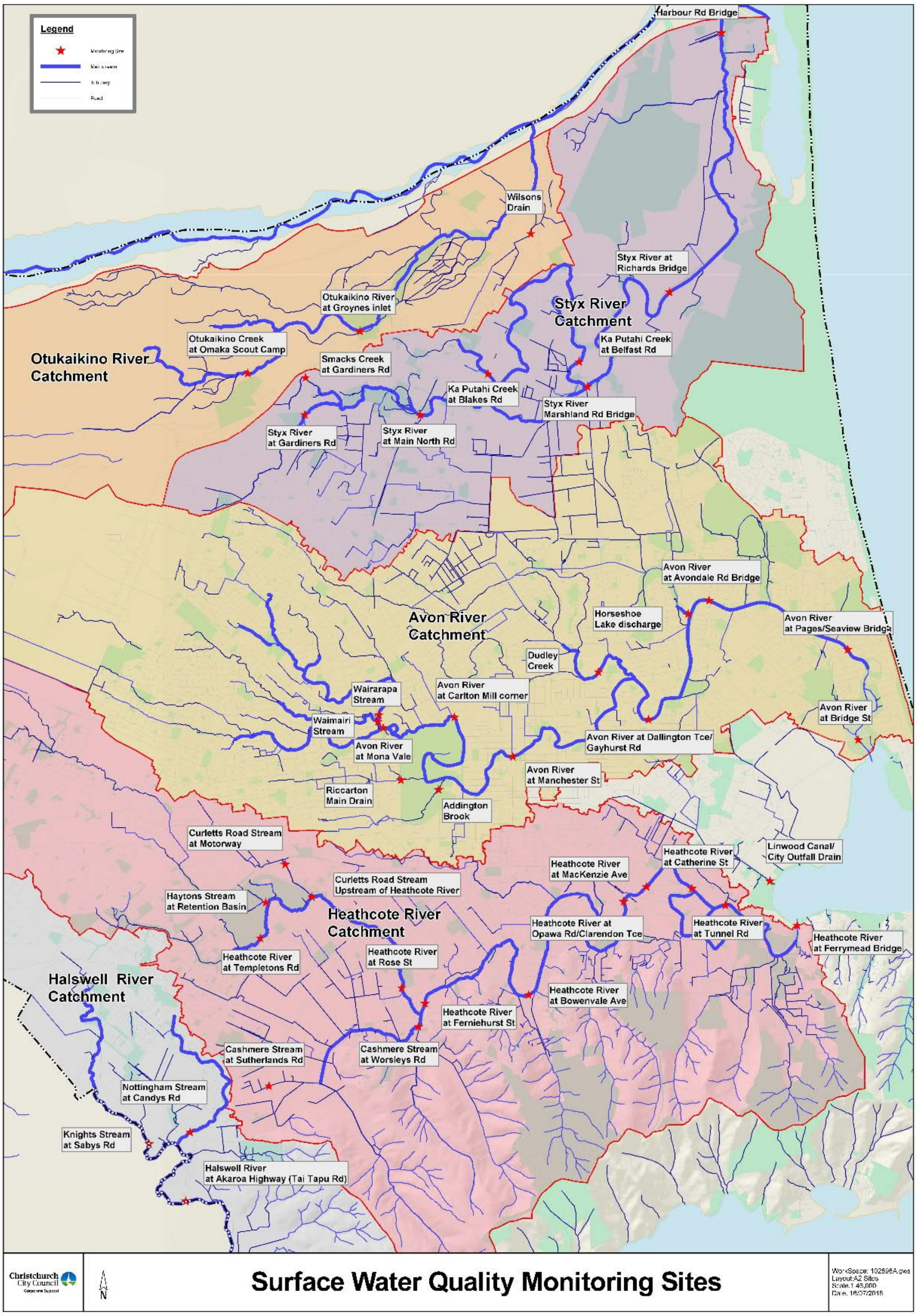

Figure 1. Location of Christchurch City Council surface water quality monitoring sites

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 2019 monitoring year, no monitoring was undertaken at the Haytons Stm site in March and June, as the site was dry, and at the Kā Pūtahi at Blakes Rd site in August and Ōtūkaikino at Scout Camp site in February, as these sites could not be accessed.

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 6 – 10. Of note:

- 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

Wet weather monitoring of the Pūharakekenui/ Styx River catchment was required by the Styx SMP in 2018. However, due to insufficient rain events, a second event could not be sampled until 2019. Therefore, the results are present in this 2019 monitoring report, rather than the 2018 report. The wet weather samples from this catchment were collected on the 3rd of September 2018 and 4th of September 2019. Total Petroleum Hydrocarbons (TPH) were unable to be analysed during the first event due to a sampling error. In the 2019 monitoring year, wet weather monitoring was required in the Ōtākaro/ Avon River catchment under the IGSC. Wet weather samples were collected in this catchment on the 18th of October and 17th of December 2019. Wet weather samples from both catchments were collected via grab sampling, and field testing of temperature and oxygen using a hand-held meter (YSI Pro ODO meter). Wet weather events were required to meet the following criteria:

- Minimum of a three-day dry period prior to sampling[11]
- Minimum of 5 mm total rainfall depth[12]
- Catching of the "First Flush" (considered to be up to the first 15-25mm; Christchurch City Council, 2003), by sampling within 1 – 2 hours of the desired rainfall depth being achieved (this means that tide cycles do need to be taken into consideration for tidal sites)

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 are required to be tested at all sites (e.g. turbidity), 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.

[11] On advice from Dr Aisling O'Sullivan (University of Canterbury) that even 24 hours is sufficient time for contaminants to accumulate

[12] Based on modelling by Peter Christensen (CCC) for Avon SMP that shows this is a 'typical' Christchurch storm event

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

Parameter	Units of Measurement
Total ammonia (ammoniacal nitrogen)	mg/L
Dissolved 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	MPN/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 (TPH)*	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, 2019) 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 highest species protection level (99%) applies to 'Banks Peninsula' waterways, while 'spring-fed – plains' waterways are given a 95% species protection level, and 'spring-fed – plains – urban' waterways have 90% species protection (Environment Canterbury, 2019). These species protection levels apply to toxicants (metals and ammonia), Dissolved Oxygen (DO), Dissolved Inorganic Nitrogen (DIN) and Dissolved Reactive Phosphorous (DRP).

The WRRP does not have guideline levels for several 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. Proposed Plan Change 7 to the LWRP proposes to classify the currently unclassified Pūharakekenui/ Styx River as 'spring-fed – plains'. 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 lead and zinc in freshwater, and therefore the risk of adverse biological effects, alters depending on several abiotic factors. These factors include, but are not limited to, organic carbon, hardness, pH, temperature, alkalinity and inorganic ligands (Warne *et al*., 2018). The LWRP refers to default ANZG (2018) guidelines for metals. However, current recommendations are to modify these default guideline levels by water hardness (ANZG, 2018; Warne *et al*., 2018). As such, CCC has recently updated the Hardness Modified Guideline Values (HMGV) for dissolved lead and zinc, in accordance with ANZG (2018) and Warne *et al*., (2018) (see Appendix B). In contrast to ANZECC (2000), it is no longer recommended to modify the default copper guideline by water hardness (ANZG, 2018; Warne *et al*., 2018). Alternative methods to modify guideline values for abiotic factors based on updated knowledge have been proposed but are not yet finalised.

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, 2019). 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. This approach is consistent with current recommendations from ECan; however, this guideline will be reviewed in future reports, following publication of the proposed changes to the National Policy Statement for Freshwater Management (Michele Stevenson, ECan, personal communication, 19 June 2020).

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.

DO is the concentration of oxygen dissolved or freely available in water and is commonly expressed as percent saturation. Adequate DO concentrations 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). However, guidelines will be reviewed in future reports, following publication of the proposed changes to the National Policy Statement for Freshwater Management (Michele Stevenson, ECan, personal communication, 19 June 2020).

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 concentrations 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, the data presented in this report is conservative, as it relates to total BOD_5, instead of the guideline requirement of filtered.

Total ammonia (ammoniacal nitrogen) is typically a minor component of the nitrogen available for plant growth, but at high concentrations 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, 2019). 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 95th 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). However, guidelines will be reviewed in future reports, following publication of the proposed changes to the National Policy Statement for Freshwater Management (Michele Stevenson, ECan, personal communication, 19 June 2020).

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 guideline 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.

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.

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 concentrations, but can cause eutrophication at high concentrations. 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.

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 concentrations 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 RStudio (Version 1.2.5033). To allow statistical analyses of monthly samples, concentrations less than the LOD were converted to half the detection limit. In some years, monthly *E.coli* concentrations exceeded the maximum laboratory limit for counting (24,000 MPN/100ml) and were analysed as 24,000, although concentrations may have been much higher than this. There were two such *E. coli* cases during the 2019 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 concentrations. 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 14 (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. A change was considered meaningful when there was a statistically significant positive or negative result of greater than 1% (NIWA, 2020). In previous reports, any statistically significant results between -0.99 and 0.99 were identified, but this is no longer considered appropriate, given the above information defining what is meaningful. Time Trends (V 6.3) accommodates for variable LODs, and the option for using censored concentrations in Sen slope calculation was selected. 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 five new sites in 2018/2019: Kā Pūtahi at Blakes Rd, Styx Drain at Redbrook Rd, Smacks at Wilkinsons Rd, Rhodes Drain at Hawkins Rd and Horner's Drain at Hawkins Rd. Therefore, there was insufficient data to run trends analysis for these sites.

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. However, a flow recorder is only directly present at one of the sites (Heathcote at Ferniehurst St). 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. 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. To ensure accurate comparisons between sites, the flow data for Heathcote River at Ferniehurst St was not used.

This monitoring year, an issue was encountered when analysing the BOD_5 data in Time Trends. At most sites the direction of change could be calculated, but not the magnitude (i.e. %). This was due to the programme being unable to deal with the high proportion of censored (below the LOD) data. It is unclear whether this will continue to be an issue in future reports, as it is dependent on the results of future testing. CCC is currently investigating lowering the LOD to mitigate these potential impacts.

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 – 39.99), 'poor' (40 – 69.99), 'fair' (70 – 79.99), 'good' (80 – 89.99) 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. The update to the hardness modified guideline values for dissolved metals affected the calculation of the WQI. Therefore, WQI scores from 2013–2018 were recalculated using the new dissolved copper and zinc guideline values, to enable accurate temporal changes to be determined (Section 2.3; Appendix B). 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 RStudio (Version 1.2.5033). 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 were 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- 2019 inclusive. Trends analysis was conducted using Time Trends (NIWA, 2020). 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. A change was considered meaningful when there was a statistically significant positive or negative result of greater than 1% (NIWA, 2020).

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.
- Over the last five years rainfall has been variable, including dry years (2015 and 2016), wet years (2017 and 2018) and intermediate years (2019) (Figure 2).
- For the 2019 monitoring year (for the CCC monthly data only) the Ōtūkaikino catchment recorded the most number of sampling days affected by rain (47%), followed by the Pūharakekenui/ Styx River catchment (44%), Ōtākaro/ Avon River catchment (29%), Linwood Canal catchment (25%), Ōpāwaho/ Heathcote River catchment (15%) and Huritini/ Halswell River catchment (8%). This was based on observations of the water quality samplers as to whether it had rained within the 24 hours prior to sampling.

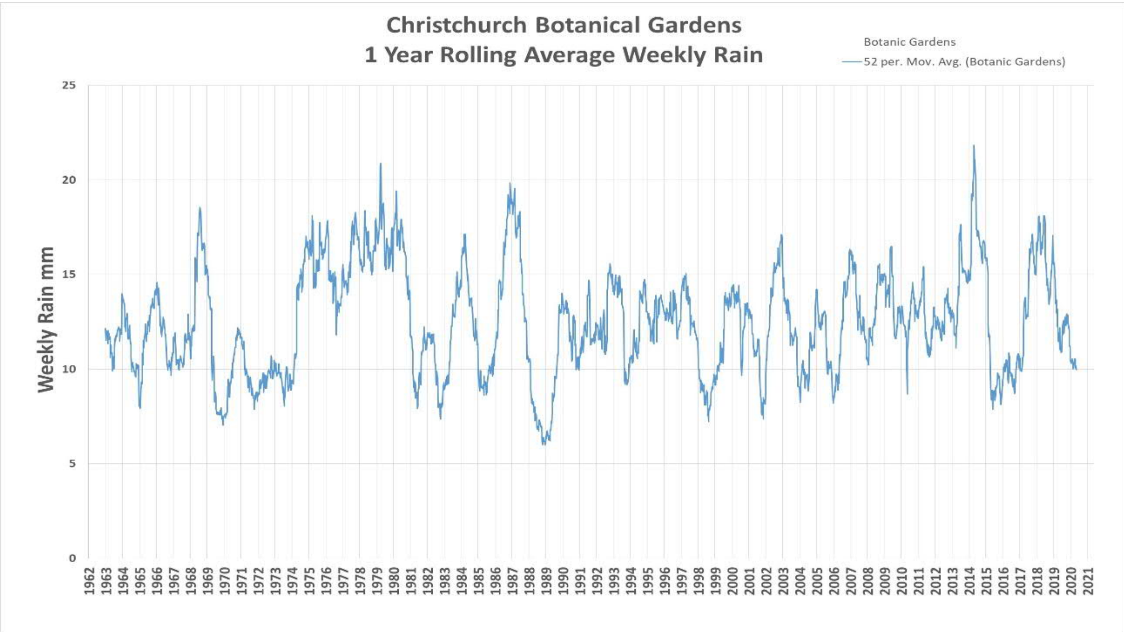

Figure 2. Average weekly rainfall at the Botanic Gardens in Hagley Park

3.2 Water Quality Parameters

3.2.1 Summary

- Over 11,000 tests were conducted during the monitoring year for the CCC monthly monitoring, with 7,440 of these allowing the assessment of each waterway site against relevant guideline levels (Table 3). Twenty percent of these samples did not meet the guideline level, with 41 sites (97.6%) not meeting the guideline for at least one parameter.

- The parameters that were exceeded at the most sites were *E. coli* (36 sites), NNN (32 sites), and DRP and dissolved copper (both 23 sites). The NNN guideline was exceeded most frequently (80% of samples), followed by DRP (54% samples) and DIN (41% of samples).
- Most parameters did not change in concentration since monitoring began, with 420 (64%) parameter-site combinations recording no significant upwards or downwards trends in concentrations (Appendix D, Tables i–iv). However, 182 (28%) parameter-site combinations recorded a significant improvement in water quality, 50 (8%) recorded a significant decline in water quality, and 1 (0.2%) recorded a significant change that could represent either a decline or improvement in water quality (pH).
- The majority of sites across all catchments recorded a small decrease in BOD_5, DRP and NNN/DIN. Many sites in the Pūharakekenui/ Styx River recorded an increase in *E. coli* concentrations.
- The largest increases in parameter concentrations at individual sites were:
    - 17% for NNN and 15% for DIN at the Ōtūkaikino at Scout Camp site, due to some high peaks in concentrations in 2017–2019 (Figures 3 – 4)
    - 16% in dissolved zinc at Curletts at Motorway, due to a steady increase over time, particularly since 2019 (Figure 5)
- The largest decreases in parameter concentrations at individual sites were:
    - 33% for total ammonia (driven by concentrations peaking in 2011 and a gradual decrease in concentrations since then), 28% for dissolved lead (due to peak concentrations in 2014-2016 and generally lower concentrations since then) and 19% for TSS at the Halswell Basin Outlet site (with concentrations generally decreasing over time, particularly since 2012) (Figures 6 – 7, 10)
    - 31% for NNN and 24% for DIN at the Curletts at Motorway site, due to lower concentrations since 2016 (Figures 8 – 9)
- Whilst not classified as one of the largest changes over time above, the following results are of interest:
    - 12% increase in copper at the Curletts at Motorway site, due to a large increase since early 2019
    - 16% and 13% reduction in copper and lead, respectively, at Curletts U/S of Heathcote, due to steady decreases over time
    - 13%, 13%, 10%, 16% and 16% reduction in zinc at Wairarapa Stm, Heathcote at Templetons, Styx at Gardiners, Smacks at Gardiners and Otukaikino at Groynes, respectively
    - 12% increase in ammonia at the Wilsons Stm site, due to a steady increase over time; however, concentrations are still low overall. This is of note as this trend is unusual, and this parameter is extremely toxic to biota and is typically associated with industry.
    - 18% decrease in DRP at Cashmere Stream at Sutherlands Rd, due to reductions in large peaks since 2014
- Although there was no significant change in either TSS or turbidity at the Cashmere at Worsleys Rd site, there is potentially a steady increase in these parameters occurring, and this should be assessed carefully in next year's report to see if concentrations decrease or increase (Figures 11–12).

3.2.2 Dissolved Copper

- 95th percentiles for most sites in the Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments, as well as at the Ōtūkaikino at Groynes and Linwood Canal sites exceeded their respective guideline levels (Appendix E, Figure i (a) – (b)).
- Copper concentrations were generally higher in the Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments compared to the other catchments.
- Addington Brook, Haytons Stm and Curletts at Motorway recorded higher concentrations that the other waterway sites.
- Of the three highest concentrations recorded (0.018 mg/L, 0.017 mg/L and 0.014 mg/L), all were from the Curletts at Motorway site and only the lowest of these concentrations was associated with rain.
- The Halswell Basin sites recorded concentrations generally higher than the waterway sites, except for the Curletts at Motorway site. Concentrations were higher at the inlet compared to the outlet.
- Concentrations have remained stable (i.e. there were no significant trends) since regular monitoring of dissolved metals was instigated, except for the Curletts U/S of Heathcote (decrease of 16%), Halswell Basin Outlet (decrease of 7%) and Curletts at Motorway (increase of 12%) sites (Appendix D, Tables i–iv).

3.2.3 Dissolved Lead

- All 95th percentiles for each site complied with the respective guidelines (Appendix E, Figure ii (a) – (b)).
- Lead concentrations were generally higher in the Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments compared to the other catchments.
- The three highest concentrations were all from the lower Heathcote River: Heathcote at Mackenzie Ave (0.0096 mg/L), Heathcote at Catherine St (0.0059 mg/L) and Heathcote at Tunnel Rd (0.0049 mg/L). Only the highest concentrations was associated with rain; however, all three samples were taken during a period when upstream dredging was occurring (CCC, *unpublished data*).
- Concentrations with the Halswell Basin sites were generally higher compared to most waterway sites, and higher at the inlet than the outlet.
- Much higher lead concentrations were recorded at the Heathcote at Catherine St, Heathcote at Tunnel Rd and Heathcote at Ferrymead Bridge sites compared to 2018. These samples were all associated with upstream dredging.
- Concentrations remained stable over time at all sites except the Halswell Basin Outlet (Figure 7), Dudley Creek and Curletts U/S of Heathcote sites, which recorded 32%, 15%, and 13% reductions, respectively (Appendix D, Tables i–iv).

3.2.4 Dissolved Zinc

- 95th percentiles for most sites in the Ōtākaro/ Avon, approximately half of the sites in the Ōpāwaho/ Heathcote catchments, as well as the Kā Pūtahi at Blakes Rd and Nottingham at Candys Rd sites, all exceeded their respective guideline levels (Appendix E, Figure iii (a) – (b)).
- Zinc concentrations were generally higher in the Ōtākaro/ Avon and Ōpāwaho/ Heathcote catchments compared to the other catchments.
- The three highest concentrations (0.77 mg/L, 0.60 mg/L and 0.52 mg/L) were from the Curletts at Motorway site and only the second highest was associated with rain.

- Concentrations in the Halswell Basin sites were generally higher than the waterway sites.
- Sites within areas with high industrial and commercial land use, such as Addington Brook, Curletts Stream and Haytons Stream, typically had higher concentrations than the rest of their respective catchments.
- Concentrations have generally remained stable since sampling was instigated (Appendix D, Tables i–iv). A few sites showed large decreases: Wairarapa Stm (13%), Heathcote at Templetons Rd (13%), Styx at Gardiners Rd (11%), Smacks at Gardiners Rd (16%) and Ōtūkaikino at Groynes (17%). However, large increases were recorded at Curletts at Motorway (16%; Figure 5), with a particularly large peak recorded in April of the monitoring year, and Heathcote at Ferrymead Bridge (14%).

3.2.5 pH

- Medians of all CCC and SLLT waterway sites complied with the guideline levels (Appendix D, Figure iv (a) – (c)).
- The three highest values at the waterway sites were from Haytons Stm (9.5), Curletts at Motorway (8.6) and Avon at Pages Rd (8.2 on two occasions), and Avon at Bridge St (8.2), with none of these values recorded in association with rain. The lowest recorded pH of 6.5 was at the Heathcote at Templetons Rd site and was not associated with rain.
- The Halswell Basin sites recorded substantially higher pH than the waterway sites. Levels were slightly lower at the outlet than the inlet.
- Concentrations remained stable over time, except for small very changes at Ōtūkaikino at Scout Camp and most SLLT sites where trends analysis could be run (Appendix D, Tables i–v).

3.2.6 Conductivity

- No relevant guidelines exist for conductivity.
- The tidal sites had greater conductivity and variability in 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 Basin sites had levels comparable to the waterway sites, and levels were slightly lower at the outlet.
- Conductivity at the SLLT sites were similar to the CCC waterway sites.
- Of particular note was a substantial increase at the three lower sites in the Heathcote catchment compared to 2018. At these sites, medians increased by 1.5–3.7 fold, minimums by 1–4 fold and maximums by 1.7–12.6 fold.
- Concentrations generally did not change over time by any large degree, with increases from 1–8% and decreases from 1–4% (Appendix D, Tables i–v).

3.2.7 TSS

- Medians of all waterway sites complied with the guideline level, except for Heathcote at Tunnel Rd and Heathcote at Ferrymead Bridge (Appendix D, Figure vi (a) – (b)).
- The three highest TSS concentrations were recorded from the Ōpāwaho/ Heathcote catchment in association with dredging: Heathcote at Opawa Rd (310 mg/L, 210 mg/L) and Heathcote at Mackenzie Ave (140 mg/L), with no concentrations recorded in association with rain.

- The Halswell Basin Inlet generally recorded concentrations higher than the waterway sites. Concentrations were lower at the outlet than the inlet.
- Typically, 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. Concentrations were particularly high at the Cashmere at Worsleys Rd site compared to the other non-tidal sites.
- Concentrations at the Heathcote at Mackenzie Ave site were much higher in 2019 compared to 2018.
- The Halswell Basin Outlet was the only site to record a substantial change in concentrations over time, with a 20% decrease recorded (Figure 10; Appendix D, Tables i–iv).

3.2.8 Turbidity

- The medians of the following sites exceeded the guideline: Addington Brook, Avon at Bridge St, Haytons Stm, Cashmere at Worsleys Rd, Heathcote at Ferniehurst St, Heathcote at Opawa Rd, Heathcote at Tunnel Rd, Heathcote at Ferrymead Bridge and Linwood Canal (Appendix D, Figure vii (a) – (b)).
- The three highest turbidity readings were recorded from the Ōpāwaho/ Heathcote catchment: Heathcote at Opawa Rd (110 NTU, 140 NTU) and Heathcote at Tunnel Rd (46 NTU). None of these recordings were associated with rain; however, they were all recorded in association with dredging (CCC, *unpublished data*).
- The Ōpāwaho/ Heathcote River catchment, followed by the Ōtākaro/ Avon River catchment, generally recorded higher turbidity concentrations compared to the other catchments. The lower three Ōpāwaho/ Heathcote River tidal sites typically recorded higher turbidity than the other sites in this catchment. Concentrations were particularly high at the Cashmere at Worsleys Rd site compared to the other non-tidal sites from all catchments.
- The most substantial decrease over time (11%) was at the Ōtūkaikino at Groynes site and the most substantial increase (13%) was at the Wilsons Stm site (Appendix D, Tables i–iv).

3.2.1 Water Clarity (SLLT sites only)

- The medians of all sites did not comply with the guidelines, except for Smacks at Wilkinsons Rd and Styx Drain at Redbrook Rd (Appendix D, Figure viii).
- The three highest values were from Horner's Drain at Hawkins Rd (32 cm, 35 cm and 45 cm).
- Except for Horner's Drain at Hawkins Rd and Rhodes Drain at Hawkins Rd, water clarity was similar across sites, and between the mainstem and tributaries.
- No substantial changes in were recorded over time (Appendix D, Table v).

3.2.2 DO

- Medians of the following sites did not meet the guideline: Horseshoe Lake, Heathcote at Templetons Rd, both Curletts Road Stream sites, both Cashmere Stream sites, Styx at Gardiners Rd, Smacks at Gardiners Rd and Linwood Canal (Appendix D, Figure ix (a) – (b)).
- The three lowest readings were 13% and 20% (Curletts U/S of Heathcote), and 23% (Curletts at Motorway). None of these records were associated with rain.

- DO concentrations were generally higher at the Halswell Basin Outlet than the Inlet, and both sites were fairly comparable to the waterway sites.
- Dissolved oxygen concentrations were lower in the Ōpāwaho/ Heathcote catchment, particularly at the upstream sites.
- Concentrations did not change over time by any large degree at any of the sites (Appendix D, Tables i–iv).

3.2.3 Water Temperature

- Medians of all CCC and SLLT sites complied with their respective guidelines (Appendix D, Figure x (a) – (c)).
- The three highest readings from the waterway sites were from Linwood Canal (22.8 °C, 22.4 °C), Heathcote at Tunnel Rd (22.4 °C) and Heathcote at Ferrymead Bridge (22.2 °C).
- The inlet and the outlet of the Halswell Retention Basin recorded similar concentrations to each other. These two sites typically recorded higher and more variable temperatures than the waterway sites.
- The SLLT sites recorded generally similar temperatures to the CCC sites.
- Concentrations did not change over time by any large degree (Appendix D, Tables i–v).

3.2.4 BOD_5

- Medians of all waterway sites complied with the guideline (Appendix D, Figure xi (a) – (b)).
- The highest concentrations recorded at the waterway sites were from Kā Pūtahi at Blakes Rd (5.9 mg/L), Curletts U/S of Heathcote (4.2 mg/L) and Haytons Stm (3.6 mg/L). None of these concentrations were recorded in association with rain.
- Concentrations in the Halswell Basin sites were generally higher than the waterway sites and concentrations were lower at the outlet.
- Concentrations were typically higher in the Ōtākaro/ Avon River and Ōpāwaho/ Heathcote River catchments.
- Compared to 2018, concentrations were markedly lower at the Curletts at Motorway and Heathcote at Ferrymead Bridge sites.
- Most sites across all catchments recorded decreases in BOD_5 since sampling began (Appendix D, Tables i–iv).

3.2.5 Total Ammonia

- 95^{th} percentiles of all sites complied with their respective guidelines (Appendix D, Figure xii (a) – (b)).
- The three highest concentrations within the waterway sites were from the Linwood Canal (0.57 mg/L, 0.56 mg/L) and Haytons Stm (0.55 mg/L) sites, with only the Haytons Stm sample associated with rain
- The Halswell Basin Inlet generally recorded concentrations higher than the waterway sites, and concentrations were substantially lower at the outlet.
- Ammonia was generally higher in the tributaries compared to mainstems.
- Over half of sites remained stable over time (Appendix D, Tables i–iv). The following sites recorded large decreases in concentrations: Halswell Basin Outlet (33%),

Halswell Basin Inlet (25%; Figure 6) and Heathcote at Ferrymead Bridge (13%). Wilsons Stm recorded a significant increase of 12%.

3.2.6 Nitrate, NNN and DIN

- All waterway sites complied with the nitrate guidelines, except for Heathcote at Templetons Rd and Knights at Sabys Rd where the median exceeded the grading guideline (Appendix D, Figure xiii (a) – (b)). Medians of most sites did not comply with the NNN guideline (Appendix D, Figure xiv (a) – (b)). The medians of over half of the sites complied with their respective DIN guideline, but the majority sites in the Ōpāwaho/ Heathcote did not (Appendix D, Figure xv (a) – (b)).
- Heathcote at Templetons Rd and Knights at Sabys Rd recorded much higher concentrations of nitrogen than the other sites, with the three highest exceedances of nitrate, NNN and DIN from these sites: Heathcote at Templetons Rd (DIN: 4.4 mg/L and 4.3 mg/L (three samples)), Knights at Sabys Rd (DIN: 4.4 mg/L (two samples), 4.3 mg/L (two samples) and 4.2mg/L). Only one record was associated with rain (4.3 mg/L at the Heathcote at Templetons Rd site).
- Both Halswell Basin sites recorded concentrations comparable to the waterway sites. Concentrations at the outlet and inlet were generally comparable.
- All three parameters typically decreased downstream in the mainstem, and were lower in the Pūharakekenui/ Styx, Ōtūkaikino and Linwood Canal catchments.
- NNN and DIN concentrations generally remained stable or decreased over time, with over 50% of sites recording a decrease in at least one parameter (Appendix D, Tables i–iv). Comparatively large decreases were recorded at Curletts at Motorway (NNN = 30%, DIN = 24%; Figures 8 and 9), Halswell Basin Outlet (DIN = 18%), Halswell Basin Inlet (DIN = 15%), and Haytons Stm (NNN = 11%, DIN = 14%). An increase in NNN (17%) and DIN (15%) was recorded at Ōtūkaikino at Scout Camp, due to some high peaks in concentrations in 2017–2019 (Figures 3–4).

3.2.7 DRP

- The medians of over half of the sites did not comply with their respective guidelines, with the majority of sites in the Ōpāwaho/ Heathcote exceeding this concentration (Appendix D, Figure xvi (a) – (b)).
- Particularly high concentrations were recorded in Haytons Stm, with the three highest concentrations (0.43 mg/L, 0.35 mg/L and 0.27 mg/L) from this site. Only the highest concentration was associated with rain.
- The Halswell Basin sites were within the higher range of the waterway sites, and concentrations were slightly lower at the outlet.
- DRP generally increased downstream in the catchments.
- Most sites recorded a decrease in DRP concentrations since monitoring began (Appendix D, Tables i–iv). The largest decreases were from Cashmere at Sutherlands Rd (18%), Ōtūkaikino at Groynes (14%), Heathcote at Ferrymead Bridge (14%), Heathcote at Templetons Rd (12%), Haytons Stm (11%), and Halswell Basin Outlet (11%). No site increased in concentration.

3.2.8 *E. coli*

- The 95th percentiles for Heathcote at Templetons Rd, Haytons Stm, Curletts U/S of Heathcote, Cashmere at Sutherlands Rd, Ōtūkaikino at Scout Camp and Ōtūkaikino at Groynes all complied with the guideline level (Appendix D, Figure xvii (a) – (b)). Concentrations were exceeded at all other sites. In 2018, Cashmere at Sutherlands Rd was the only site to comply with the guideline level.
- The highest concentration (>24,000 MPN/100ml) was recorded on one occasion each at the Riccarton Main Drain and Nottingham at Candys Rd sites. The next highest record of 16,000 MPN/100ml was from Dudley Creek, while the third highest (12,000 MPN/100ml) was from Kā Pūtahi at Belfast Rd. Only the Kā Pūtahi at Belfast Rd record was associated with rain. No *E. coli* samples were associated with a recorded CCC wastewater overflow event.
- The Halswell Basin sites were within the range of that recorded at the waterway sites, and the outlet concentrations were generally lower than the inlet.
- Concentrations generally remained stable over time (Appendix D, Tables i–iv). The largest changes were recorded at Curletts U/S of Heathcote (13% decrease) and Wilsons Stm (13% increase).

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 2019.

Parameter	Guideline	Number of Sites Monitored	Number of Samples Analysed	Number of Samples Not Meeting Guideline	Number of Sites Not Meeting Guidelines
Escherichia coli	95%th percentile <550/100ml	42	500	147 (29.4%)	36
Nitrate Nitrite Nitrogen	Median <0.444 mg/L	42	500	399 (79.8%)	32
Dissolved Reactive Phosphorus	Varies depending on catchment, from median <0.016 mg/L to <0.025 mg/L	42	500	269 (53.8%)	23
Dissolved copper	Varies depending on catchment, from 95th percentile <0.001 mg/L to ≤0.0018 mg/L	42	500	47 (9.4%)	23
Dissolved zinc	Varies depending on catchment, from 95th percentile <0.00634 mg/L to ≤0.12691 mg/L	42	500	51 (10.2%)	18
Dissolved Inorganic Nitrogen	Varies depending on catchment, from median <0.09 mg/L to <1.5 mg/L	42	500	204 (40.8%)	17
Turbidity	Median <5.6 NTU	37	440	120 (27.3%)	9
Dissolved oxygen	Varies depending on catchment, from median >70% to >90%	42	500	125 (25.0%)	9
Total Suspended Solids	Median <25 mg/L	42	500	48 (9.6%)	2 (Heathcote at Tunnel Rd, Heathcote at Ferrymead Bridge)
Nitrate	Median <3.8 mg/L and/or 95%ile <5.6 mg/L	42	500	21 (4.2%)	2 (Heathcote at Templetons Rd, Knights Stream)
Biochemical Oxygen Demand	Median <2 mg/L	42	500	16 (3.2%)	0
Water temperature	Varies depending on catchment, from median <20°C to <25°C	42	500	13 (2.6%)	0
pH	Median 6.5 to 8.5	42	500	3 (0.6%)	0
Dissolved lead	Varies depending on catchment, from 95th percentile <0.00427 mg/L to ≤0.13610 mg/L	42	500	0 (0%)	0
Total ammonia	Varies depending on catchment, from 95th percentile <0.32 mg/L to <1.99 mg/L	42	500	0 (0%)	0
Total	-	42	7,440	1,463 (19.7%)	41 of 42 (97.6%) (for at least one parameter)

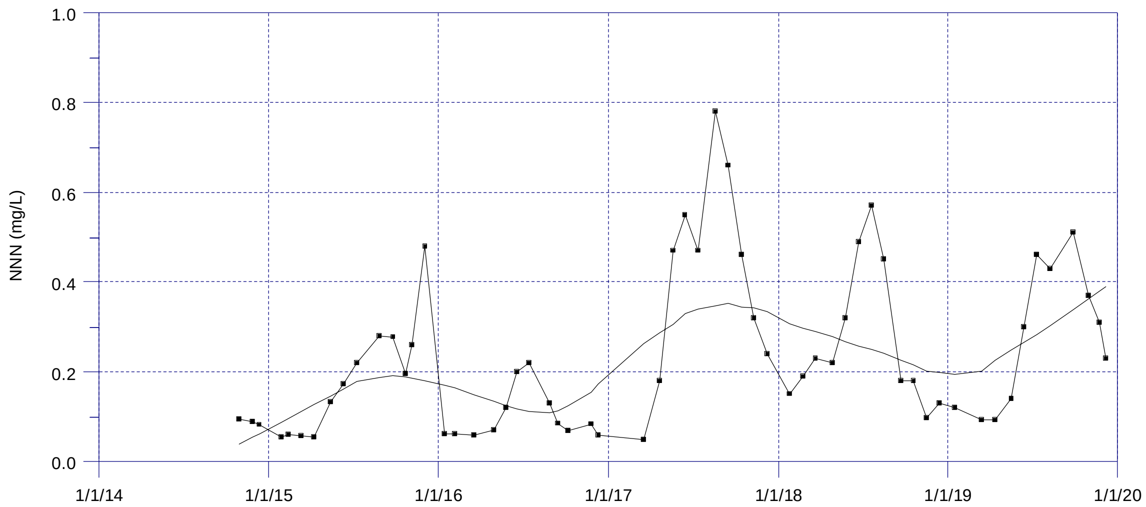

Figure 3. NNN concentrations at the Ōtūkaikino at Scout Camp site for the monitoring period October 2014 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A positive (i.e. increasing) trend of 18% was recorded over the sampling period.

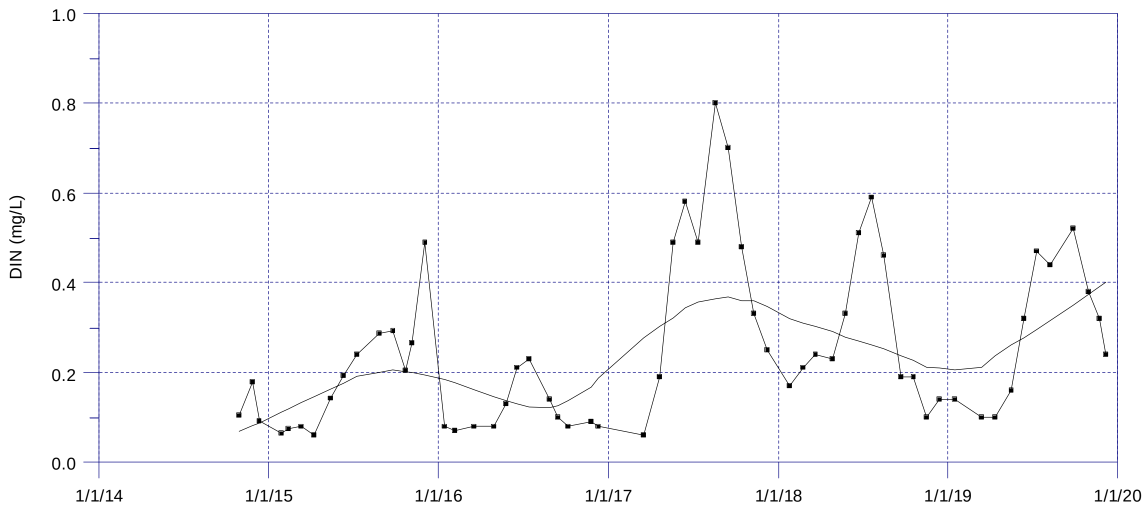

Figure 4. DIN concentrations at the Ōtūkaikino at Scout Camp site for the monitoring period October 2014 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A positive (i.e. increasing) trend of 16% was recorded over the sampling period.

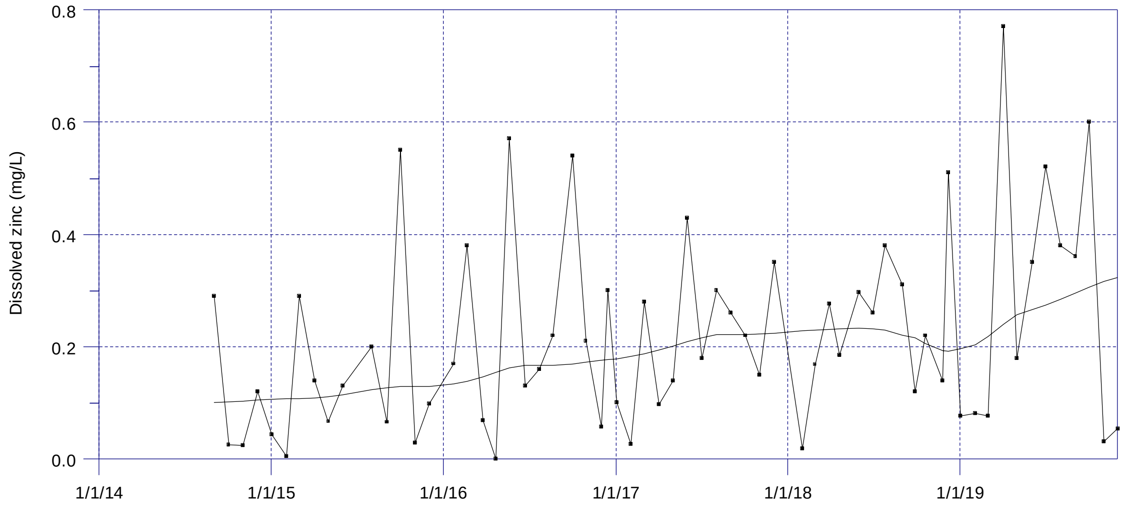

Figure 5. Dissolved zinc concentrations at the Curletts at Motorway site for the monitoring period September 2014 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A positive (i.e. increasing) trend of 16% was recorded over the sampling period.

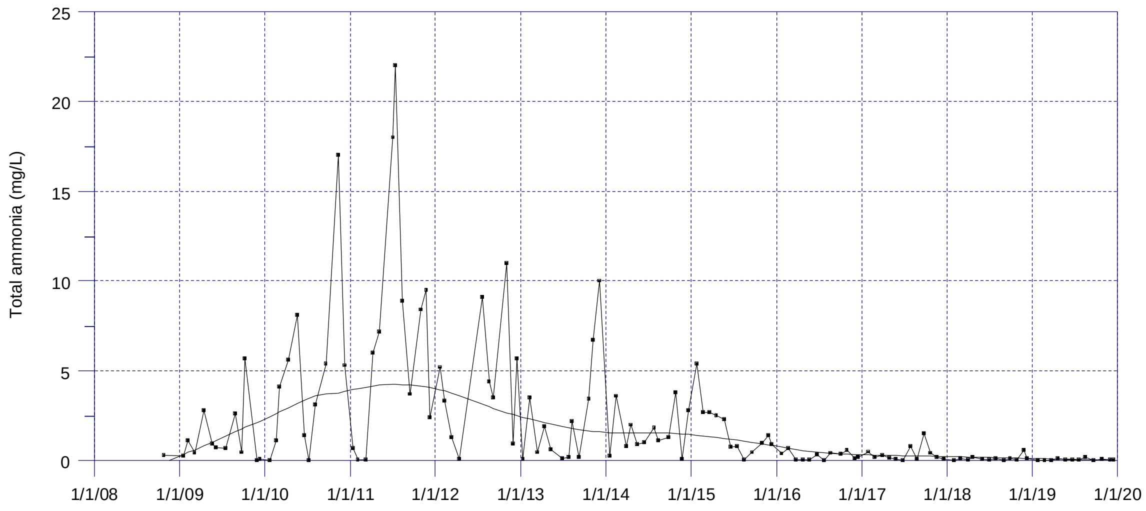

Figure 6. Total ammonia concentrations at the Halswell Basin Outlet site for the monitoring period October 2008 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 33% was recorded over the sampling period.

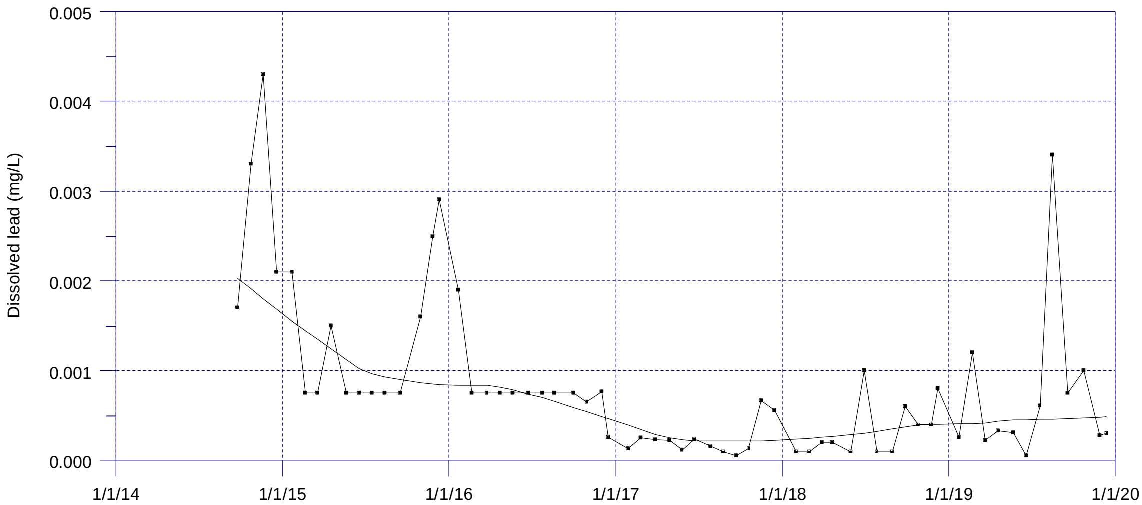

Figure 7. Dissolved lead concentrations at the Halswell Basin Outlet site for the monitoring period September 2014 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 28% was recorded over the sampling period.

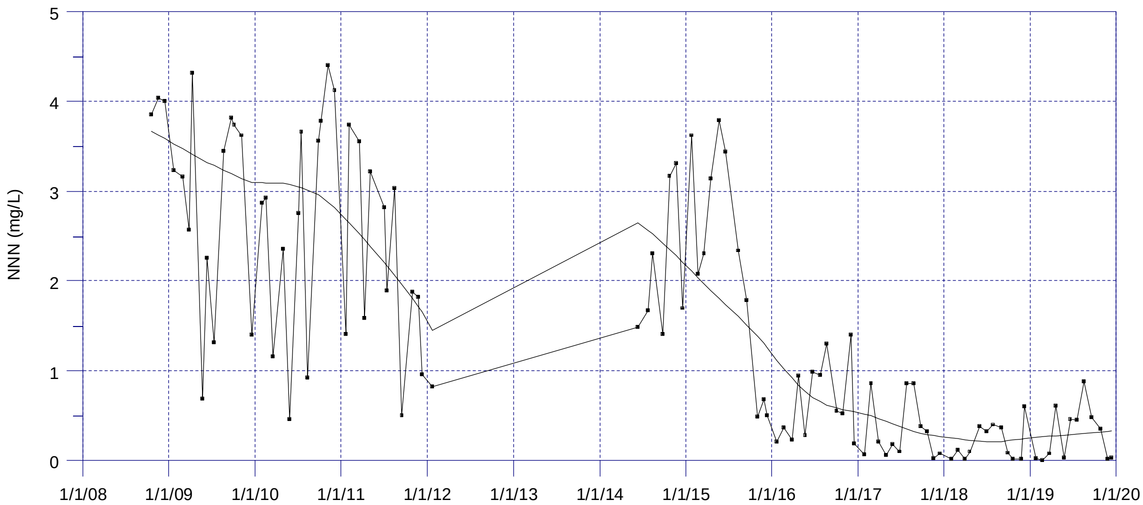

Figure 8. NNN concentrations at the Curletts at Motorway site for the monitoring period October 2008 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 31% was recorded over the sampling period. This site was unable to be sampled from February 2012 – May 2014, due to motorway construction.

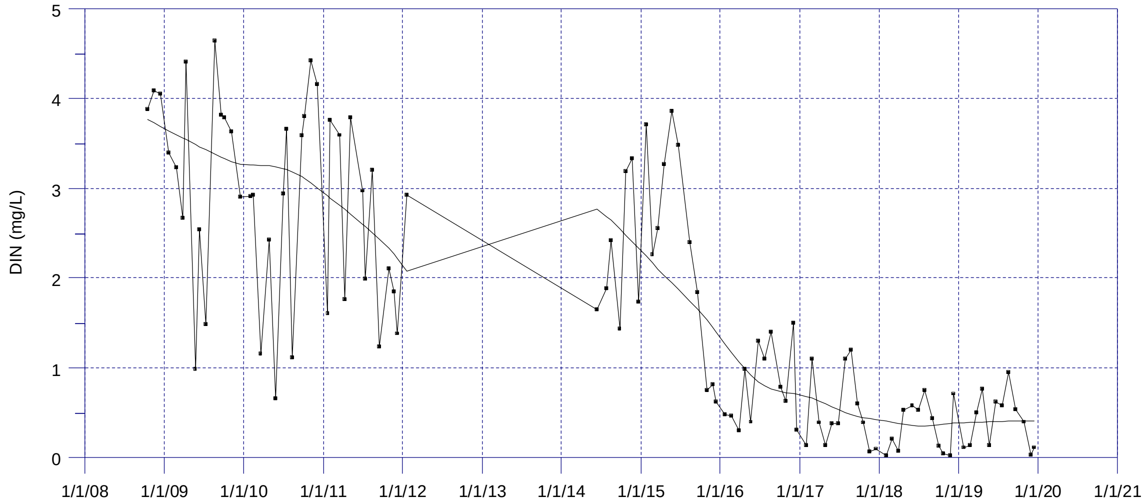

Figure 9. DIN concentrations at the Curletts at Motorway site for the monitoring period October 2008 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 24% was recorded over the sampling period. This site was unable to be sampled from February 2012– May 2014, due to motorway construction.

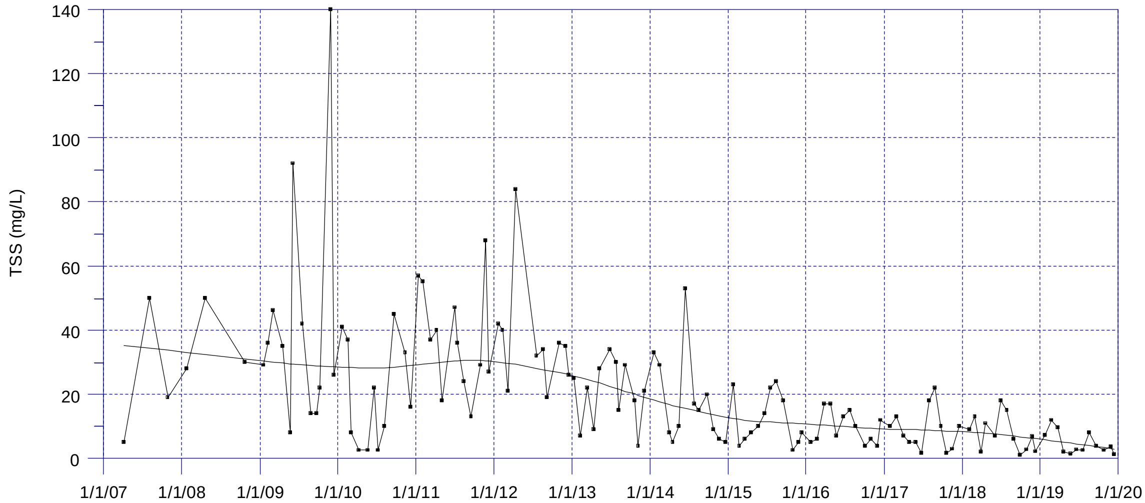

Figure 10. TSS concentrations at the Halswell Basin Outlet site for the monitoring period April 2007 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. A negative (i.e. decreasing) trend of 20% was recorded over the sampling period.

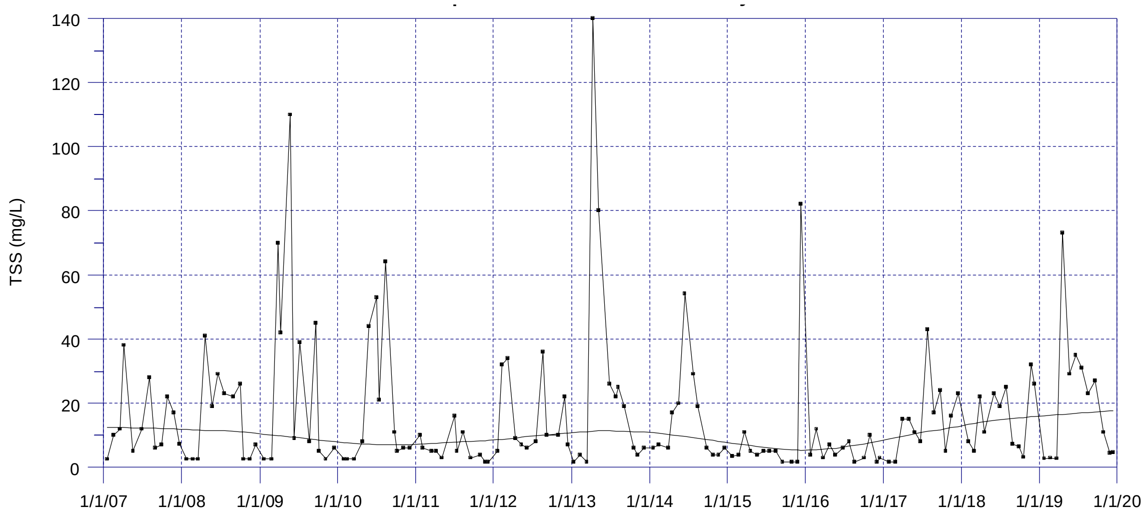

Figure 11. TSS concentrations at the Cashmere at Worsleys Rd site for the monitoring period January 2007 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. No significant trend was recorded over the sampling period.

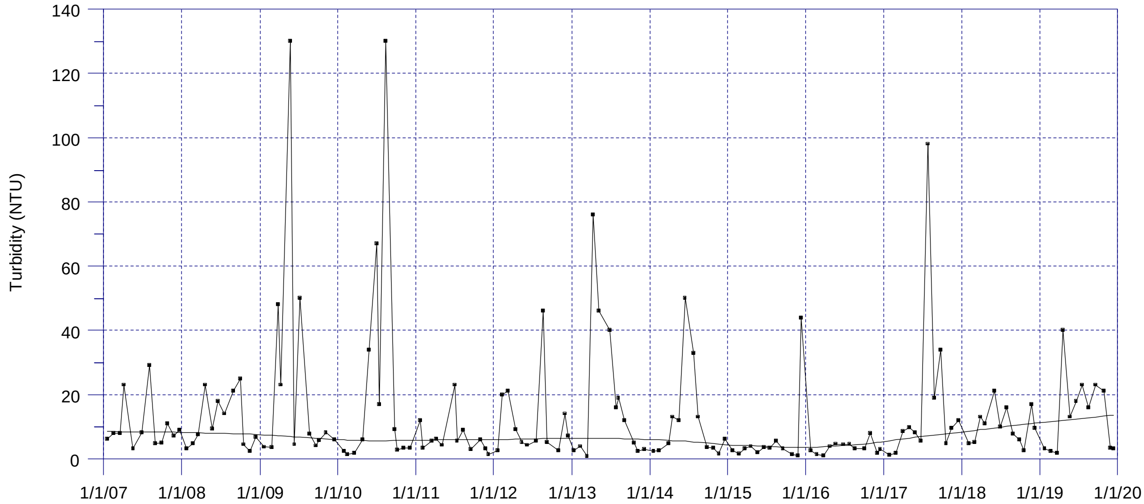

Figure 12. Turbidity concentrations at the Cashmere at Worsleys Rd site for the monitoring period January 2007 to December 2019. Squares indicate individual sampling events. The trendline was fitted using the Locally Weighted Scatterplot Smoothing (LOWESS) method in the Time Trends software. No significant trend was recorded over the sampling period.

3.3 *Water Quality Index*

- 59.5%, 23.8% and 16.7% of sites were recorded as having 'poor', 'fair' and 'good' water quality, respectively (Table 4; Figure 13). No site had 'very poor' or 'very good' water quality, the latter being because the guidelines were exceeded on at least one occasion at all sites.
- All catchments generally recorded 'poor' or 'fair' water quality, except the Ōtūkaikino River and the upper Pūharakekenui/ Styx, which recorded 'good' water quality (Table 4; Figure 14).
- The Ōtūkaikino River recorded the best water quality out of all the catchments and Ōpāwaho/ Heathcote catchment recorded the worst water quality (Table 5).
- The best sites for water quality was jointly Styx at Main North Rd and Ōtūkaikino at Scout Camp, followed by Ōtūkaikino at Groynes, and then Smacks at Gardiners Rd (Table 5).
- The worst site for water quality was Curletts at Motorway, followed by Heathcote at Tunnel Rd, and then Haytons Stm and Heathcote at Ferrymead Bridge (Table 5).
- 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 = 259.12, d.f.= 35, $p<0.0001$; Figure 14):
  - Ōtākaro/ Avon: initially showed an improvement in WQI over time, peaking in 2016 with the median WQI in the 'good' category. However, the median has since declined and now falls in the 'poor' category, where it was in 2013.
  - Ōpāwaho/ Heathcote: no improvement in WQI over time, with the median WQI always within the 'poor' category.
  - Huritini/ Halswell: some improvement in WQI over time; however, median WQI has remained in the 'poor' category for all years. The catchment consists of only three sites which may not be a thorough representation of the catchment.
  - Pūharakekenui/ Styx: has recorded an improvement in WQI over time, improving from the 'poor' category in 2013 to 'good' in 2019. However, water quality regressed to the 'poor' category in 2018.
  - Ōtūkaikino: very 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 which may not be a thorough representation of the catchment.
  - Linwood Canal: has recorded no overall improvement in WQI over time, with the median WQI always in the 'poor' category. As this data is from only one site, extrapolation to the entire catchment may not be appropriate.
- Time Trends analysis showed that three sites recorded a significant improvement in WQI over time (Nottingham at Candys Rd, Heathcote at Bowenvale Ave and Cashmere at Sutherlands Rd) and one site recorded a significant decline (Curletts at Motorway) (Table 4).

Table 4. Water Quality Index (WQI) scores at each site for the monitoring period of January to December 2019 and direction of significant trends ($p \leq 0.05$) since 2013. Additional water quality categories not represented by sites in 2019 are 'very poor' (0–39.99) and 'very good' (≥90).

Catchment	Site	WQI	Water Quality Category	Change over time
Ōpāwaho/ Heathcote	Curletts at Motorway	41.8	Poor	↓ 5%
Ōpāwaho/ Heathcote	Heathcote at Tunnel Rd	48.4	Poor	
Ōpāwaho/ Heathcote	Haytons Stm	52.6	Poor	
Ōpāwaho/ Heathcote	Heathcote at Ferrymead Bridge	53.3	Poor	
Ōpāwaho/ Heathcote	Curletts U/S of Heathcote	54.3	Poor	
Ōtākaro/ Avon	Addington Brook	55.4	Poor	
Ōpāwaho/ Heathcote	Heathcote at MacKenzie Ave	55.8	Poor	
Ōtākaro/ Avon	Dudley Creek	59.2	Poor	
Ōtākaro/ Avon	Avon at Pages Rd	59.4	Poor	
Ōtākaro/ Avon	Riccarton Main Drain	59.9	Poor	
Linwood Canal	Linwood Canal	61.1	Poor	
Ōpāwaho/ Heathcote	Heathcote at Rose St	61.9	Poor	
Ōpāwaho/ Heathcote	Heathcote at Catherine St	61.9	Poor	
Pūharakekenui/ Styx	Kā Pūtahi at Blakes Rd	63.0	Poor	
Huritini/ Halswell	Halswell at Tai Tapu Rd	64.4	Poor	
Ōtākaro/ Avon	Avon at Bridge St	64.8	Poor	
Ōtākaro/ Avon	Avon at Dallington Tce	64.8	Poor	
Ōtākaro/ Avon	Avon at Carlton Mill	64.9	Poor	
Ōpāwaho/ Heathcote	Heathcote at Opawa Rd	65.0	Poor	
Ōtākaro/ Avon	Avon at Manchester St	66.1	Poor	
Pūharakekenui/ Styx	Kā Pūtahi at Belfast Rd	67.0	Poor	
Ōtākaro/ Avon	Avon at Mona Vale	67.6	Poor	
Ōpāwaho/ Heathcote	Cashmere at Worsleys Rd	68.8	Poor	
Ōtākaro/ Avon	Horseshoe Lake	69.0	Poor	
Huritini/ Halswell	Knights at Sabys Rd	69.1	Poor	
Ōtākaro/ Avon	Avon at Avondale Rd	70.0	Fair	
Huritini/ Halswell	Nottingham at Candys Rd	70.5	Fair	↑ 3%
Ōpāwaho/ Heathcote	Heathcote at Templetons Rd	70.6	Fair	
Ōtūkaikino	Wilsons Stm	73.0	Fair	
Ōpāwaho/ Heathcote	Heathcote at Bowenvale Ave	73.1	Fair	↑ 6%
Ōpāwaho/ Heathcote	Heathcote at Ferniehurst St	75.4	Fair	
Pūharakekenui/ Styx	Styx at Richards Bridge	75.6	Fair	
Ōtākaro/ Avon	Wairarapa Stm	76.9	Fair	
Ōpāwaho/ Heathcote	Cashmere at Sutherlands Rd	77.8	Fair	↑ 3%
Pūharakekenui/ Styx	Styx at Marshland Rd	79.9	Fair	
Pūharakekenui/ Styx	Styx at Harbour Rd	80.3	Good	
Ōtākaro/ Avon	Waimairi Stm	82.0	Good	

Catchment	Site	WQI	Water Quality Category	Change over time
Pūharakekenui/ Styx	Styx at Gardiners Rd	82.4	Good	
Pūharakekenui/ Styx	Smacks at Gardiners Rd	82.5	Good	
Ōtūkaikino	Ōtūkaikino at Groynes	84.0	Good	
Ōtūkaikino	Ōtūkaikino at Scout Camp	89.2	Good	
Pūharakekenui/ Styx	Styx at Main North Rd	89.3	Good	

Table 5. Best and worst catchments and sites for the monitoring period January to December 2019, 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, and purple = Huritini/ Halswell River catchment. Linwood Canal (WQI = 61) is not included as a catchment, as only one site is monitored.

Placing	Best Sites		Worst Sites	
	Catchment Scale	Site Scale	Catchment Scale	Site Scale
	Ōtūkaikino River (median WQI = 84)	Styx at Main North Rd Ōtūkaikino at Scout Camp (WQI = 89)	Ōpāwaho/ Heathcote River (median WQI = 62)	Curletts at Motorway (WQI = 42)
	Pūharakekenui/ Styx River (median WQI = 80)	Ōtūkaikino at Groynes (WQI = 84)	Ōtākaro/ Avon River (median WQI = 65)	Heathcote at Tunnel Rd (WQI = 48)
	Huritini/ Halswell River (median WQI = 69)	Smacks at Gardiners Rd (WQI = 83)	Huritini/ Halswell River (median WQI = 69)	Haytons Stm Heathcote at Ferrymead Bridge (WQI = 53)

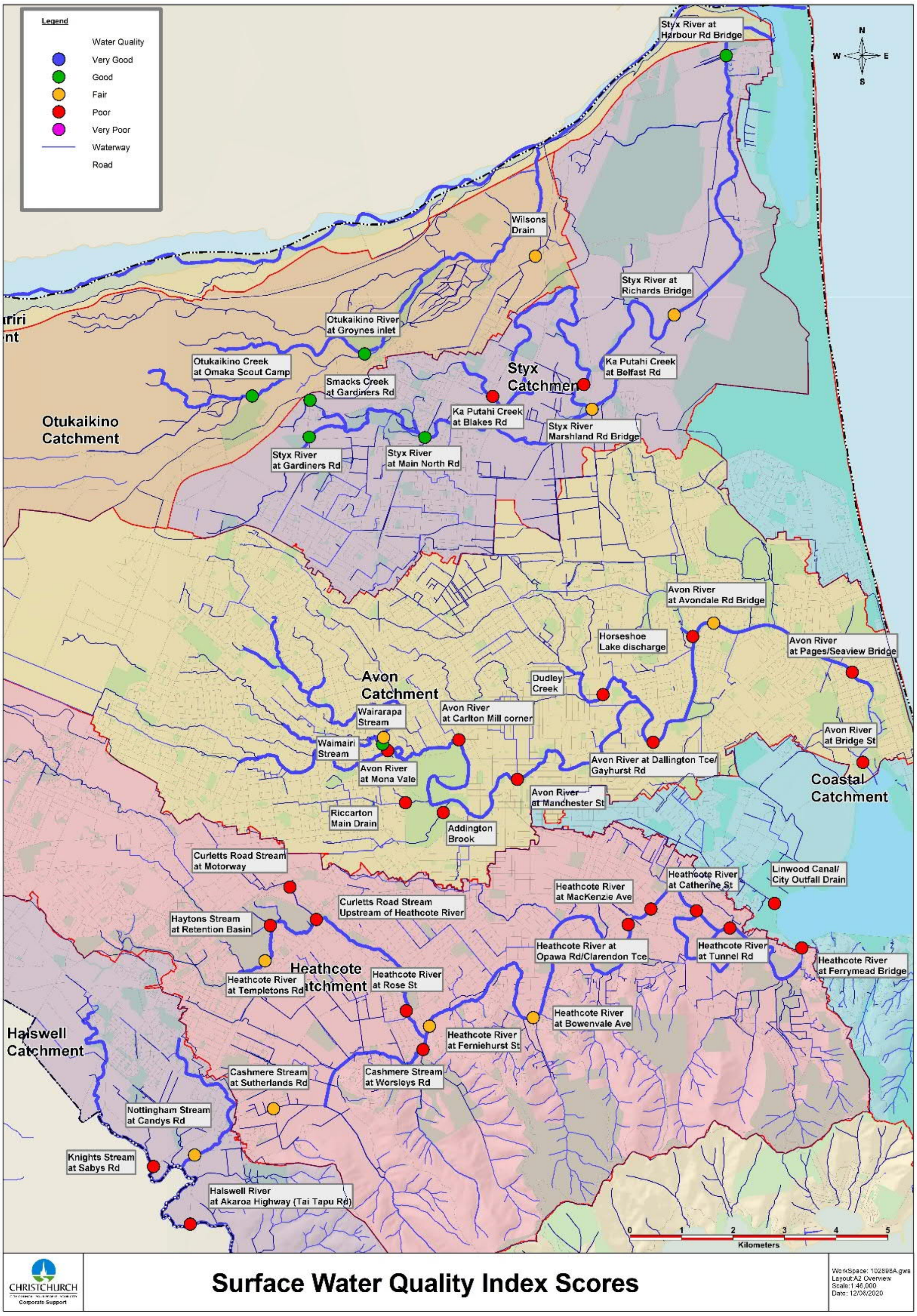

Figure 13. Water Quality Index (WQI) categories for 2019 at the Christchurch City Council water quality monitoring sites. No sites were in the Very Poor or Very Good categories.

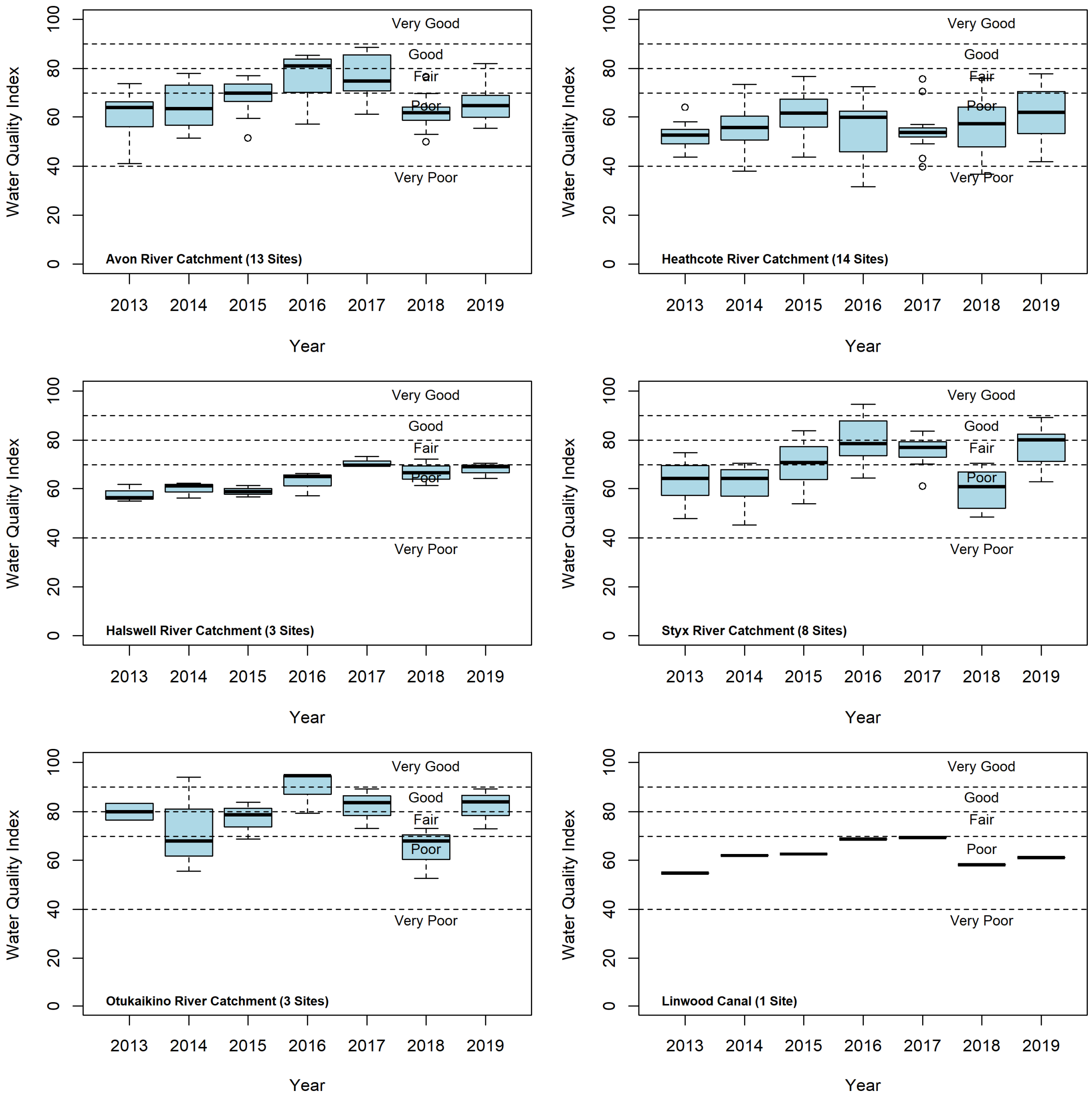

Figure 14. Boxplots of Water Quality Index for each catchment for the 2013 to 2019 monitoring years

4 Results: Wet Weather Monitoring

4.1 Styx River

4.1.1 Rainfall

- The amount of rainfall that had fallen for the first and second wet weather event before samples were taken was 8 mm and 3 mm, respectively (Figure 15).
- Both sampling events therefore occurred during the First Flush (up 25 mm). Both rain events occurred after three dry days (where daily rainfall totals were less than 1 mm). However, the second event did not meet the criteria of a minimum of 5 mm total rainfall depth prior to sampling.
- The concentrations of parameters for the second event may therefore be lower than what typically occurs in waterways during wet weather.

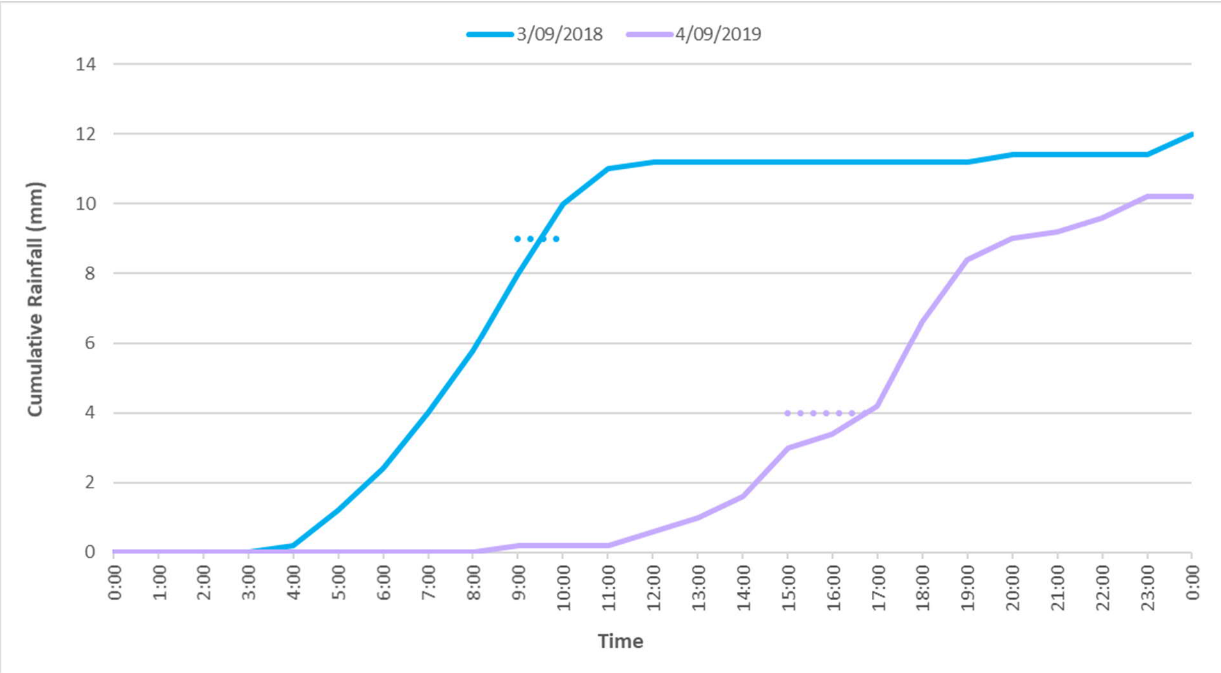

Figure 15. Rainfall during the wet weather events of 3/09/2018 (blue line) and 4/09/2019 (purple line), with approximate sampling times indicated by dotted lines.

4.1.2 Water Quality Parameters

- Parameter concentrations were generally similar between monitoring events (Figures 16–20).
- The guidelines were not met for:
    - TSS at the Styx at Main North Rd and Styx at Marshlands Rd sites during the first event (recording a high concentration of 190 mg/L – eight times higher than the guideline level)
    - Turbidity at all sites during the first event; concentrations were particularly high at the Styx at Marshlands Rd site, where a concentration of 57 NTU was recorded – 10 times higher than the guideline level

- Dissolved oxygen at Styx at Marshlands Rd during the first event
  - BOD_5 at the Styx at Marshlands Rd site during the first event
  - NNN generally at all sites during both events
  - DRP generally at all sites during both events
  - *E. coli* all sites during the first event and at Kā Pūtahi at Belfast Rd site during the second event. No *E. coli* samples were associated with a recorded wastewater overflow event
- Concentrations were generally comparable to the monthly monitoring (although the monthly monitoring also included some rain events), with the following notable exceptions:
  - TSS concentrations during the first event at the Styx at Marshlands Rd site were much higher
  - Turbidity at the Styx at Marshlands Rd site during the first event was much higher
  - DO concentrations were higher at the Smacks at Gardiners Rd site during both events
  - BOD_5 was generally higher at all sites during the first event
  - Nitrate, NNN and DIN were generally lower at all sites
  - DRP at the Smacks at Gardiners Rd and Styx at Main North Rd sites were higher during the first event
  - *E. coli* at Styx at Main North Rd during the first event

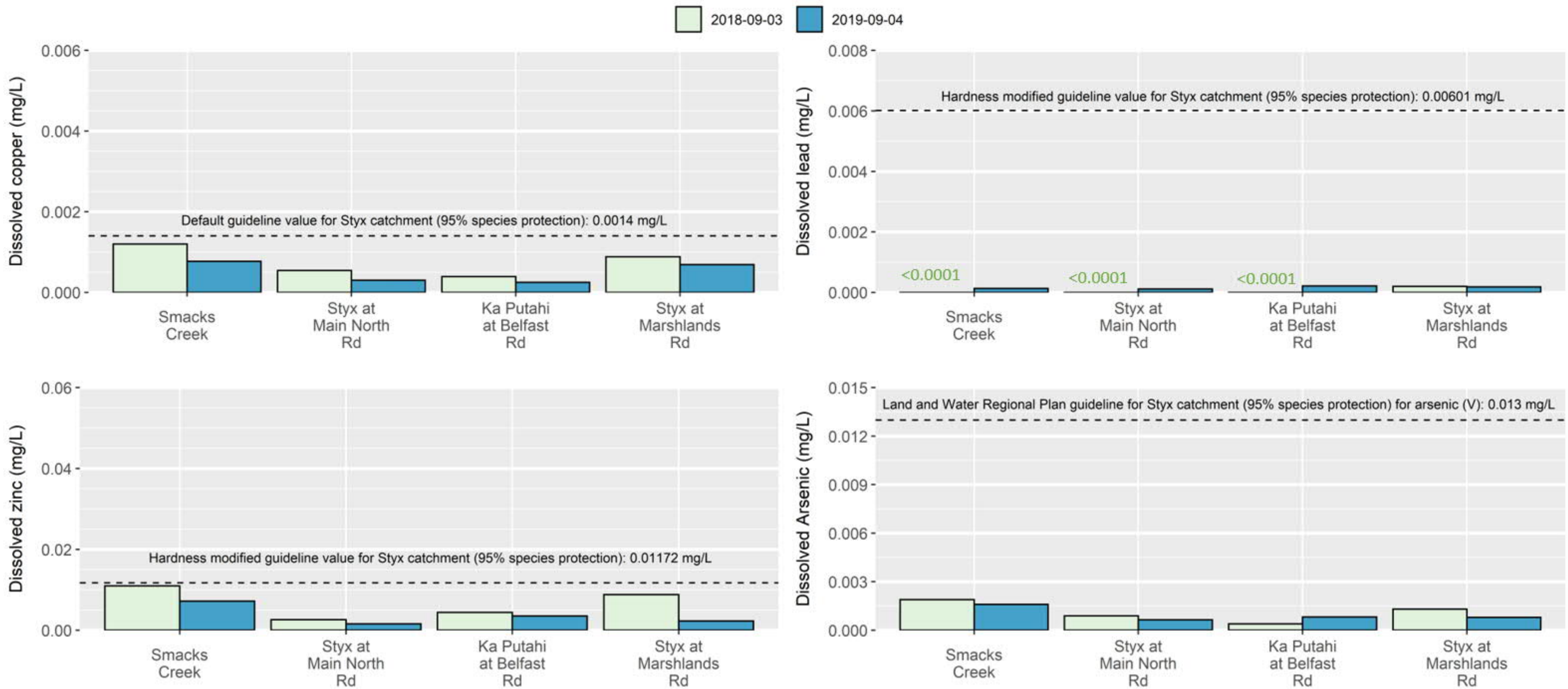

Figure 16. Dissolved copper (top left), lead (top right), zinc (bottom left) and arsenic (bottom right) concentrations in water samples taken from the Pūharakekenui/ Styx River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent either the 95% default (copper, arsenic) or hardness modified (lead, zinc) guideline values as per the Land and Water Regional Plan (Environment Canterbury, 2019) and Warne *et al.*, (2018).

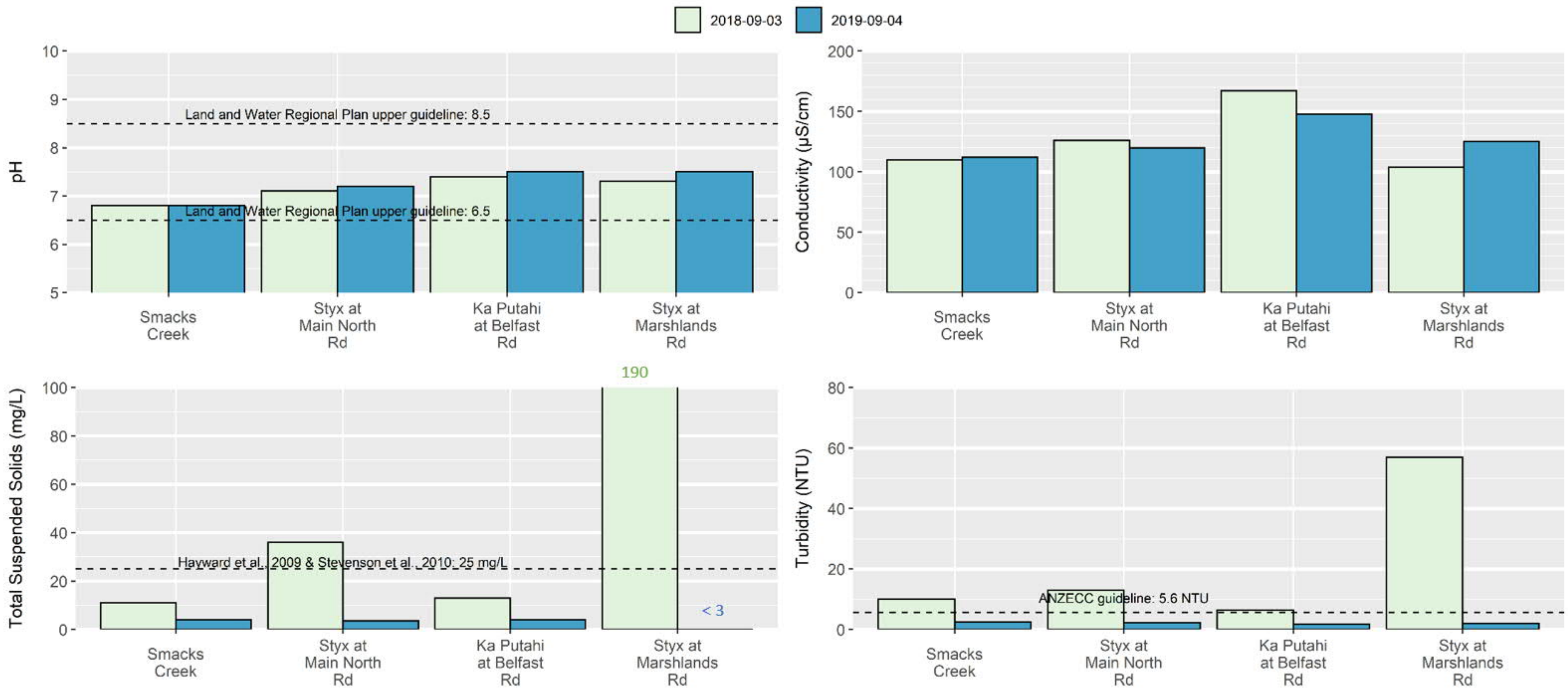

Figure 17. pH (top left), conductivity (top right), Total Suspended Solids (TSS; bottom left) and turbidity (bottom right) concentrations in water samples taken from the Pūharakekenui/ Styx River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the respective guidelines (pH: Environment Canterbury (2017); TSS: Hayward *et al.* (2009) & Stevenson *et al.* (2010); Turbidity: ANZECC (2000)).

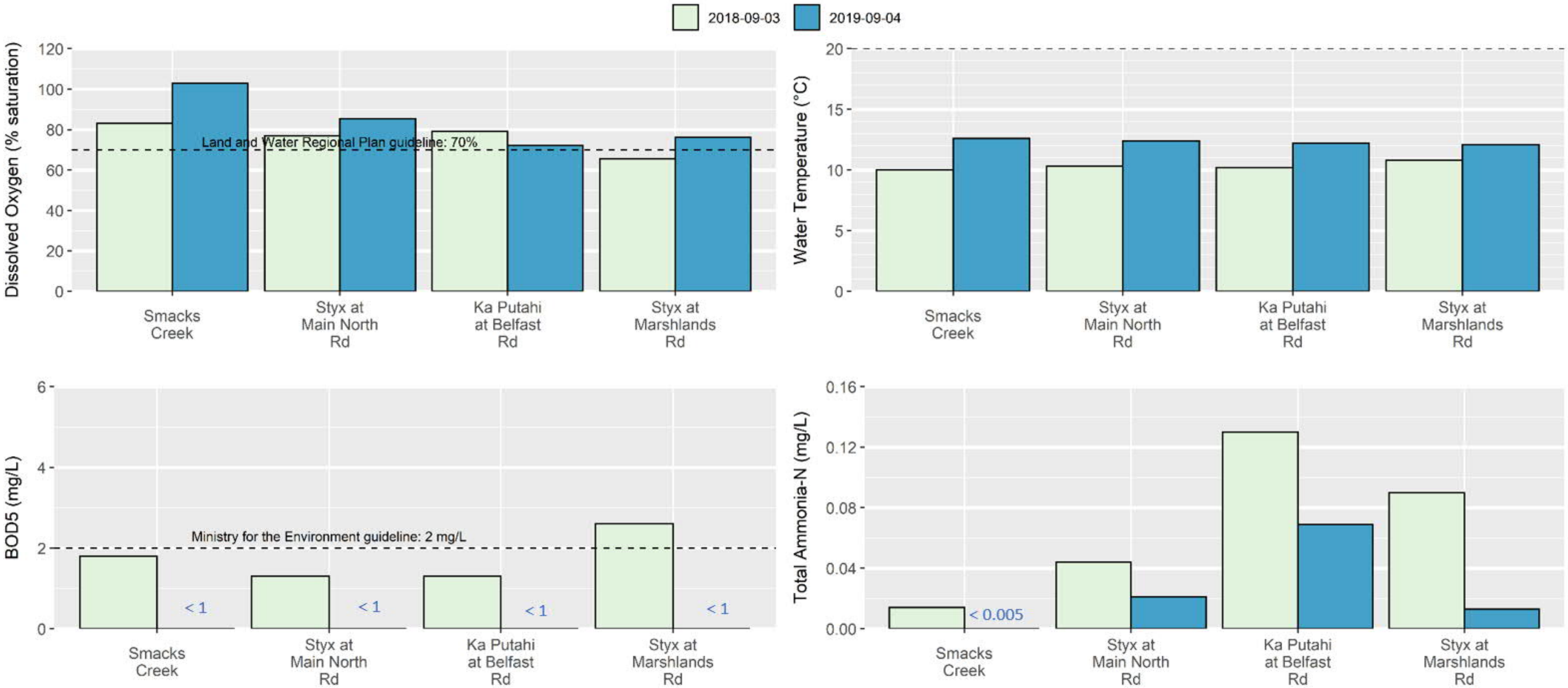

Figure 18. Dissolved oxygen (DO; top left), water temperature (top right), BOD_5 (bottom left) and total ammonia-N (bottom right) concentrations in water samples taken from the Pūharakekenui/ Styx River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the respective guidelines (DO, water temperature: Environment Canterbury, 2019; BOD_5: Ministry for the Environment, 1992). The guideline value for total ammonia-N, adjusted in accordance with median 2019 pH (7.2; Environment Canterbury, 2019), is not visible as it is off the scale (1.99 mg/L).

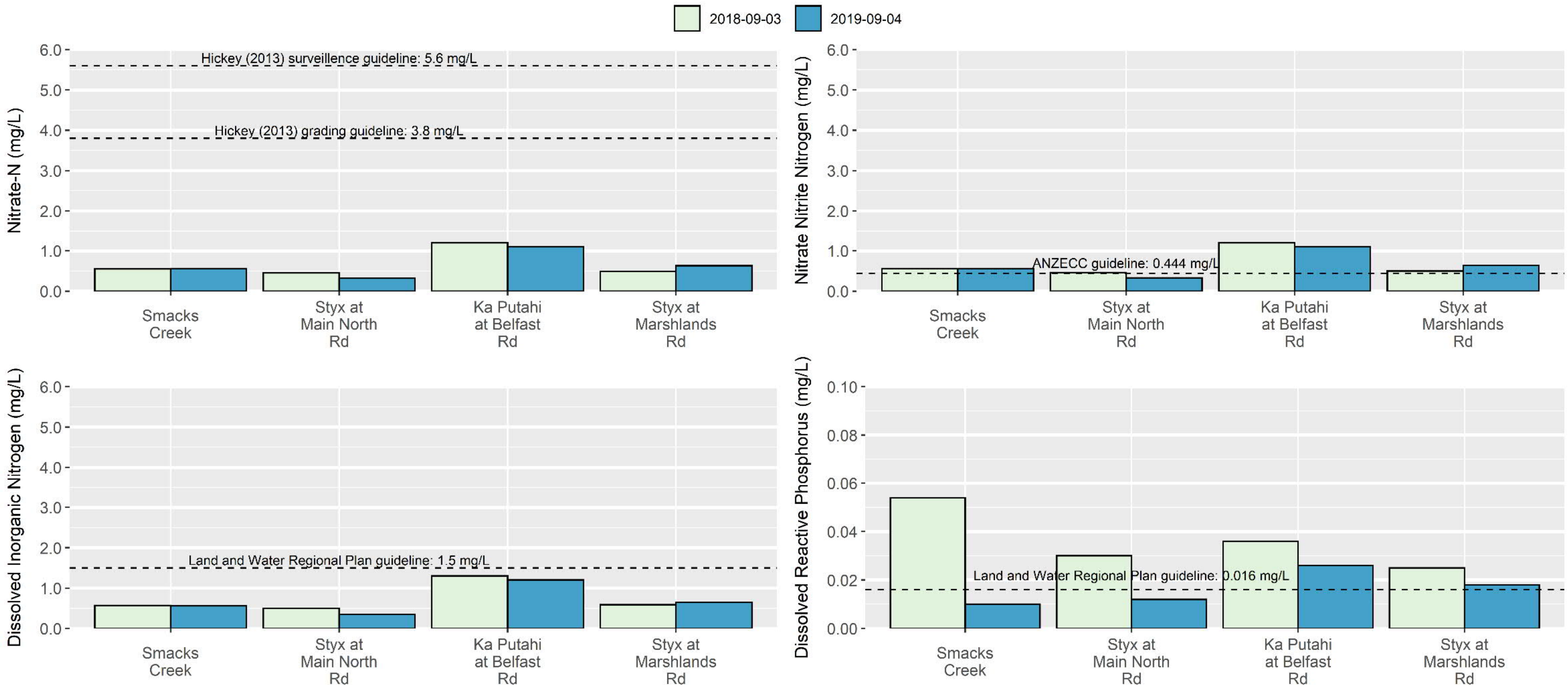

Figure 19. Nitrate-N (top left), Nitrate Nitrite Nitrogen (NNN; top right), Dissolved Inorganic Nitrogen (DIN; bottom left) and Dissolved Reactive Phosphorus (DRP) concentrations in water samples taken from the Pūharakekenui/ Styx River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the respective guidelines (Nitrate-N: Hickey, 2013; NNN: ANZECC, 2000; DIN, DRP: Environment Canterbury, 2019).

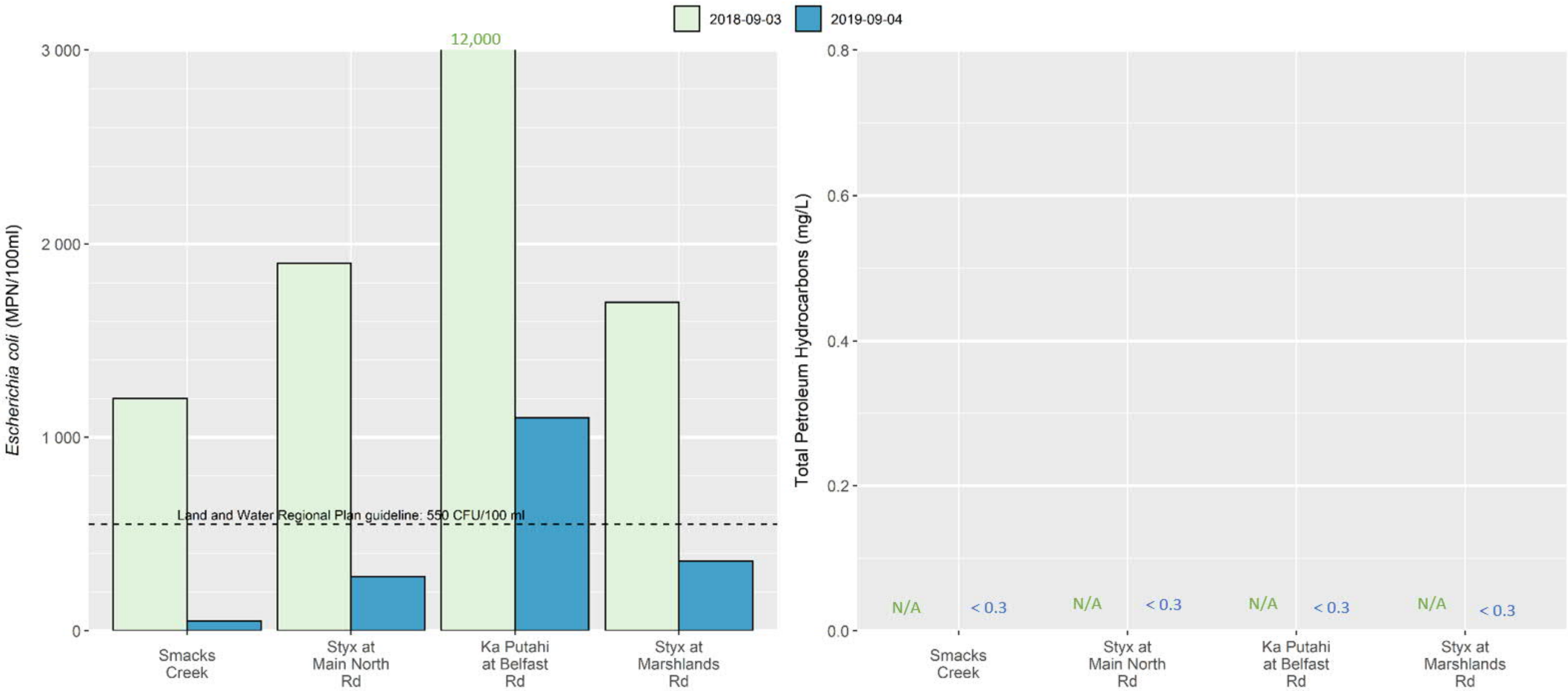

Figure 20. *Escherichia coli* (left) and Total Petroleum Hydrocarbons (TPH; right) concentrations in water samples taken from the Pūharakekenui/ Styx River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed line represents the Land and Water Regional Plan guideline value of 550 MPN/100ml for 95% of samples for ‘spring-fed – plains’ waterways (Environment Canterbury, 2019).

4.2 *Avon River*

4.2.1 Rainfall

- The amount of rainfall that had fallen for the first and second wet weather event before samples were taken was 11 mm and 8 mm, respectively (Figure 21).
- Both sampling events therefore occurred during the First Flush (up 25 mm).
- Prior to sampling the first event, approximately 2 mm of rain was recorded each day for the three days preceding sampling. The second rain event occurred after three dry days (where daily rainfall totals were less than 1 mm).
- Due to the first event not meeting the minimum antecedent dry period, concentrations may be lower than what typically occurs in waterways during wet weather.

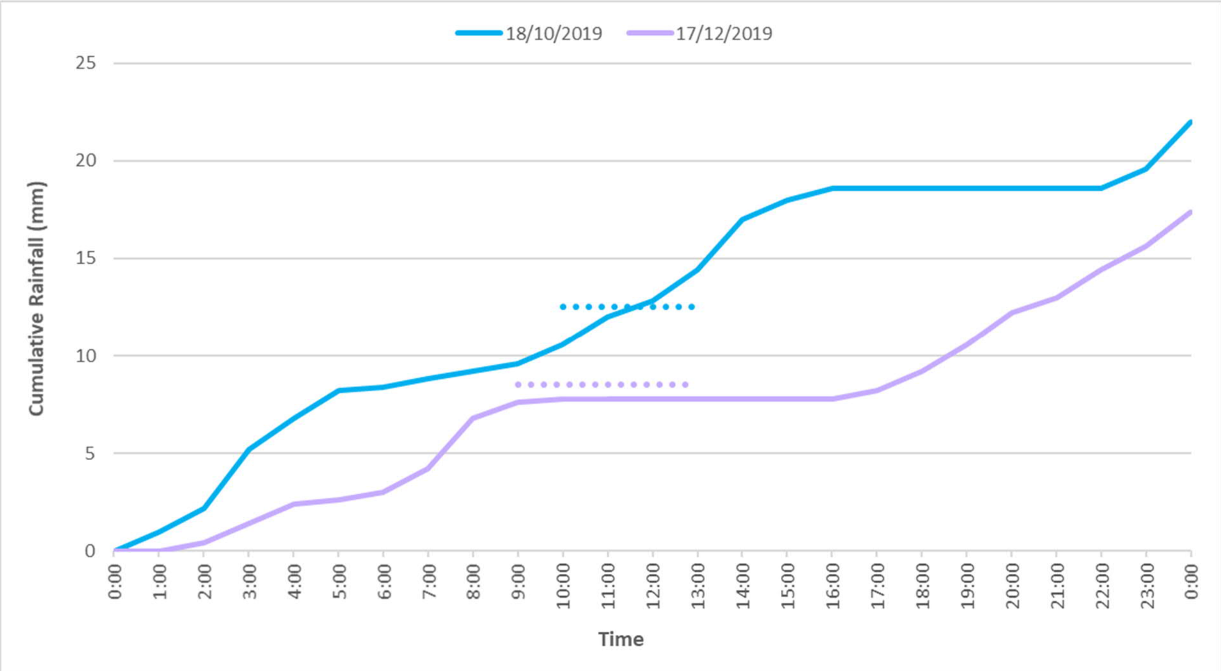

Figure 21. Rainfall during the wet weather events of 18/10/2019 (blue line) and 17/12/2019 (purple line), with approximate sampling times indicated by dotted lines.

4.2.2 Water Quality Parameters

- Parameter concentrations were usually similar between monitoring events, or higher during the second event, depending on the parameter (Figures 22–26).
- No one site typically recorded much higher concentrations compared to the other sites.
- The guidelines were not met for:
  - Dissolved copper and zinc generally at all sites during both events
  - TSS at the Avon at Carlton Mill and Avon at Manchester St sites during the second event
  - Turbidity generally at all sites during both events
  - Dissolved oxygen at Dudley Creek during the second event
  - BOD_5 generally at all sites during both events
  - NNN generally at all sites during both events
  - DIN at the Avon at Mona Vale site during the second event
  - DRP generally at all sites during both events
  - *E. coli* generally at all sites. No *E. coli* samples were associated with a recorded wastewater overflow event

- Concentrations were generally comparable to that recorded during the monthly monitoring (although the monthly monitoring also included some rain events), with the following exceptions:
  - Dissolved copper and zinc were generally higher during both events at all sites
  - Dissolved lead was higher during the first event at the Avon at Mona Vale, Avon at Manchester St and Dudley Creek sites
  - TSS and turbidity concentrations were higher during both events at Avon at Manchester St
  - BOD_5 was generally higher at all sites during both events, and particularly high in Dudley Creek during the second event
  - Total ammonia concentrations were higher during the second event at the Avon at Mona Vale, Riccarton Main Drain, Addington Brook and Dudley Creek sites
  - Nitrate, NNN and DIN were generally lower at all sites, particularly at Riccarton Main Drain, Addington Brook, Avon at Manchester St and Avon at Avondale Rd
  - DRP concentrations were higher during the second event at the Avon at Mona Vale, Riccarton Main Drain and Addington Brook sites
  - *E. coli* concentrations were higher predominantly during the second event at the Avon at Mona Vale, Addington Brook, Avon at Manchester St, and Dudley Creek sites

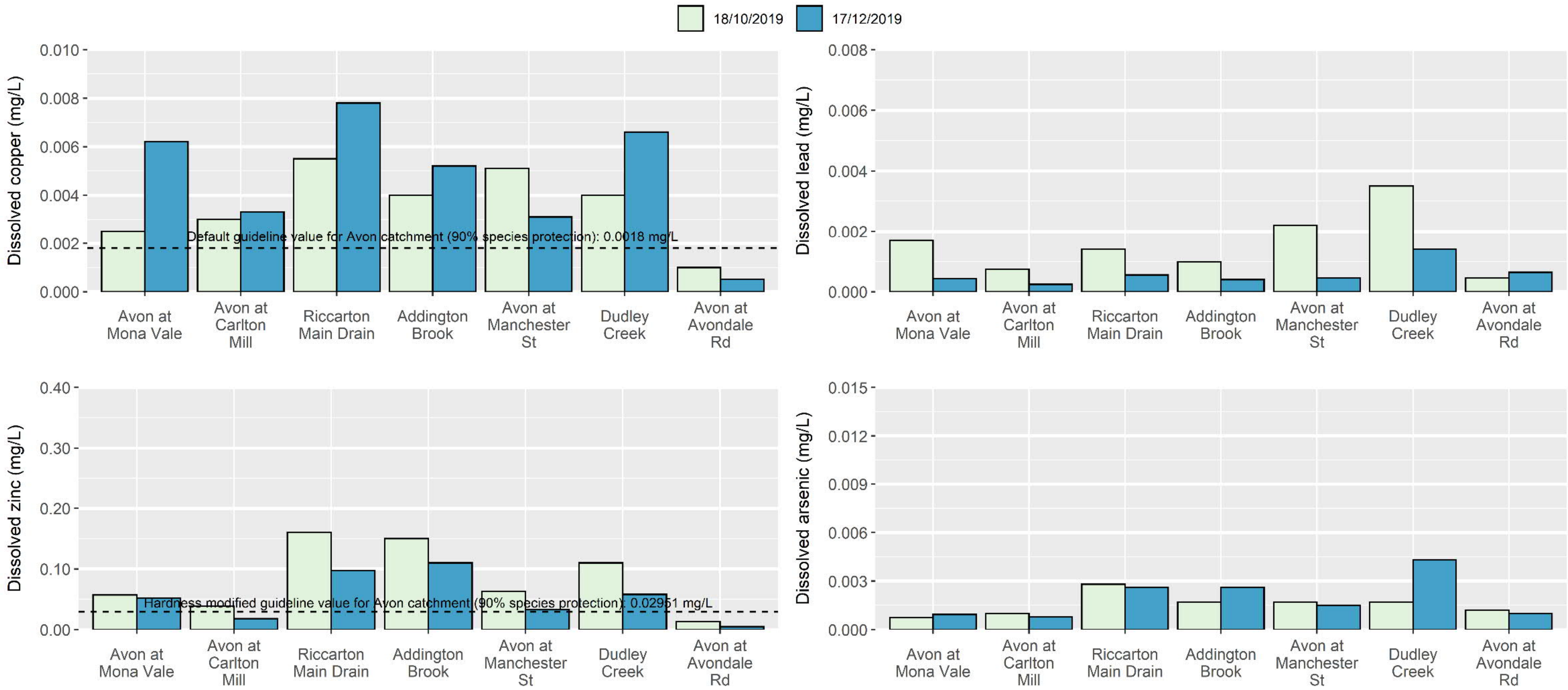

Figure 22. Dissolved copper (top left), lead (top right), zinc (bottom left) and arsenic (bottom right) concentrations in water samples taken from the Ōtākaro/ Avon River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent either the 90% default (copper) or hardness modified (zinc) guideline values as per the Land and Water Regional Plan (Environment Canterbury, 2019) and Warne *et al.* (2018). The lead (hardness modified: 0.01539 mg/L) and arsenic (V) (default: 0.042 mg/L) guidelines are not visible as they are off the scale.

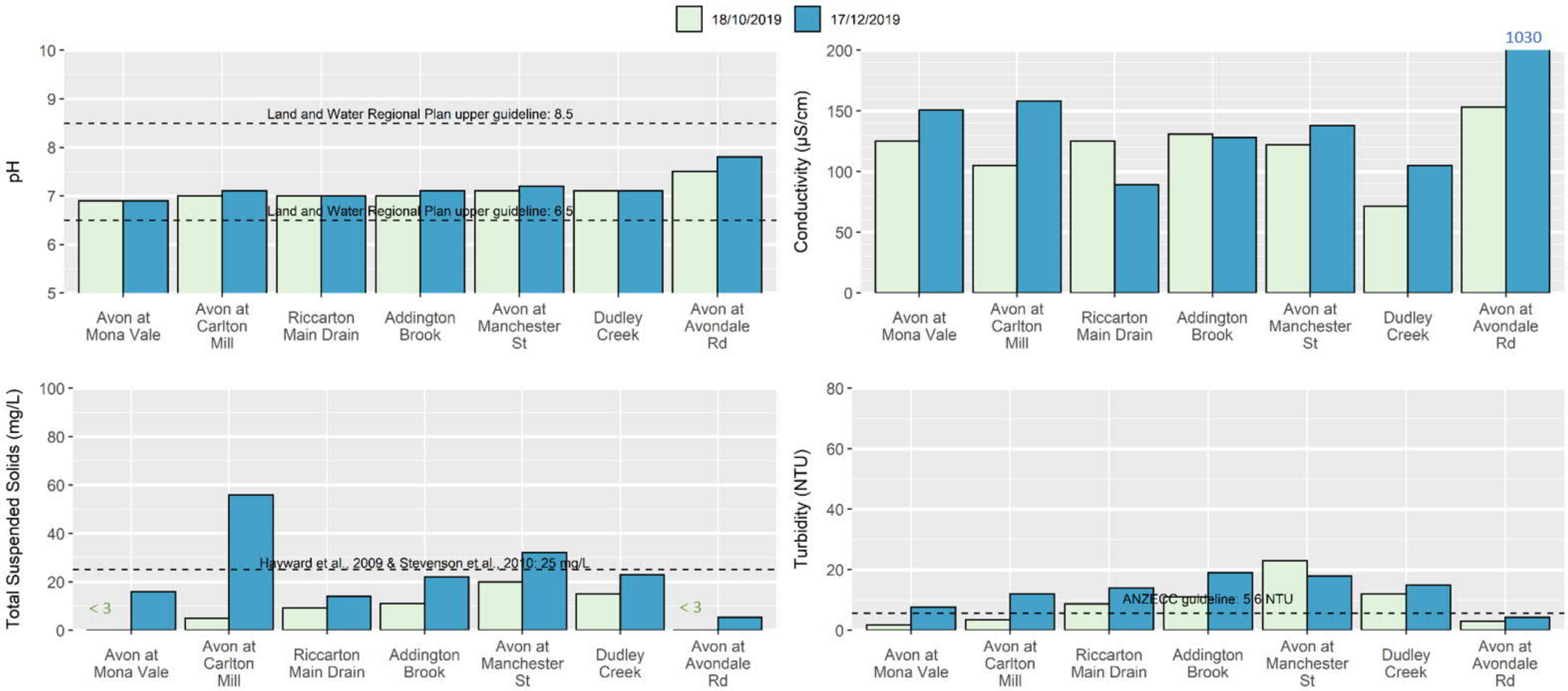

Figure 23. pH (top left), conductivity (top right), Total Suspended Solids (TSS; bottom left) and turbidity (bottom right) concentrations in water samples taken from the Ōtākaro/ Avon River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the respective guidelines (pH: Environment Canterbury (2017); TSS: Hayward *et al.* (2009) & Stevenson *et al*. (2010); Turbidity: ANZECC (2000)).

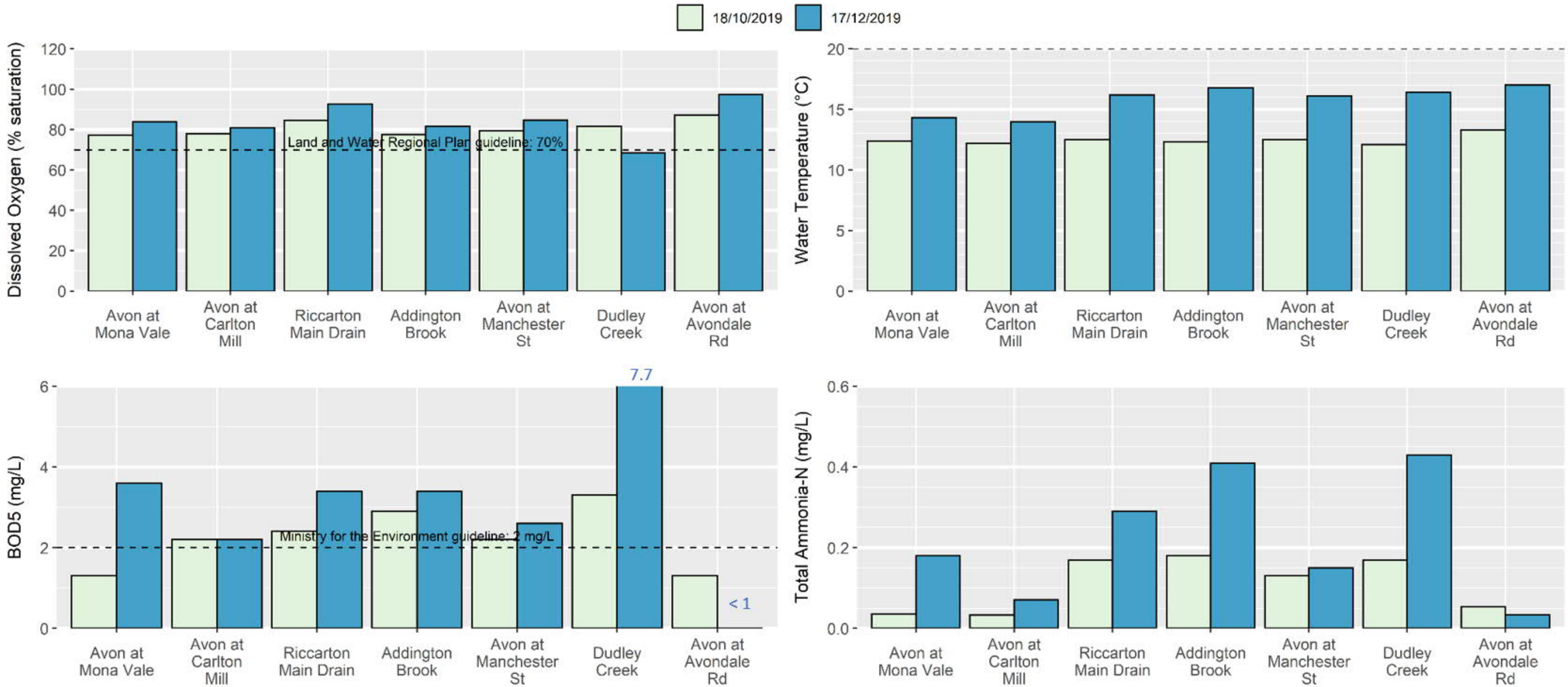

Figure 24. Dissolved oxygen (DO; top left), water temperature (top right), BOD_5 (bottom left) and total ammonia-N (bottom right) concentrations in water samples taken from the Ōtākaro/ Avon River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the respective guidelines (DO, water temperature: Environment Canterbury, 2019; BOD_5: Ministry for the Environment, 1992). The guideline value for total ammonia-N, adjusted in accordance with median 2019 pH (7.3; Environment Canterbury, 2019) is not visible as it is off the scale (1.88 mg/L).

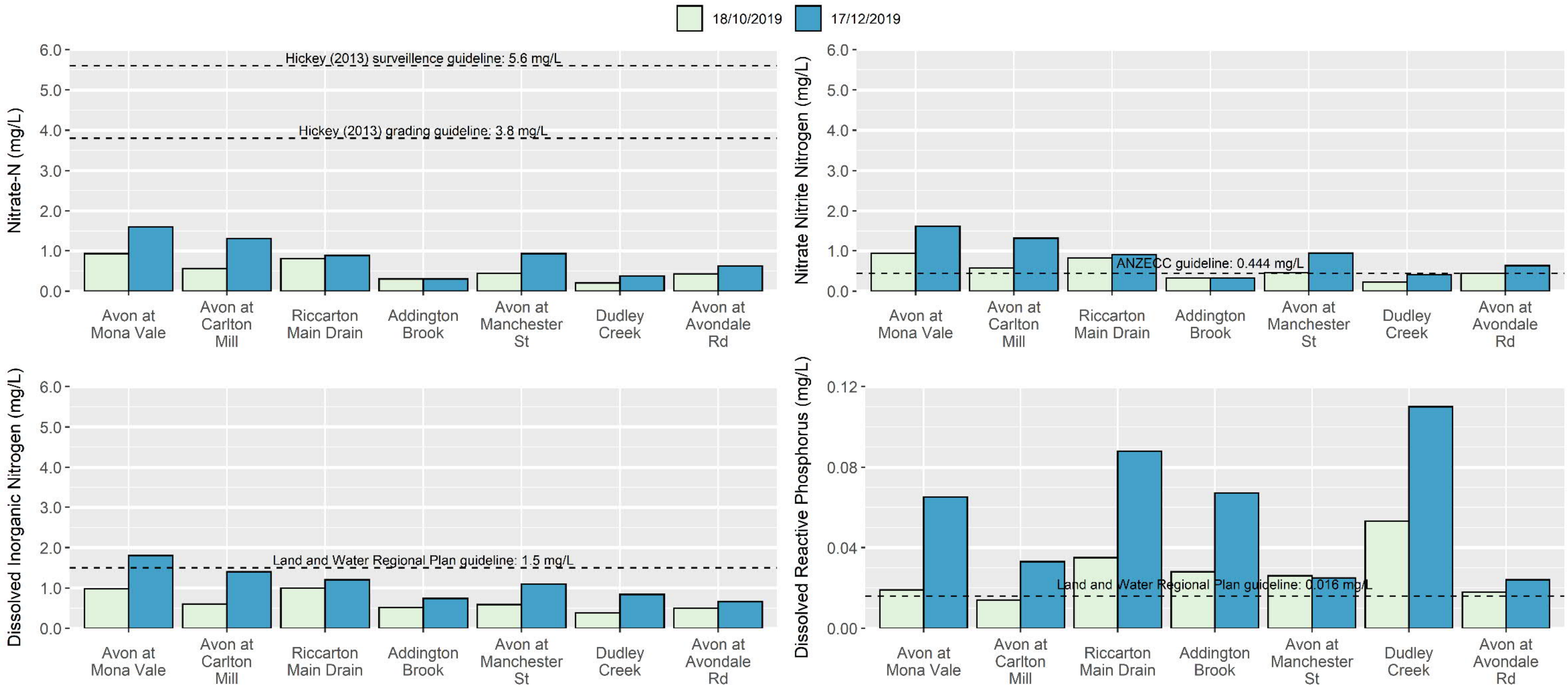

Figure 25. Nitrate-N (top left), Nitrate Nitrite Nitrogen (NNN; top right), Dissolved Inorganic Nitrogen (DIN; bottom left) and Dissolved Reactive Phosphorus (DRP) concentrations in water samples taken from the Ōtākaro/ Avon River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the respective guidelines (Nitrate-N: Hickey, 2013; NNN: ANZECC, 2000; DIN, DRP: Environment Canterbury, 2019).

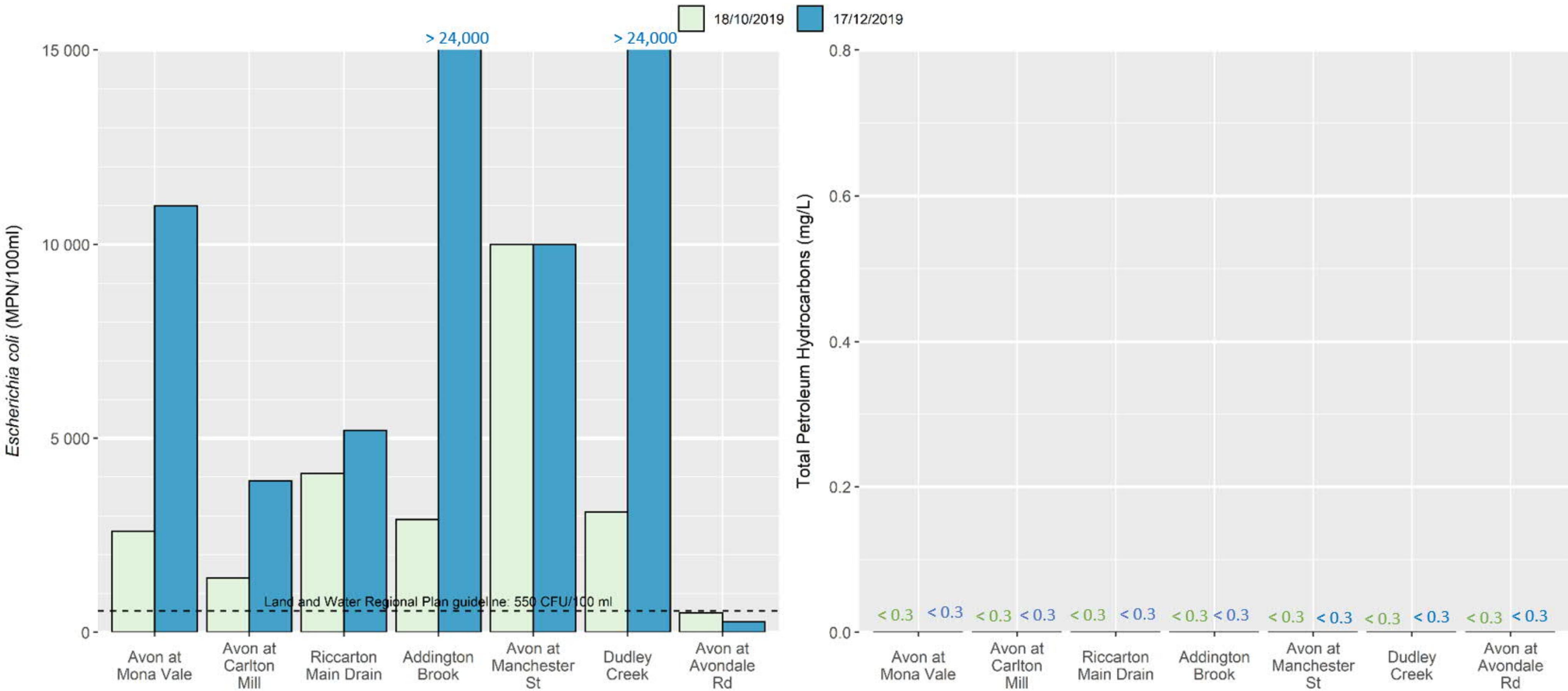

Figure 26. *Escherichia coli* (left) and Total Petroleum Hydrocarbons (TPH; right) concentrations in water samples taken from the Ōtākaro/ Avon River catchment during two rain events. Sites are ordered from upstream to downstream (left to right). The dashed line represents the Land and Water Regional Plan guideline value of 550 MPN/100ml for 95% of samples for 'spring-fed – plains – urban' waterways (Environment Canterbury, 2019).

5 Discussion

There were several parameters within the waterways that were recorded at concentrations unlikely to cause adverse effects, including dissolved lead, pH, water temperature, BOD_5, and total ammonia. However, 20% of samples (1,463 of 7,440 samples) did not meet the guideline levels. The parameters that recorded concentrations well outside the guidelines across most sites included dissolved copper, dissolved zinc, NNN, DIN, DRP, and *E. coli*. There were also some parameters that generally recorded concentrations within the guidelines, but on several occasions, or regularly at a small number of sites, concentrations exceeded the guidelines. These parameters were TSS, turbidity, dissolved oxygen, and nitrate. The parameters that did not meet guidelines at the most sites were *E. coli* (36 sites), NNN (32 sites), and DRP and dissolved copper (both 23 sites).

The concentrations of parameters at the sites have mostly remained steady over time (64%), but some improvements in water quality were recorded this year (28%) and some declines (8%). The following temporal trends of note were recorded:

- A small decrease in BOD_5, DRP and NNN/DIN, across all catchments.
- An increase in *E. coli* concentrations at many mainstem sites in the Pūharakekenui/ Styx River. It is unclear why this has occurred and indicates a catchment wide change, potential due to land use changes or waterfowl inputs. Further investigation is required.
- An increase in nitrogen at the Ōtūkaikino at Scout Camp site. This indicates that there are still some nutrient sources entering the stream, likely due to agricultural land use in the catchment.
- An increase in dissolved copper and zinc at the Curletts at Motorway site and a decrease in nitrogen. This is the first year copper has exhibited a significant trend. An increase in copper and zinc over time is not unusual, especially in an industrial catchment like this, due to increases in traffic volumes (with copper coming from brake pads and zinc from tyres) and degradation of roofs with zinc over time. This is supported by the increase in zinc being due to a gradual change in concentrations over time, rather than sudden peaks in concentrations. This was the first year of monitoring that there was a significant increase in copper at this site. The reason for the decrease in nitrogen is unclear, but may be due to, less input from nitrogen rich groundwater, or more stormwater inputs diluting groundwater.
- Reductions in copper and lead at the Curletts U/S of Heathcote site. This site is downstream of the Curletts at Motorway site, followed by the Curletts Wetland which has recently been constructed within the waterway, but is not yet fully operational. The steady decrease in copper may be due to reductions in the source of this contaminant (predominantly brake pads), due to the building of the motorway with related stormwater treatment in approximately 2011. However, peaks in concentrations were still recorded many years prior to 2011. The reduction in lead may be due to a decrease over time due to the phasing out of leaded petrol.
- A steady increase in ammonia over time within Wilsons Drain, with more peaks in later years. This catchment drains the industrial area of Belfast, so this indicates that ammonia has been reaching the stormwater system from some businesses for some time, with overall concentrations slowly increasing.
- A decrease in DRP at the Cashmere Stream at Sutherlands Rd site, due to a reduction in large peaks since 2014. This is likely due to the gradual urbanisation for this traditionally agricultural catchment (i.e. reducing runoff and erosion).

- Reductions in the concentrations of a number of parameters at the Halswell Basin outlet, including dissolved copper, dissolved lead, TSS, ammonia, BOD5, DIN and DRP. TSS levels at the outlet generally decreased over time, particularly since 2012, and there was a small reduction in TSS recorded over time at the inlet. Therefore, inputs within the catchment may have decreased over time, but the treatment efficiency of the basin could also have improved with extensions carried out in 2012. Copper and lead generally recorded decreasing trends since monitoring began in 2014. As there were no significant reductions in these contaminants at the inlet, these trends may be due improved efficiency of the basin over time, particularly in relation to the increased TSS removal efficiency, as a proportion of metals adsorb to sediment. Even though it was expected that lead inputs would have reduced over time since the phasing out of leaded petrol, this parameter still occurs within the basin, with the highest concentrations recorded this monitoring year since monitoring began. This could indicate an industrial source within the catchment. As there was a large decrease in ammonia at the inlet, and the basin is a wet pond not likely to treat these contaminants, it may be that inputs into the catchment of this parameter have reduced overall. As ammonia makes up a proportion of DIN, it is likely the reduction in DIN at both the inlet and outlet is due to the reduction in ammonia, with trends between the two parameters also similar over time. In contrast, the reductions in ammonia and DIN could be related to less waterfowl inputs over time, due to the maturing of vegetation preventing access to the pond. This would also explain the reduction in BOD5 (at both the inlet and outlet), DRP (at both the inlet and outlet), E. coli at the inlet, and ammonia at the inlet as well as the outlet.

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, TSS and turbidity may be trending towards a significant increase over time at Cashmere at Worsleys Rd, and this should be assessed in next year's report. In addition, 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 aquatic ecology monitoring undertaken by the CCC.

In 2019, major instream projects such as dredging and bank stabilisation occurred in the Ōpāwaho/ Heathcote River. Separate monitoring for these projects showed that high TSS and turbidity levels occurred due to the dredging works. In this monitoring, much higher conductivities were recorded at the three lower Ōpāwaho/ Heathcote River sites this year, compared to last year, and this is likely to be due to the dredging. Atypically high dissolved lead concentrations were also recorded at these sites during the latter part of the year, with sample collection coinciding with periods of dredging. However, these increases did not result in any significant change in parameters since monitoring began, with the exception of conductivity at the Heathcote at Catherine St site.

Based on the WQI, the Ōtūkaikino and Pūharakekenui/ Styx River catchments generally had 'good' water quality; however, all other catchments generally had 'poor' water quality. The Ōtūkaikino River recorded the best overall water quality out of all the catchments, but the best site was shared between the Ōtūkaikino at Scout Camp and Styx at Main North Rd sites, followed by the Ōtūkaikino at Groynes site, and then the Smacks at Gardiners Rd site. The catchment recording the worst water quality was Ōpāwaho/ Heathcote River. The worst sites were in this catchment, at the Curletts at Motorway, then Heathcote at Tunnel Rd, followed jointly by Haytons Stm and Heathcote at Ferrymead Bridge sites. There were a number of contaminants of particular concern at the Curletts at Motorway (copper, zinc, DO, DRP, *E. coli*), Heathcote at Tunnel Rd (TSS, turbidity, NNN, DRP), Haytons Stm (copper, zinc, turbidity, DRP) and Heathcote at Ferrymead Bridge (TSS, turbidity, NNN, DRP) sites.

Most catchments showed improvement in the WQI compared to 2018, with seven sites in the ‘good’ category, up from zero in 2018. Improvement of these seven sites is largely due to a decrease in the number of parameters exceeding the guideline, particularly for pH and DRP, but also copper, zinc, TSS, DO, temperature, BOD_5, and *E. coli*. Differences in rainfall alone cannot explain the reduced number of exceedances observed this year. Compared to 2018, the number of rainfall events varied by only ± 1. Significant increases in WQI scores over time were recorded at Nottingham at Candys Rd, Heathcote at Bowenvale Ave and Cashmere at Sutherlands Rd. However, the Curletts at Motorway site WQI significantly declined over time. Improvements at the Nottingham at Candys Rd and Heathcote at Bowenvale Ave sites were like to be largely driven by reductions in the number of parameters exceeding guidelines, particularly for copper and BOD_5 (both sites), DO (Heathcote at Bowenvale Ave), and TSS (Nottingham at Candys Rd). At the Cashmere at Sutherlands Rd site, zinc exceedances have not occurred since 2016, and this appears to be driving the improvement in WQI. The original source of zinc is unclear, considering that these headwaters are not located within urban areas, which are usually the source of zinc (through roofing and car tyres). The decline in WQI at the Curletts at Motorway site is likely driven by the 2014 year recording fewer exceedances across many parameters, compared to later years.

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 at Motorway, which generally recorded worse levels of contaminants than other waterway sites (for copper, zinc, pH, dissolved oxygen, BOD_5 and DRP). Haytons Stm also recorded higher concentrations of copper, zinc, pH, BOD_5, and DRP compared to the other waterway sites, as Avon at Mona Vale did occasionally for TSS.

The two Halswell Basin sites (inlet and outlet) generally recorded higher concentrations of parameters than the waterway sites. In particular, the basin recorded higher concentrations of copper, zinc, pH, TSS, BOD_5, and total ammonia. 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 concentrations than the inlet. Lower concentrations 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 be a reflection that peak contaminant levels had not reached the outlet yet. Of note, pH levels were very high at both the inlet and outlet. Previously only the outlet levels were elevated, and it was thought that basin processes were causing basic conditions. This years’ results indicate that there may be processes higher in the catchment creating the basic conditions. Overall, these monitoring results for the basin are similar to those recorded in previous years (e.g. Margetts & Marshall, 2015; Margetts & Marshall, 2016; Margetts & Marshall, 2018; Marshall & Burrell, 2017; Marshall & Noakes, 2019).

Wet weather monitoring in the Ōtākaro/ Avon and Pūharakekenui/ Styx River catchments was generally similar to the monthly monitoring. However, there were a number of exceptions for many parameters across many sites. The most widespread exceptions were higher concentrations in the wet weather monitoring for BOD_5 in both catchments and higher copper concentrations in the Ōtākaro/ Avon River catchment. As the main source of copper is from brake pads, these higher concentrations than the monthly monitoring are likely due to stormwater input from roads and carparks.

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, Marshall & Noakes, 2019). 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 by CCC, ECan and landowners themselves. The CSNDC will give the Council better focus and directive to tackle surface water quality issues within its jurisdiction. Past, current and future practices to improve stormwater quality include source control (e.g., erosion and sediment control measures, redirection of stormwater to trade waste), more effective stormwater treatment devices and community education. For example, CCC are constructing a number of stormwater basins for the purpose of flood mitigation and stormwater treatment. CCC also work with ECan to audit business in key catchments, helping reduce the amount of contaminants entering the stormwater system. Implementation of new regional and national policy will also support these measures. Due to all this, surface water quality improvements are anticipated across the City, but may only occur over long time scales, due to the size of the issue and the lag in benefits. Further monitoring and targeted management is still required to address the water quality issues detailed in this report.

6 Recommendations

- Haytons Stream and Curletts Road Stream should remain as the top priority areas for improved contaminant source control and stormwater treatment, followed by the middle tributaries of the Ōtākaro/ Avon River (Riccarton Main Drain, Addington Brook and Dudley Creek):
    - CCC and ECan should continue 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 should undertake detailed effectiveness monitoring of the two stormwater treatment facilities recently upgraded in Haytons and Curletts Streams (Haytons Retention Basin/Wigram Basin and Curletts Wetlands). Monitoring of Wigram basin is currently proposed within the stormwater device efficiency monitoring project of the CSNDC, in conjunction with ECan and the University of Canterbury.

- Haytons and Curletts Road Streams should remain the priority for the targeted wet weather monitoring project under the CSNDC, which aims to pin point hotspots of contaminants within these catchments, to inform catchment management practices. With time and if resources allow, the project should extend to the Ōtākaro/ Avon River tributaries.
  - The recommendations within the ECan catchment management plan for Addington Brook and the Haytons Stream Action Plan should be undertaken.
  - Stormwater treatment by the large CCC facilities proposed for Addington Brook and Riccarton Stream should be prioritised.
- Investigations into the sources of particularly poor water quality in non-priority catchments should be carried out for the following waterways, based on this and previous year's results:
  - Linwood Canal (DO, total ammonia, DRP, and *E. coli*).
  - Wilsons Stream (ammonia, nitrogen, and *E. coli*)
  - Cashmere Stream at Worsleys Rd (TSS/turbidity). This is particularly important given the high concentration of threatened kākahi/freshwater mussels located in Cashmere Stream (Instream Consulting Ltd, 2020; Marshall 2019, *unpublished data*).
  - Heathcote River at Templetons Road and Knights Stream (nitrogen)
  - Kā Pūtahi Creek and other sites within the Pūharakekenui/ Styx River catchment, and Nottingham Stream (*E. coli*)
  - Ōtūkaikino River at Scout Camp (NNN), although this may be due to the short monitoring period (approximately five years), compared to the other sites, with the significant annual increase decreasing each year (46% in 2017, 25% in 2018, and 17% in 2019).
  - Ōtūkaikino River at Groynes (copper).
- Investigations into the sources of phosphorus in the catchments should be carried out to identify the major source that is increasing downstream (e.g. fertilisers or faecal input).
- A long-term monitoring program is established to investigate changes in conductivity and salinity in the lower Ōpāwaho/ Heathcote River in response to dredging, and any resultant changes in biota and riparian vegetation.
- Investigations should be carried out to identify how best to reduce faecal contamination within the waterways, particularly with the public interest in swimmable rivers. 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.
-
- A Waterways Action Plan should be developed that considers collectively what we want to achieve for our waterways (this may vary between different people) and what is required to get there. For example, an improvement in stormwater quality may not result in an increase in biodiversity, due to other habitat limitations.

7 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 at Motorway, followed by Heathcote at Tunnel Rd, Haytons Stm and Heathcote at Ferrymead Bridge. The Ōtūkaikino River catchment recorded the best water quality and the best site was shared between the Ōtūkaikino at Scout Camp and Styx at Main North Rd sites. WQI largely did not change over time. The contaminants that exceeded guidelines at the most sites were *E. coli*, nitrogen, phosphorus and

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dissolved copper. The concentrations of all parameters have mostly remained steady over time, with some improvements and declines in water quality. The results of this year's monitoring are largely consistent with previous years.

8 Acknowledgements

CCC laboratory staff collected the monthly monitoring samples, and Bioresearches and Instream Consulting Limited collected the 2018 and 2019 wet weather monitoring samples, respectively. Dr James Ross (Lincoln University), Ian Jowett (Jowett Consulting), Dr Amy Whitehead (NIWA) and Dr Jennifer Gadd (NIWA) provided invaluable advice on statistical modelling. Peter Christensen (CCC), Michele Stevenson (ECan), Dr Lesley Bolton-Ritchie (ECan) and Duncan Harvest (ECan) provided helpful comments on the draft report.

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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	<0.0001 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[12]	<0.3 mg/L	Sampling instigation- current day	Extraction DCM (GC-FID)

[12] Analysed by Watercare Laboratory (IANZ accredited)

Appendix B: Metal Hardness Modified Guideline Values

Hardness Modified Guideline Values for Metals in Christchurch City Waterways

1. Introduction

The Australian and New Zealand guidelines for fresh and marine water quality provide a set of default guideline values for dissolved metals (ANZG, 2018). If measured concentrations of toxicants are below the default guideline values, then there is a low risk of adverse environmental effects.

The guidelines also provide a process of modifying the default guideline values for local environmental conditions, namely hardness, which can affect the toxicity of metals (excluding copper) and therefore increase the risk of adverse biological effects (Warne et al., 2018). The default guideline values for metals assume that water is soft (hardness 0–59 mg/L as $CaCO_3$). However, as water hardness increases, the toxicity of some metals decreases and therefore the guideline value may increase, without increasing the risk of adverse biological effects.

Hardness Modified Guideline Values (HMGV), formerly known as Hardness Modified Trigger Values (HMTV), have been previously calculated by Christchurch City Council (Dewson, 2012; Margetts & Marshall, 2015). It is considered that hardness values are unlikely to change over the years, so these values can be reassessed approximately every five years. This memorandum constitutes the five-yearly update of these values, as required under the Comprehensive Stormwater Network Discharge Consent (CRC190445), and reflects the recommendation that copper is no longer modified by hardness (Warne *et al.*, 2018).

2. Methods

In 2019, water samples were collected monthly from 36 non-tidal sites across the five main river catchments within Christchurch City (Avon, Heathcote, Styx, Ōtūkaikino and Halswell Rivers), as well as a tidal site within Linwood Canal, giving a total of 12 samples for each of the 37 sites (Appendix A, Tables i and ii). These samples were collected as part of the wider Christchurch City Council surface water quality monitoring programme. Tidal sites within this wider monitoring programme for the five main river catchments[1] were excluded from the analyses, as tidal sites typically have high hardness levels, which would skew the results for each catchment, resulting in inappropriately higher guideline levels. As there was only one site for Linwood Canal, it did not matter that this site was tidal.

Boxplots of the water hardness data were created in RStudio (version 1.2.5033), to show the median and interquartile range. 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 the 5th and 95th percentiles (using HAZEN methodology).

To calculate the HMGV, the following species protection levels were chosen, as per ECan (2018).

- Avon River, Heathcote River, and Linwood Canal catchments: 90% (Spring-fed – plains – urban)
- Styx, Ōtūkaikino, and Halswell River catchments: 95% (Spring-fed – plains)
- Cashmere Stream: 99% (Banks Peninsula)

[1] Avon River at Pages/Seaview Bridge, Avon River at Bridge Street, Heathcote River at Catherine Street, Heathcote River at Tunnel Road and Heathcote River at Ferrymead Bridge.

These default guideline values were then modified by the median catchment hardness, as per the below formula (Warne *et al.*, 2018).

$$Lead\ HMGV = Default\ Guideline\ Value\ x\ \left(\frac{hardness}{30}\right)^{1.27}$$

$$Zinc\ HMGV = Default\ Guideline\ Value\ x\ \left(\frac{hardness}{30}\right)^{0.85}$$

3. Results

Median water hardness in the five main river catchments in Christchurch (Avon, Heathcote, Styx, Ōtūkaikino and Halswell) ranged from 'soft' to 'moderate'; however, Linwood Canal fell between the 'very hard' and 'extremely hard' categories (Table 1; Figures 1–2). HMGV are greater than default guideline values in each of the rivers in Christchurch, as the default values assume water is 'soft' and thus conservatively protects aquatic ecosystems (Table 1).

Table 1. Default and HMGV for dissolved zinc and lead in Christchurch waterways.

Catchment	Median hardness (mg/L)	Species protection level (ECan, 2018)	Zinc guideline		Lead guideline	
			Default (mg/L)	HMGV (mg/L)	Default (mg/L)	HMGV (mg/L)
Heathcote River – Cashmere Stream	94.0	99%	0.0024	0.00634	0.0010	0.00427
Halswell River	75.0	95%	0.0080	0.01743	0.0034	0.01089
Styx River	47.0	95%	0.0080	0.01172	0.0034	0.00601
Ōtūkaikino River	35.0	95%	0.0080	0.00912	0.0034	0.00414
Avon River	66.5	90%	0.0150	0.02951	0.0056	0.01539
Heathcote River – remainder	94.0	90%	0.0150	0.03960	0.0056	0.02388
Linwood Canal	370.0	90%	0.0150	0.12691	0.0056	0.13610

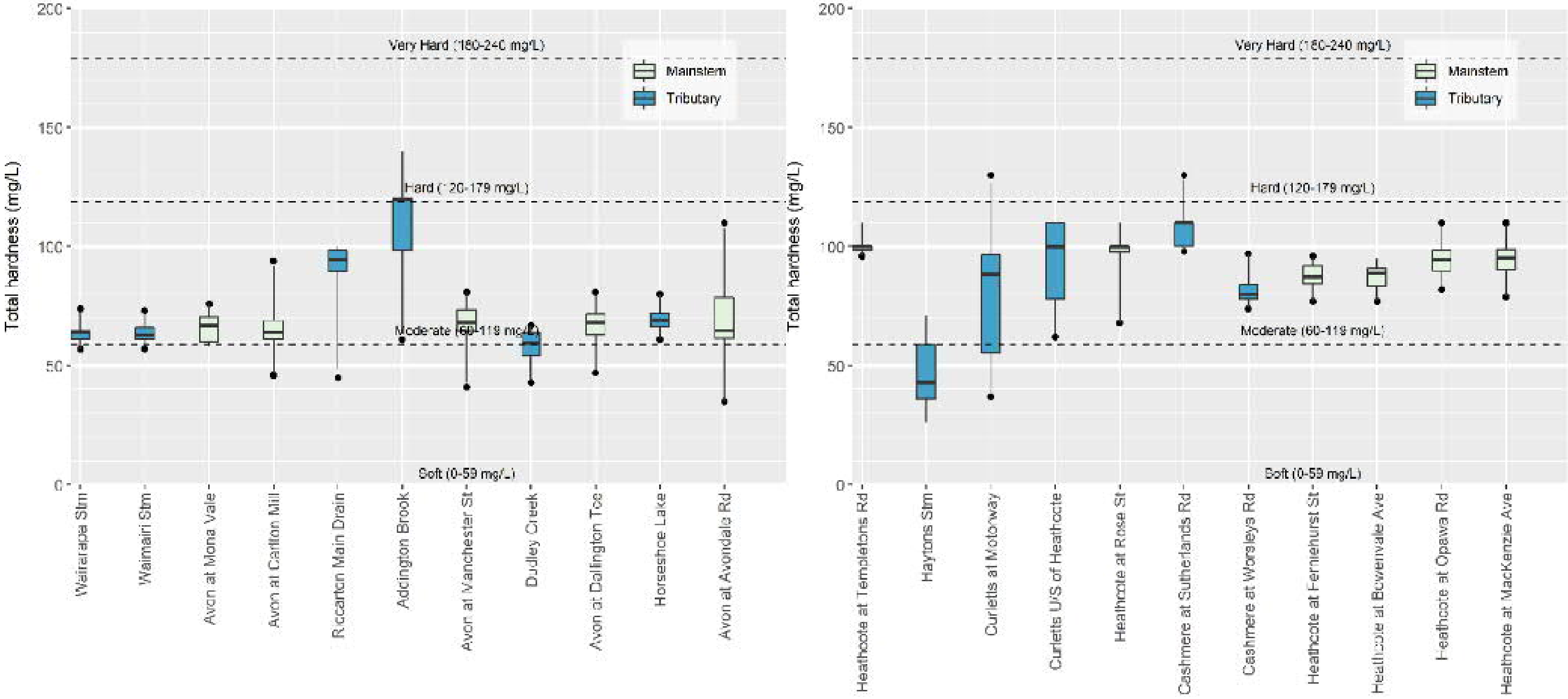

Figure 1. Total hardness (as $CaCO_3$) levels in water samples taken monthly from non-tidal sites within the Ōtākaro/Avon (left graph) and Ōpāwaho/Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June, as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the ANZECC (2000) delineations between water hardness categories.

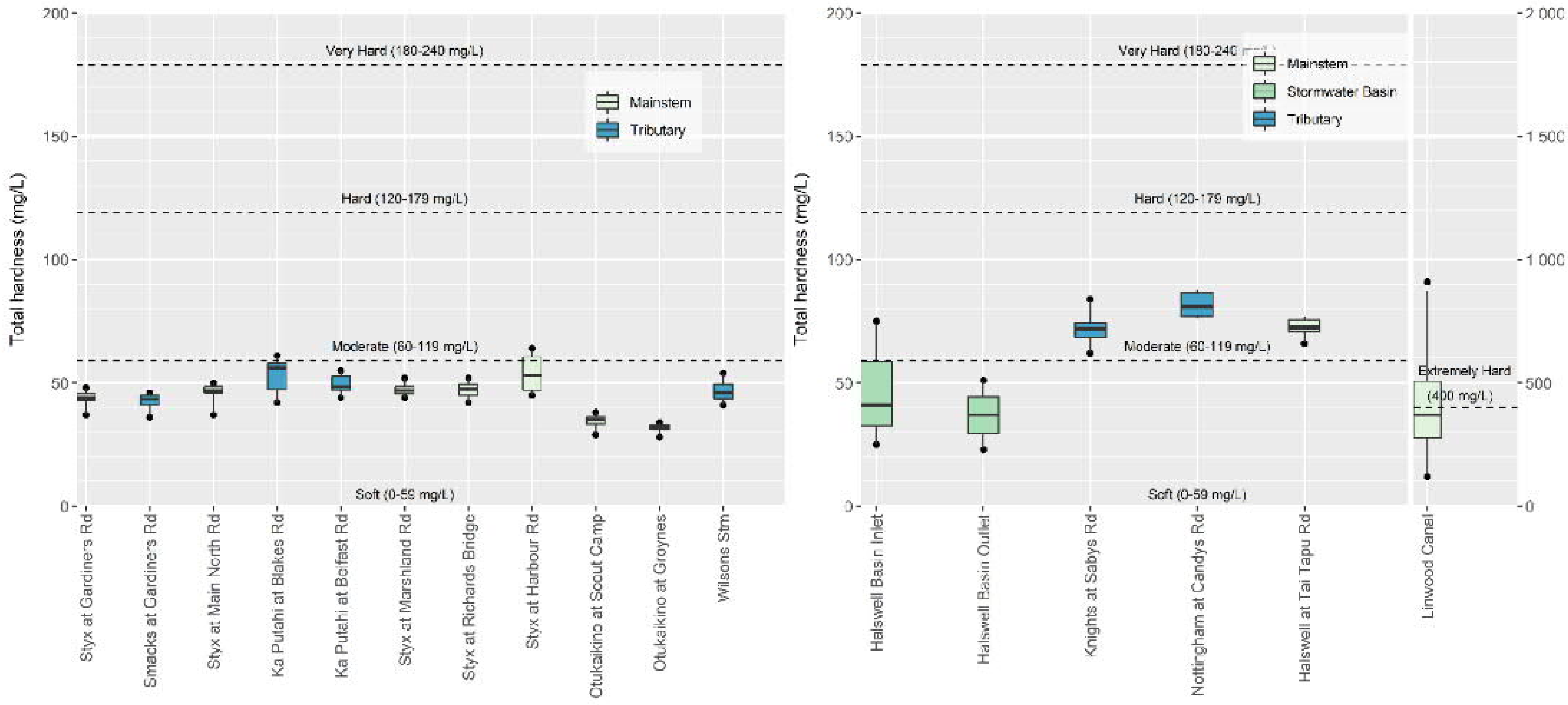

Figure 2. Total hardness (as $CaCO_3$) levels in water samples taken monthly from not-tidal sites within the Pūharakekenui/Styx and Ōtūkaikino Rivers (left graph), and the Huritini/Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the ANZECC (2000) delineations between water hardness categories.

4. References

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17th June 2020

5. Appendix A: Site locations

Table i. Water quality monitoring sites for the water hardness investigations in the Avon and Heathcote River catchments.

Catchment	Site	Easting (NZTM)	Northing (NZTM)
Ōtākaro/ Avon	Avon River at Dallington Terrace/Gayhurst Road	1573560	5181210
	Avon River at Manchester Street	1570890	5180481
	Wairarapa Stream	1568250	5181303
	Waimairi Stream	1568233	5181172
	Avon River at Mona Vale	1568334	5181046
	Riccarton Main Drain	1568683	5180019
	Addington Brook	1569427	5179826
	Dudley Creek	1572574	5182150
	Horseshoe Lake Discharge	1574342	5183294
	Avon River at Carlton Mill Corner	1569737	5181259
	Avon River at Avondale Road	1574752	5183557
Ōpāwaho/ Heathcote	Heathcote River at Opawa Road/Clarendon Terrace[4]	1573071	5177615
	Heathcote River at Bowenvale Avenue	1571198	5175780
	Cashmere Stream at Worsleys Road	1569030	5175155
	Heathcote River at Rose Street	1568701	5175918
	Heathcote River at Ferniehurst Street	1569157	5175612
	Heathcote River at Templetons Road	1565915	5176897
	Haytons Stream at Retention Basin	1566020	5177596
	Curletts Road Stream Upstream of Heathcote River Confluence	1566928	5177711
	Heathcote River at Mackenzie Avenue Footbridge	1573520	5177917
	Curletts Road Stream at Southern Motorway	1566405	5178358
	Cashmere Stream at Sutherlands Road	1566086	5173988

Table ii. Water quality monitoring sites for the water hardness investigations in the Styx River, Halswell River, Ōtūkaikino River and Linwood Canal catchments.

Catchment	Site	Easting (NZTM)	Northing (NZTM)
Pūharakekenui/ Styx	Smacks Creek at Gardiners Road near Styx Mill Road	1566804	5187956
	Styx River at Gardiners Road	1566790	5187226
	Styx River at Main North Road	1569066	5187219
	Kā Pūtahi[2] Creek at Blakes Road	1570401	5188030
	Kā Pūtahi[2] Creek at Belfast Road	1572194	5188267
	Styx River at Marshland Road Bridge	1572358	5187778
	Styx River at Richards Bridge	1573975	5189640
	Styx River at Harbour Road Bridge	1574998	5194749
Huritini/ Halswell	Halswell Retention Basin Inlet	1561701	5177022
	Halswell Retention Basin Outlet	1561796	5176914
	Nottingham Stream at Candys Road	1564532	5173080
	Halswell River at Akaroa Highway (Tai Tapu Road)	1564446	5171721
	Knights Stream at Sabys Road	1563723	5172852
Ōtūkaikino	Ōtūkaikino River at Groynes Inlet	1567878	5188869
	Wilsons Drain at Main North Road	1571241	5190793
	Ōtūkaikino Creek at Omaka Scout Camp	1565664	5188038
Linwood	Linwood Canal/City Outfall Drain	1575952	5178026

[2] 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.

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[13]
	Waimairi Stream	January 2007[13]
	Avon River at Mona Vale	January 2007[13]
	Avon River at Carlton Mill Corner	October 2008[14]
	Riccarton Main Drain	October 2008
	Addington Brook	October 2008
	Avon River at Manchester Street	July 2008[15]
	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[14]
	Avon River at Pages/Seaview Bridge	January 2007
	Avon River at Bridge Street	January 2007[13]
Ōpāwaho/ Heathcote	Heathcote River at Templetons Road	January 2007[16]
	Haytons Stream at Retention Basin	April 2007[17]
	Curletts Road Stream Upstream of Heathcote River	October 2008
	Curletts Road Stream at Motorway	October 2008[14]
	Heathcote River at Rose Street	June 2008[18]
	Cashmere Stream at Sutherlands Road	December 2010
	Cashmere Stream at Worsleys Road	January 2007
	Heathcote River at Ferniehurst Street	July 2008[17,19]
	Heathcote River at Bowenvale Avenue	January 2007
	Heathcote River at Opawa Road/Clarendon Terrace	January 2007
	Heathcote River at Mackenzie Avenue	October 2008[14]
	Heathcote River at Catherine Street	October 2008[14]
	Heathcote River at Tunnel Road	January 2007
	Heathcote River at Ferrymead Bridge	January 2007
Pūharakekenui/ Styx	Smacks Creek at Gardiners Road	January 2007[16]
	Styx River at Gardiners Road	January 2007[16]
	Styx River at Main North Road	January 2007[16]
	Kā Pūtahi at Blakes Road	January 2007[16]
	Kā Pūtahi at Belfast Road	January 2007[16]
	Styx River at Marshland Road Bridge	January 2007[16]
	Styx River at Richards Bridge	October 2008
	Styx River at Harbour Road Bridge	January 2008
Huritini/ Halswell	Halswell Retention Basin Inlet	April 2007[14,17]
	Halswell Retention Basin Outlet	April 2007[14,17,20]
	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[13]

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

Christchurch City Council

Appendix D: Time Trends analysis

Table i. Direction of significant trends (p≤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). Parameter changes represented by an arrow with no number are where a statistically significant change was recorded, but due to a high proportion of censored data, only the direction of change could be calculated.

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Wairarapa Stm			↓ 13%	↓ 8%							↓				
Waimairi Stm				↓ 7%				↓ 2%					↓ 2%	↓ 2%	
Avon at Mona Vale				↓ 7%							↓		↓ 1%	↓ 2%	
Avon at Carlton Mill				↓ 9%				Not Sampled			↓	↑ 4%	↓ 3%	↓ 3%	
Riccarton Main Drain				↓ 7%		↑ 3%					↓		↑ 4%	↑ 4%	
Addington Brook				↓ 3%							↓ 7%				↑ 5%
Avon at Manchester St				↓ 7%							↓		↓ 3%	↓ 3%	↓ 2%
Dudley Creek		↓ 15%				↓ 1%				↑ 1%	↓ 9%	↓ 3%	↓ 4%	↓ 4%	
Avon at Dallington Tce							↓ 4%	↓ 6%		↑ 1%	↓	↓ 6%	↓ 1%	↓ 2%	
Horseshoe Lake								↓ 3%		↑ 1%	↓ 3%	↓ 3%	↓ 3%	↓ 3%	
Avon at Avondale Rd				↓ 3%				Not Sampled			↓		↓ 4%	↓ 4%	
Avon at Pages Rd			↓ 9%	↓ 1%		↑ 4%		↓ 3%			↓	↓ 3%	↓ 2%	↓ 3%	↑ 4%
Avon at Bridge St				↓ 5%		↑ 5%			↑ 1%	↑ 1%	↓	↓ 7%	↓ 2%	↓ 3%	↑ 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.

Table ii. Direction of significant trends (p≤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). Parameter changes represented by an arrow with no number are where a statistically significant change was recorded, but due to a high proportion of censored data, only the direction of change could be calculated.

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Heathcote at Templetons Rd			↓13%	↓ 12%					↓ 2%		↓		↑ 2%	↑ 2%	↓ 4%
Haytons Stm			↑ 9%	↓ 11%			↑ 6%	↑ 4%			↓ 5%	↓ 7%	↓ 11%	↓ 14%	
Curletts at Motorway	↑ 12%		↑ 16%			↑ 2%	↑ 6%	Not Sampled					↓ 31%	↓24%	
Curletts U/S of Heathcote	↓16%	↓13%					↓ 5%	↓ 9%			↓ 2%	↓ 5%			↓ 13%
Heathcote at Rose St				↓ 8%							↓ 5%				
Cashmere at Sutherlands Rd				↓ 18%					↓ 2%		↓		↓ 3%	↓ 3%	
Cashmere at Worsleys Rd				↓ 6%							↓				↓ 3%
Heathcote at Ferniehurst St				↓ 6%							↓				
Heathcote at Bowenvale Ave				↓ 6%							↓				
Heathcote at Opawa Road				↓ 6%				↓ 3%			↓	↓ 2%			
Heathcote at Mackenzie Ave				↓ 8%				Not Sampled			↓				
Heathcote at Catherine St				↓ 7%		↑ 2%		Not Sampled			↓ 5%	↓ 3%		↓ 1%	
Heathcote at Tunnel Rd				↓ 9%			↓ 2%	↓ 5%				↓ 9%			
Heathcote at Ferrymead Bridge			↑ 14%	↓ 14%							↓ 4%	↓ 13%			

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. 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 iii. Direction of significant trends (p≤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). Parameter changes represented by an arrow with no number are where a statistically significant change was recorded, but due to a high proportion of censored data, only the direction of change could be calculated.

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Halswell Basin Inlet				↓ 5%			↓ 4%	Not Sampled			↓ 8%	↓ 25%		↓ 15%	↓ 4%
Halswell Basin Outlet	↓6%	↓28%		↓ 11%		↓ 4%	↓ 19%	Not Sampled	↑ 3%		↓ 19%	↓ 33%		↓ 18%	
Knights at Sabys Rd			↓ 7%	↓ 8%							↓	↓ 7%			
Nottingham at Candy's Rd			↑ 7%			↓ 3%		↓ 4%			↓		↓ 5%	↓ 5%	
Halswell River at Tai Tapu Rd			↓ 8%	↓ 3%					↑ 1%		↓		↓ 3%	↓ 3%	↑ 8%
Linwood Canal				↓ 4%		↑ 8%		↓ 3%		↑ 1%	↓ 8%	↓ 3%	↓ 7%	↓ 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.

Table iv. 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). Parameter changes represented by an arrow with no number are where a statistically significant change was recorded, but due to a high proportion of censored data, only the direction of change could be calculated.

Site	Dissolved copper	Dissolved lead	Dissolved Zinc	DRP	pH	EC	TSS	Turbidity	DO	Temp	BOD_5	Total Ammonia	NNN	DIN	*E. coli*
Styx at Gardiners Rd			↓ 10%	↓ 5%		↓ 1%					↓		↓ 6%	↓ 6%	↑ 8%
Smacks at Gardiners Rd			↓ 16%	↓ 4%		↓ 1%		↓ 8%			↓		↓ 3%	↓ 3%	
Styx at Main North Rd				↓ 3%				↓ 4%			↓		↓ 5%	↓ 5%	↑ 4%
Kā Pūtahi at Blakes Rd						↑ 2%	↑ 2%	↑ 4%			↓				
Kā Pūtahi at Belfast Rd				↓ 3%				↓ 4%	↑ 1%		↓ 5%	↓ 3%	↑ 2%	↑ 1%	
Styx at Marshland Rd				↓ 2%							↓				↑ 3%
Styx at Richards Bridge				↓ 3%							↓				↑ 5%
Styx at Harbour Rd				↓ 2%							↓		↓ 2%	↓ 2%	↑ 5%
Ōtūkaikino at Groynes			↓ 16%	↓ 14%				↓ 11%			↓	↓ 2%	↓ 6%	↓ 6%	
Ōtūkaikino at Scout Camp				↓ 7%	↓ 1%	↑ 4%			↓ 1%				↑ 17%	↑ 15%	
Wilsons Stm						↑ 1%		↑ 13%				↑ 12%	↑ 4%	↑ 4%	↑ 13%

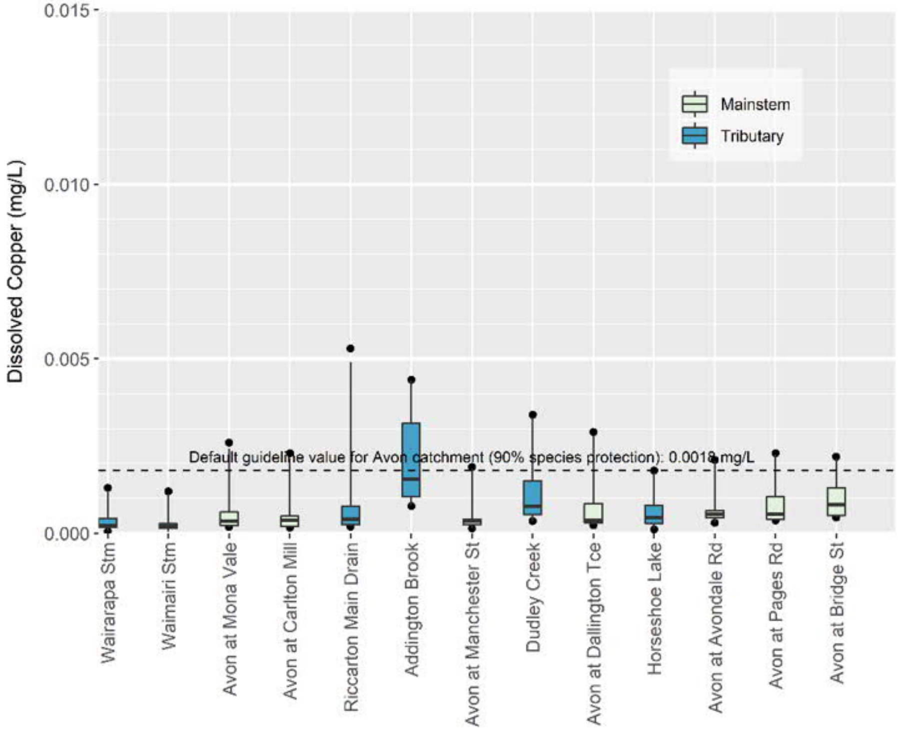
Notes: EC = Electrical Conductivity, TSS = Total Suspended Solids, DO = Dissolved Oxygen, Temp = Temperature; BOD5 = Biochemical Oxygen Demand, NNN = Nitrate Nitrite Nitrogen and DIN = Dissolved Inorganic Nitrogen. Blank cells indicate no significant upwards or downwards trends.

Table v. Direction of significant trends (p≤0.05) for parameters monitored by the Styx Living Laboratory Trust, with sufficient data to run Time Trends analysis.

Site	Clarity	pH	EC	Temp
Styx at Brooklands		↑ 2%		↑ 1%
Kā Pūtahi at Everglades		↑ 1%		
Kā Pūtahi at Ouruhia Domain		↑ 1%		
Styx at Radcliffe Rd		↑ 2%		↑ 1%
Styx at Conservation Reserve			↑ 1%	
Styx at Willowbank	↓ 2%			↑ 1%

Notes: EC = Electrical Conductivity. Blank cells indicate no significant upwards or downwards trends.

Appendix E: Monthly Monitoring Graphs



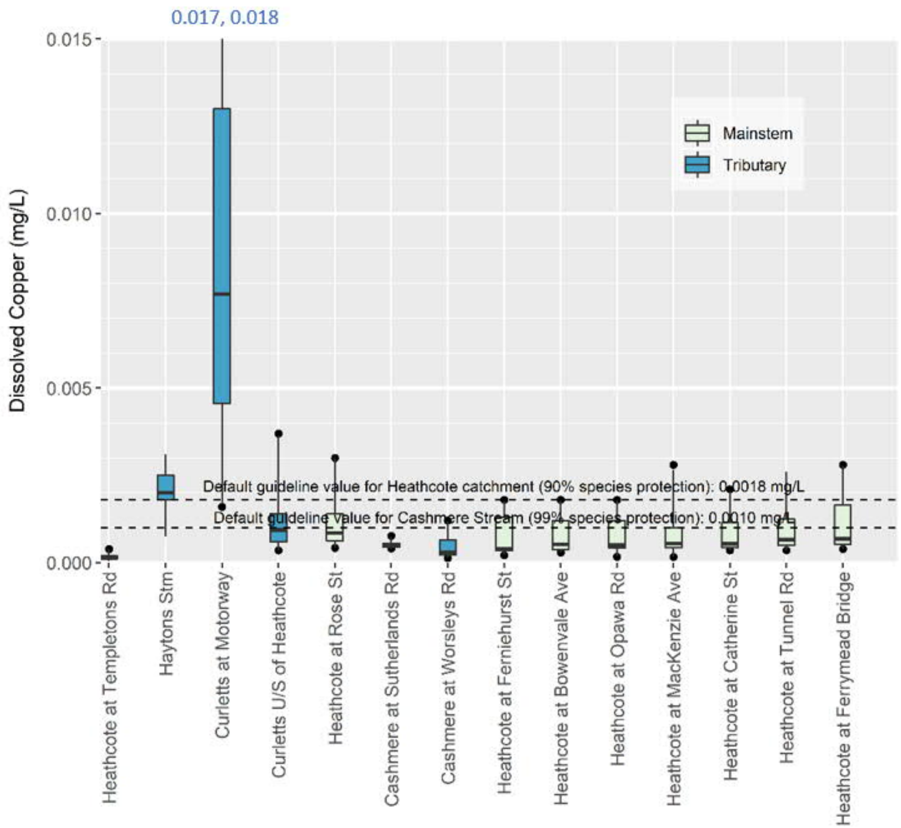


Figure i (a). Dissolved copper concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline values (Environment Canterbury, 2019). 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.

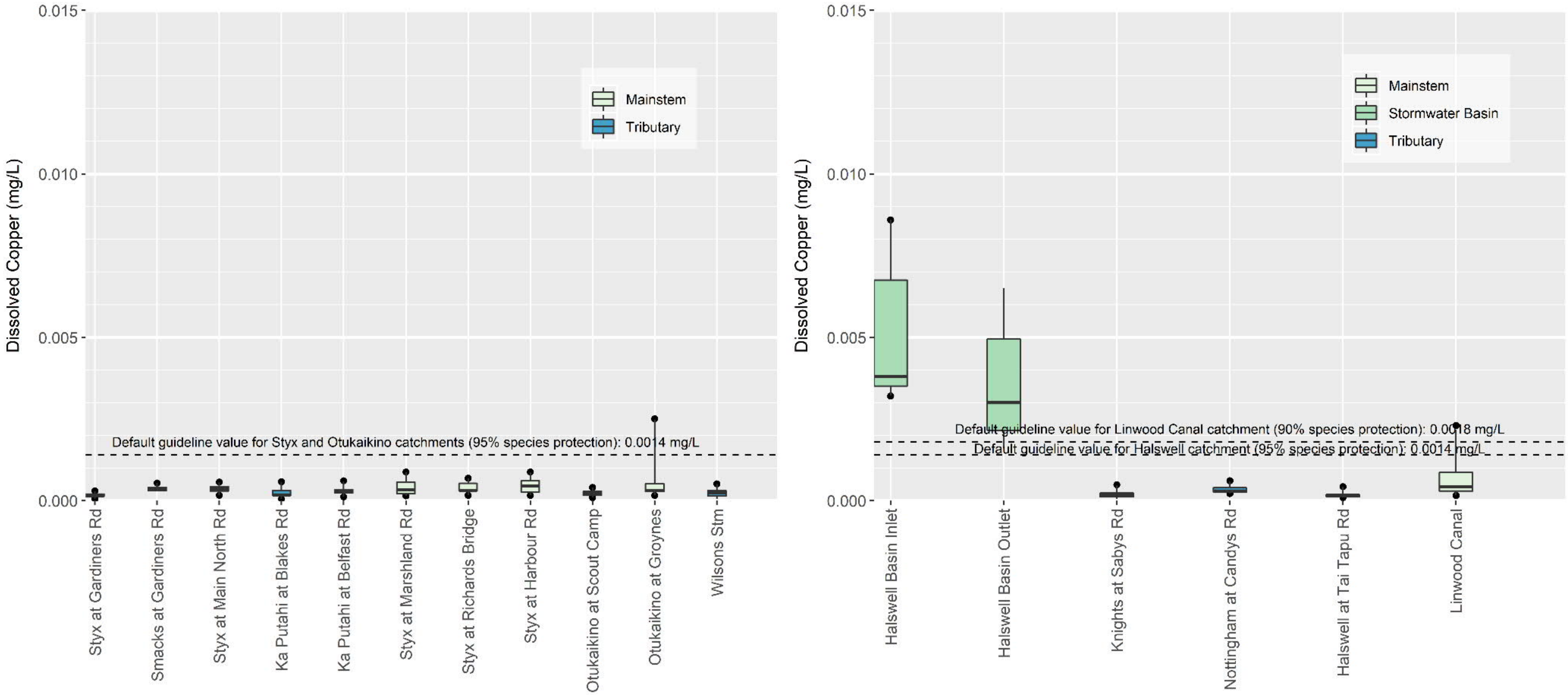


Figure i (b). Dissolved copper concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline values (Environment Canterbury, 2019). The 90% species protection HMGV for Linwood Canal (0.167 mg/L) is not visible because it is 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).

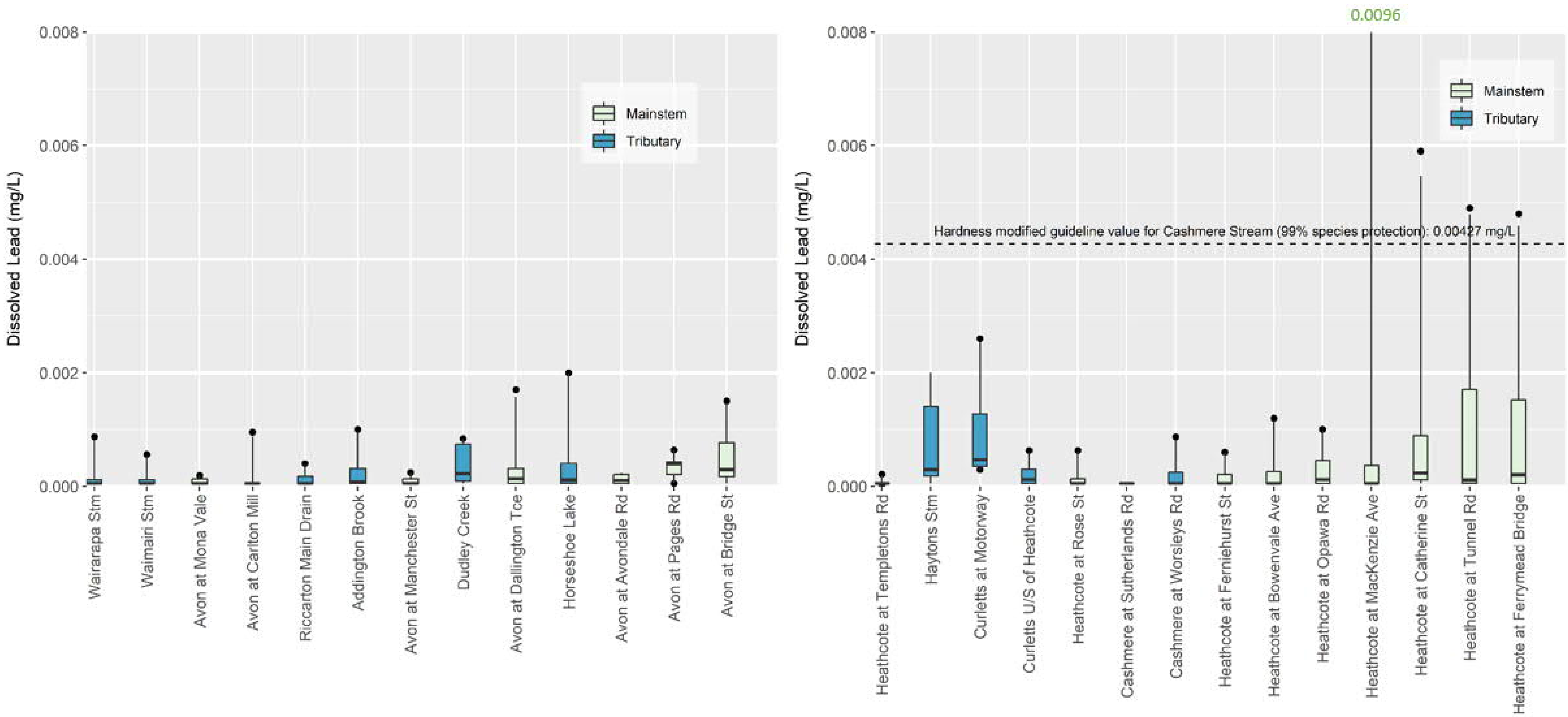
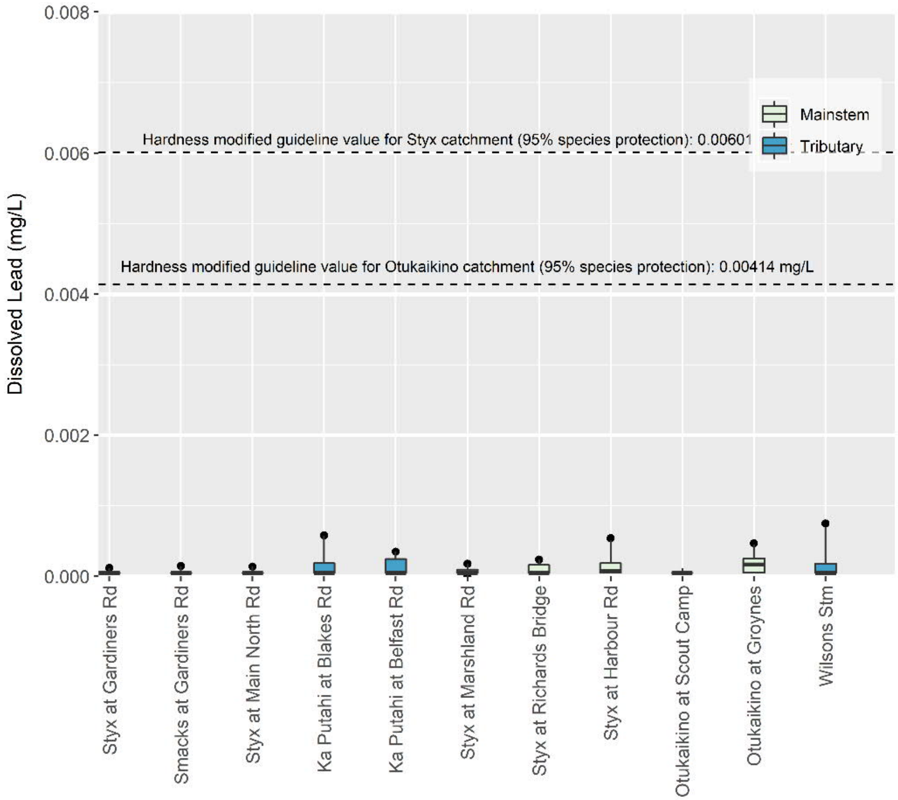


Figure ii (a). Dissolved lead concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed line represents the Land and Water Regional Plan guideline value (Environment Canterbury, 2019), which has been modified to account for water hardness (Hardness Modified Guideline Value = HMGV), as per the Warne *et al.* (2018) guidelines methodology. The 90% protection HMGV for the Ōtākaro/ Avon River (0.01539 mg/L) and the Ōpāwaho/ Heathcote River (0.02388 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.



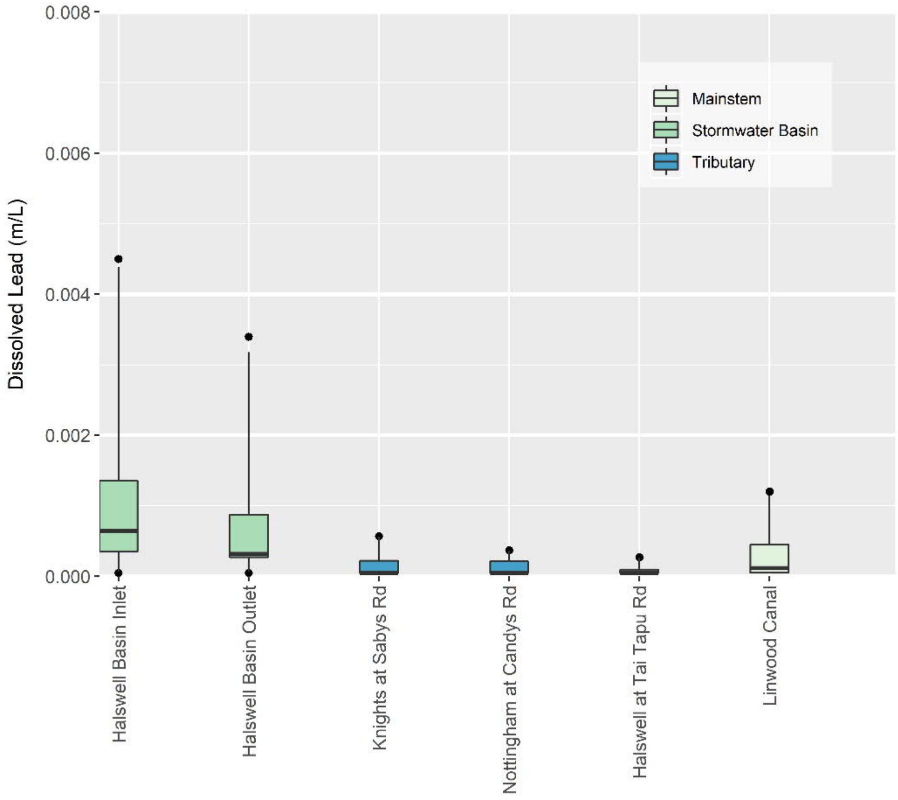


Figure ii (b). Dissolved lead concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline value (Environment Canterbury, 2019), which has been modified to account for water hardness (Hardness Modified Guideline Value = HMGV), as per the Warne *et al.* (2018) guidelines methodology. The 95% protection HMGV for Huritini/ Halswell River (0.01089 mg/L) and 90% protection HMGV for Linwood Canal (0.13610 mg/L) are 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.

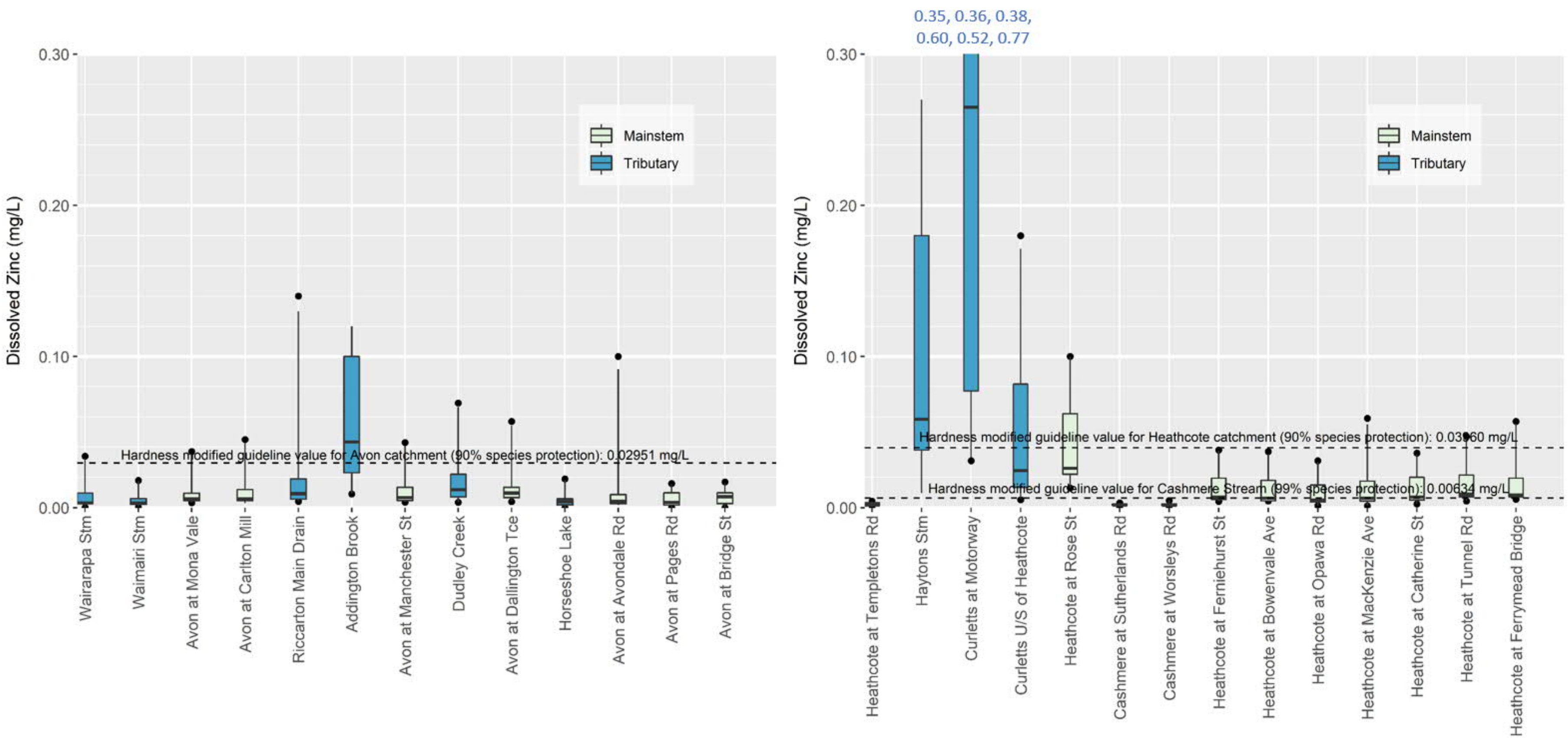


Figure iii (a). Dissolved zinc concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline values (Environment Canterbury, 2019), which have been modified to account for water hardness (Hardness Modified Guideline Value = HMGV), as per the Warne *et al.* (2018) guidelines methodology. 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.

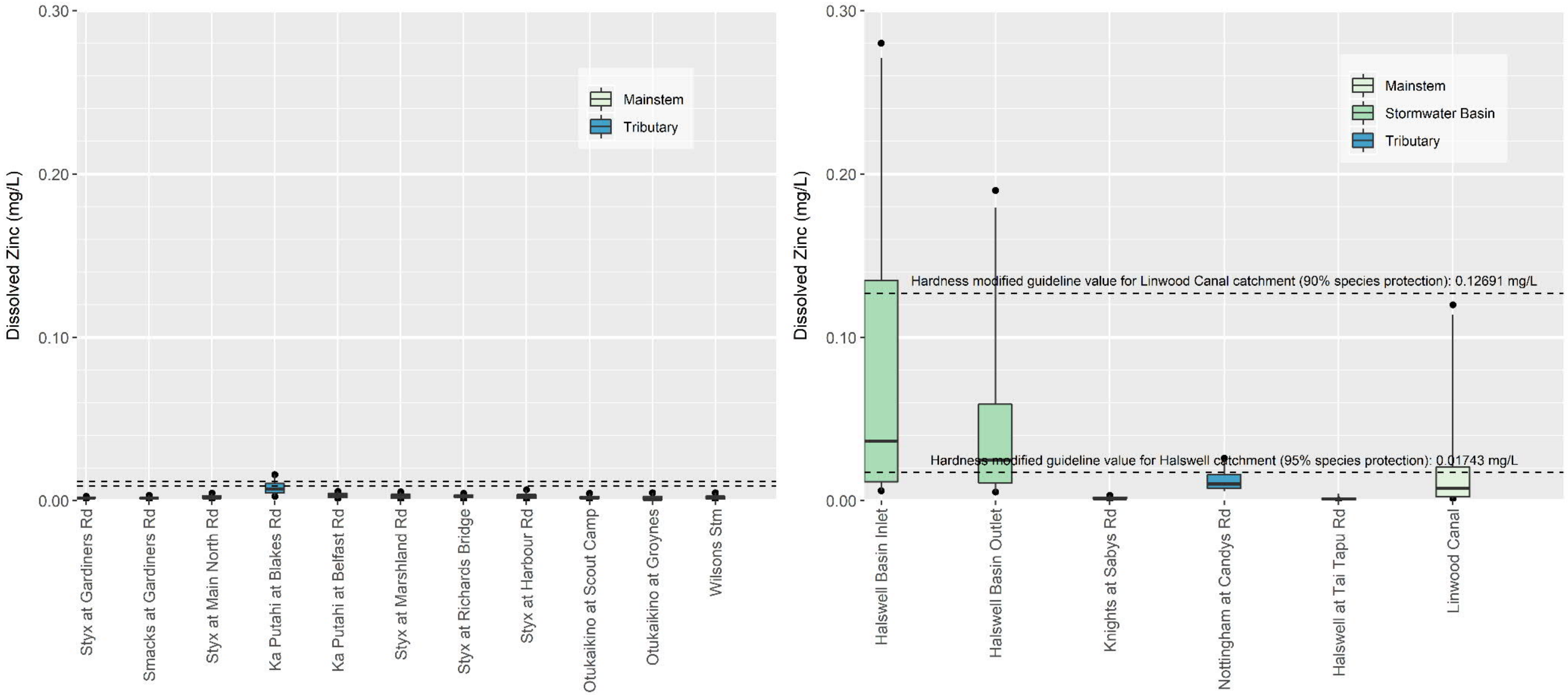


Figure iii (b). Dissolved zinc concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline values (Environment Canterbury, 2019), which have been modified to account for water hardness (Hardness Modified Guideline Value = HMGV), as per the Warne *et al.* (2018) guidelines methodology. On the left graph, the upper dashed line represents the 95% species protection for Pūharakekenui/ Styx River catchment (0.01172 mg/L), while the lower represents the 95% species protection for Ōtūkaikino River catchment (0.00912 mg/L). The 90% protection HMGV for Linwood Canal (0.12691 mg/L) is not visible because it is 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.

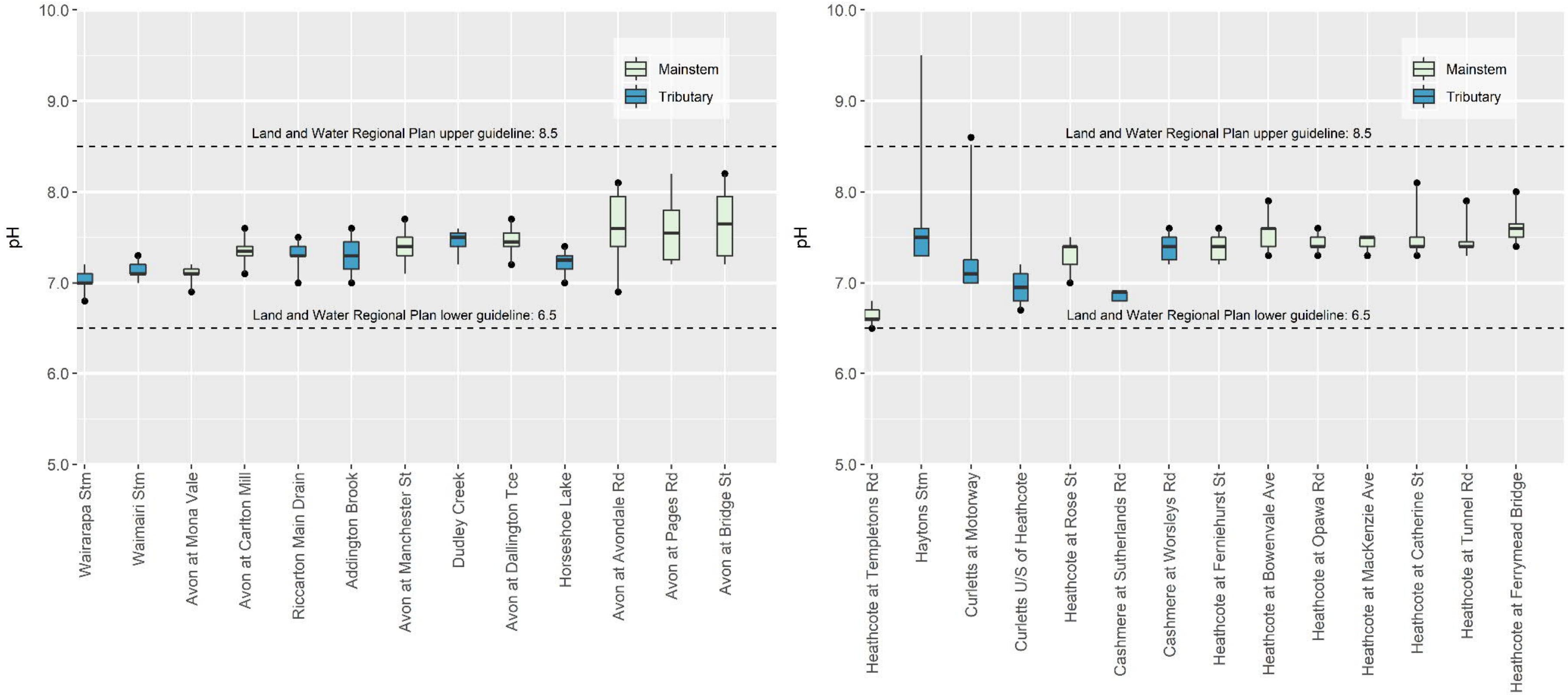
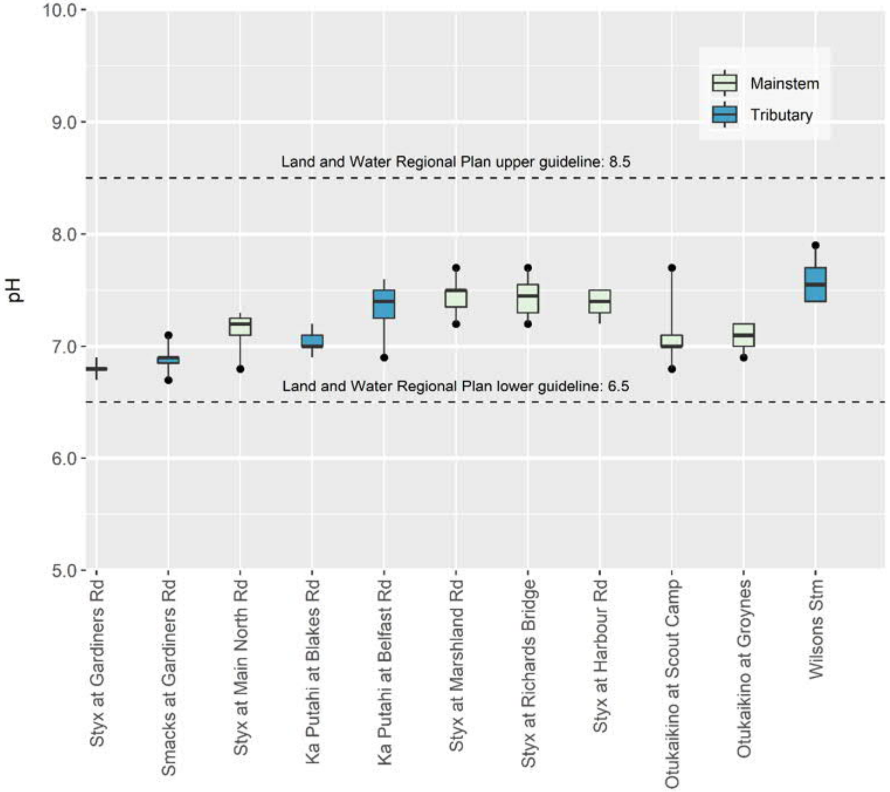


Figure iv (a). pH levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019.No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from 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, 2019).



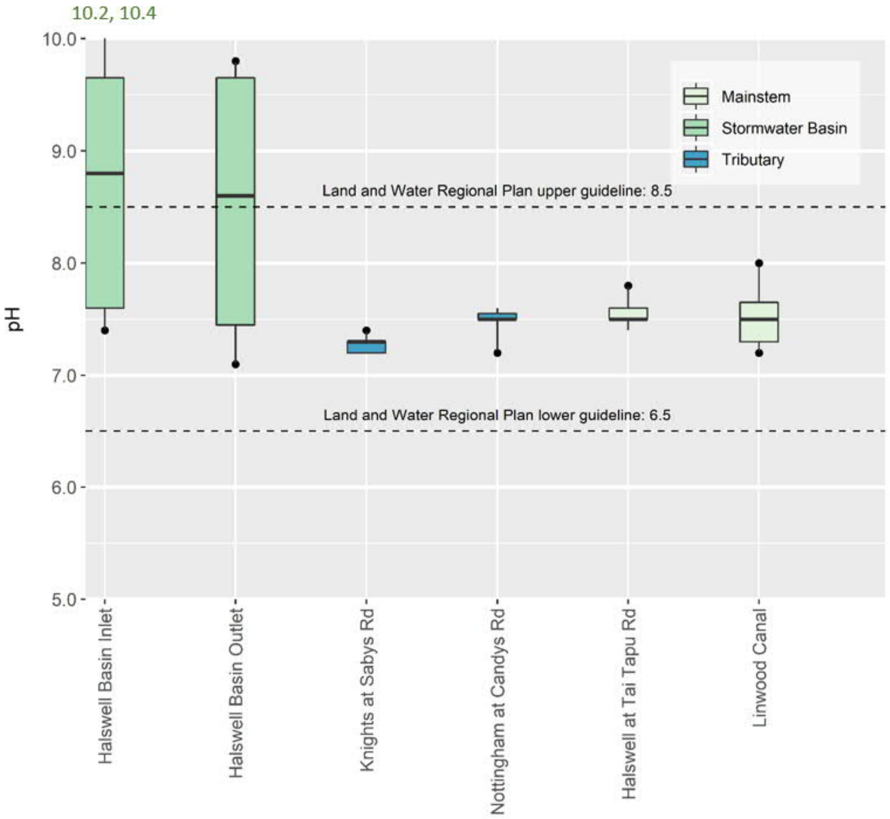


Figure iv (b). pH levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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, 2019).

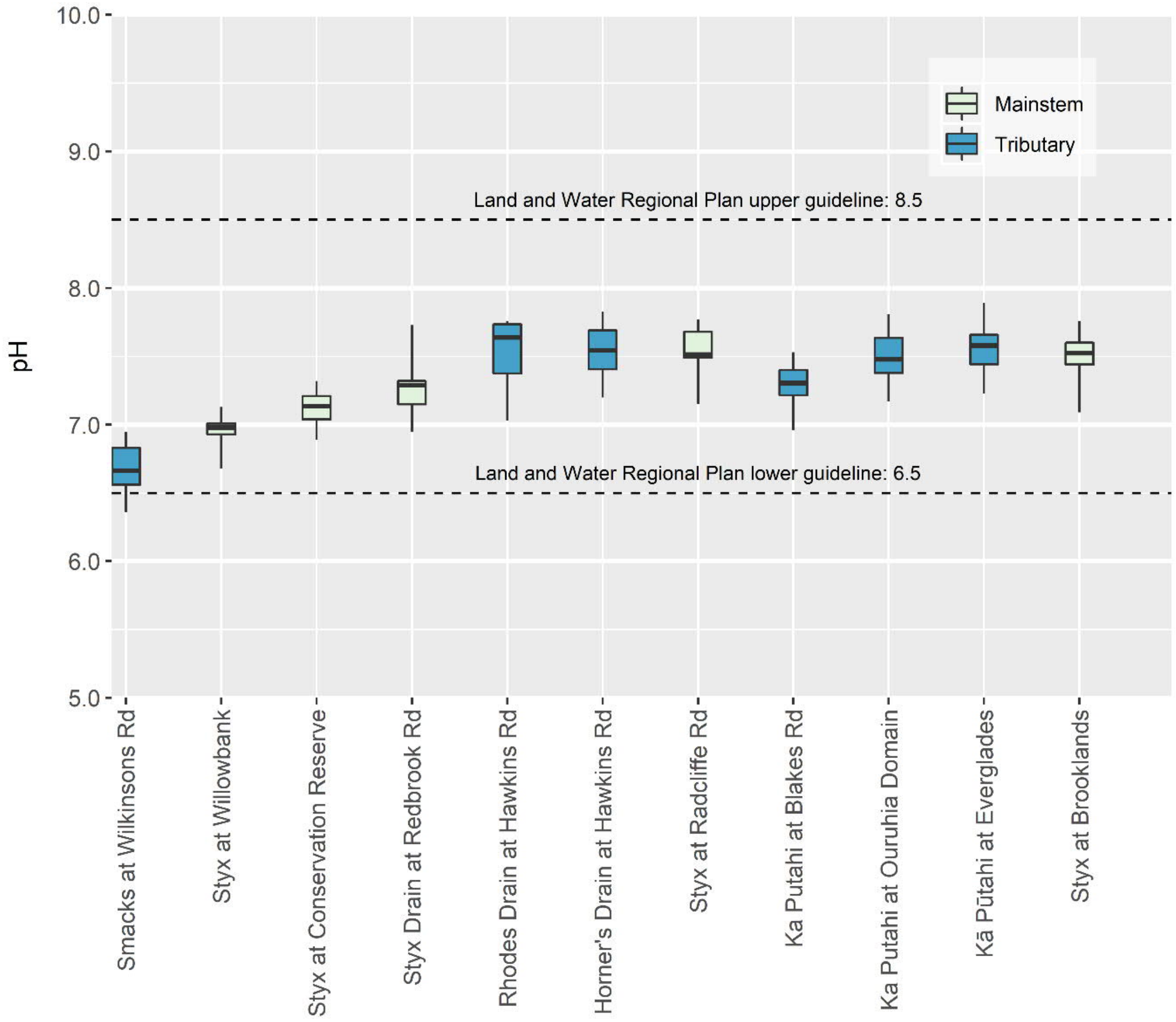


Figure iv (c). pH levels in water samples taken from the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust volunteers for the monitoring period January to December 2019 (n = 6–10 samples per site). Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan lower (6.5) and upper (8.5) limits (Environment Canterbury, 2019).

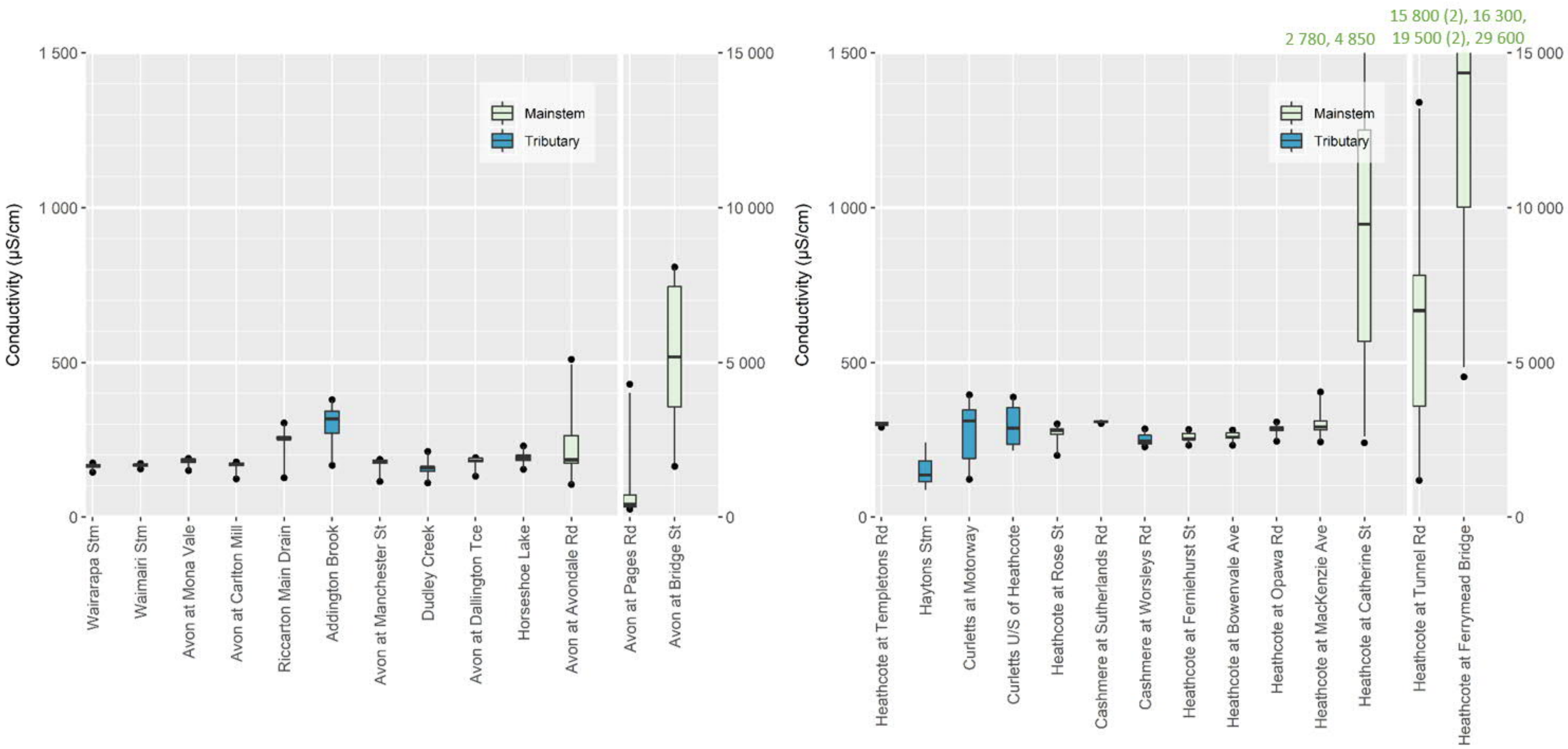


Figure v (a). Conductivity levels in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019.No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered 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 concentrations 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.

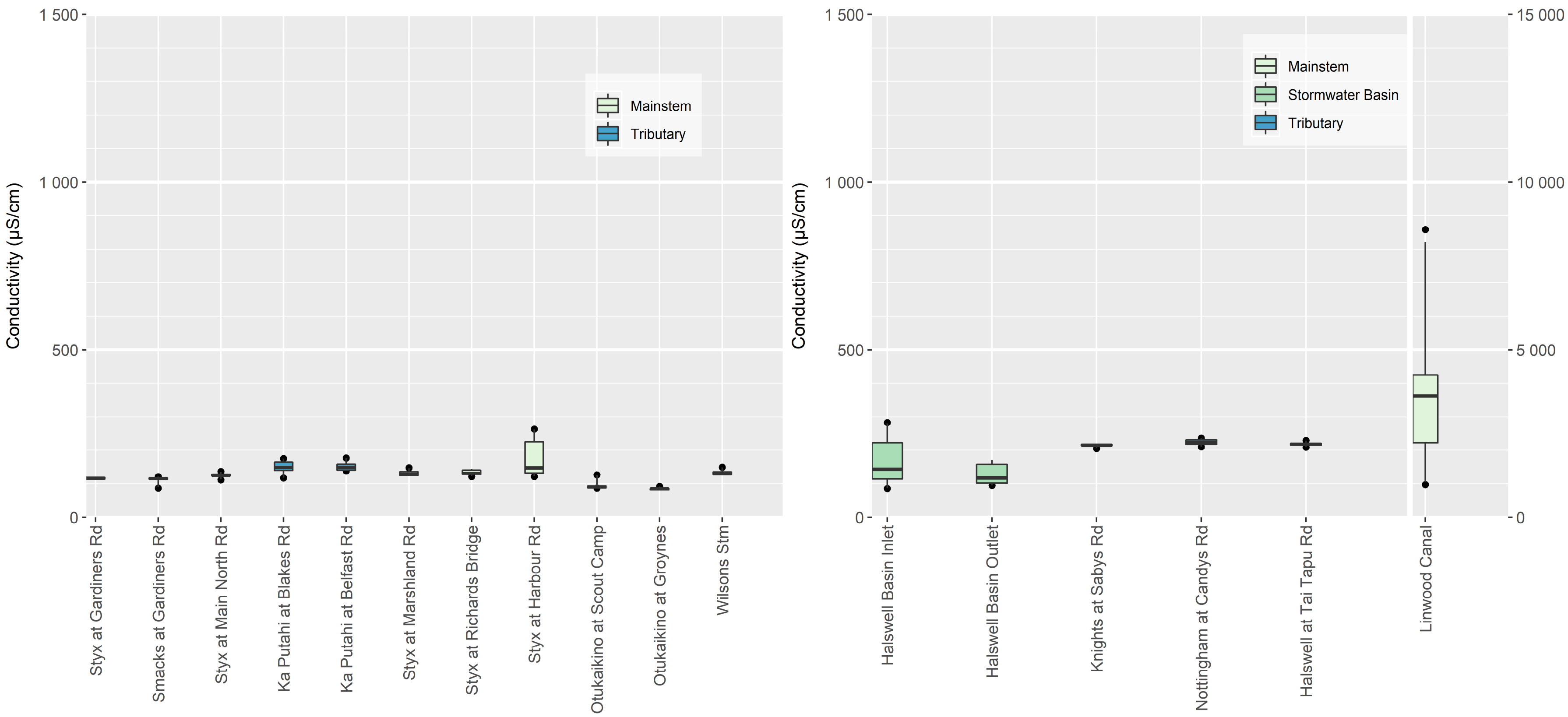


Figure v (b). Conductivity levels in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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 concentrations 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.

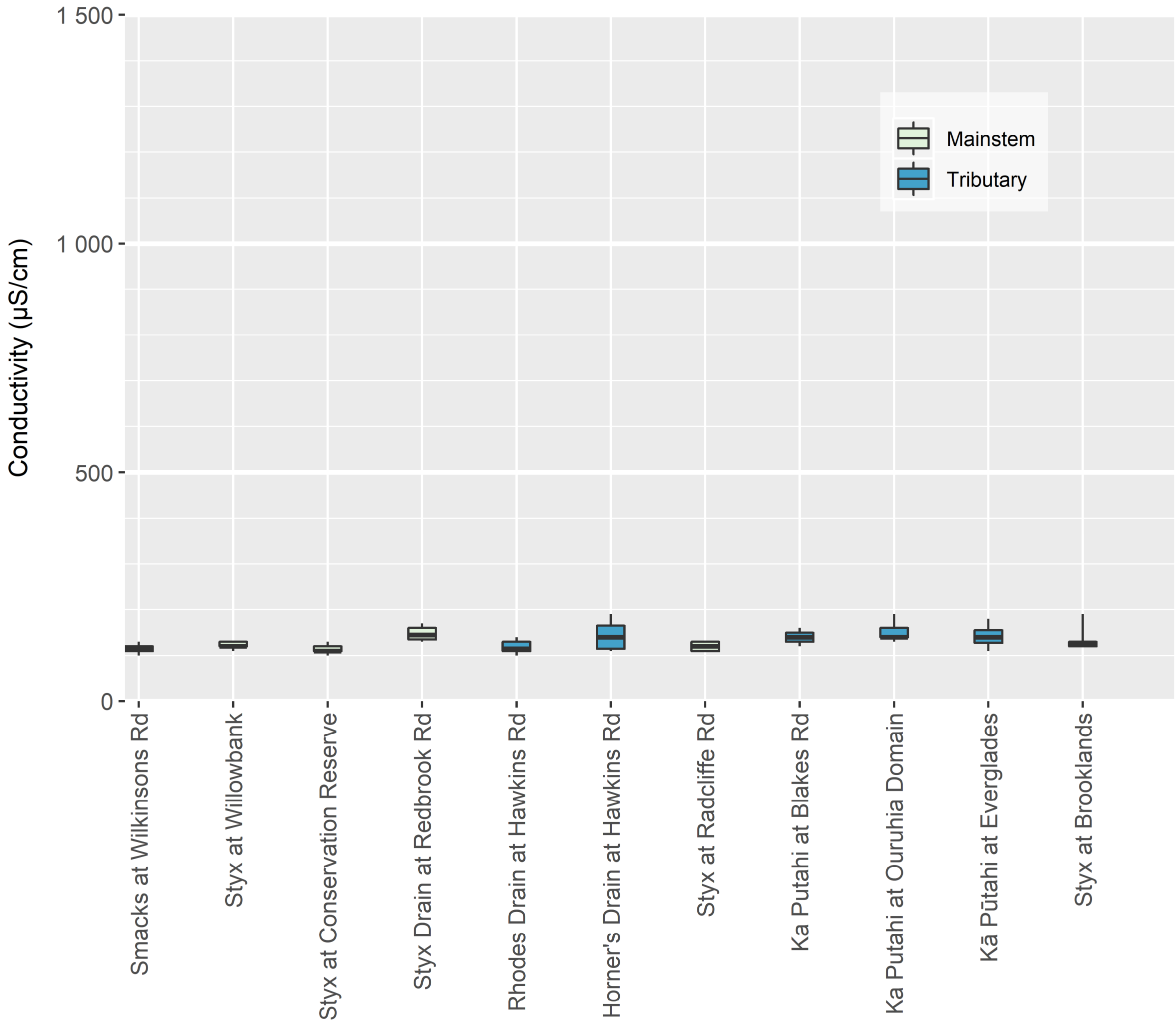


Figure v (c). Conductivity levels in water samples taken from the Pūharakekenui/ Styx River catchment by the Styx Living Laboratory Trust volunteers for the monitoring period January to December 2019 (n = 6–10 samples per site). Sites are ordered from upstream to downstream (left to right).

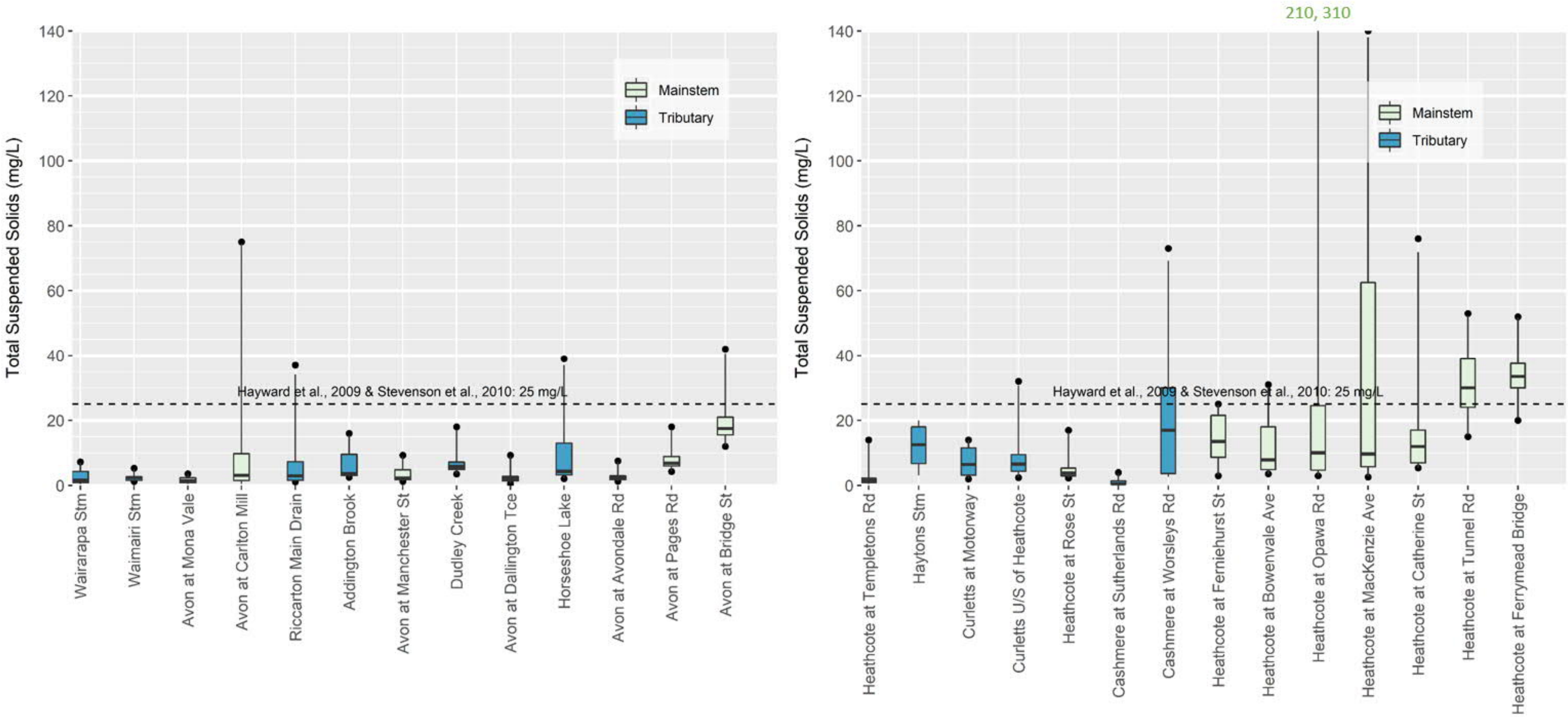


Figure vi (a). Total Suspended Solid (TSS) concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. 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 1.0 mg/L – analysed as half this value (0.5 mg/L) to allow statistics to be undertaken.

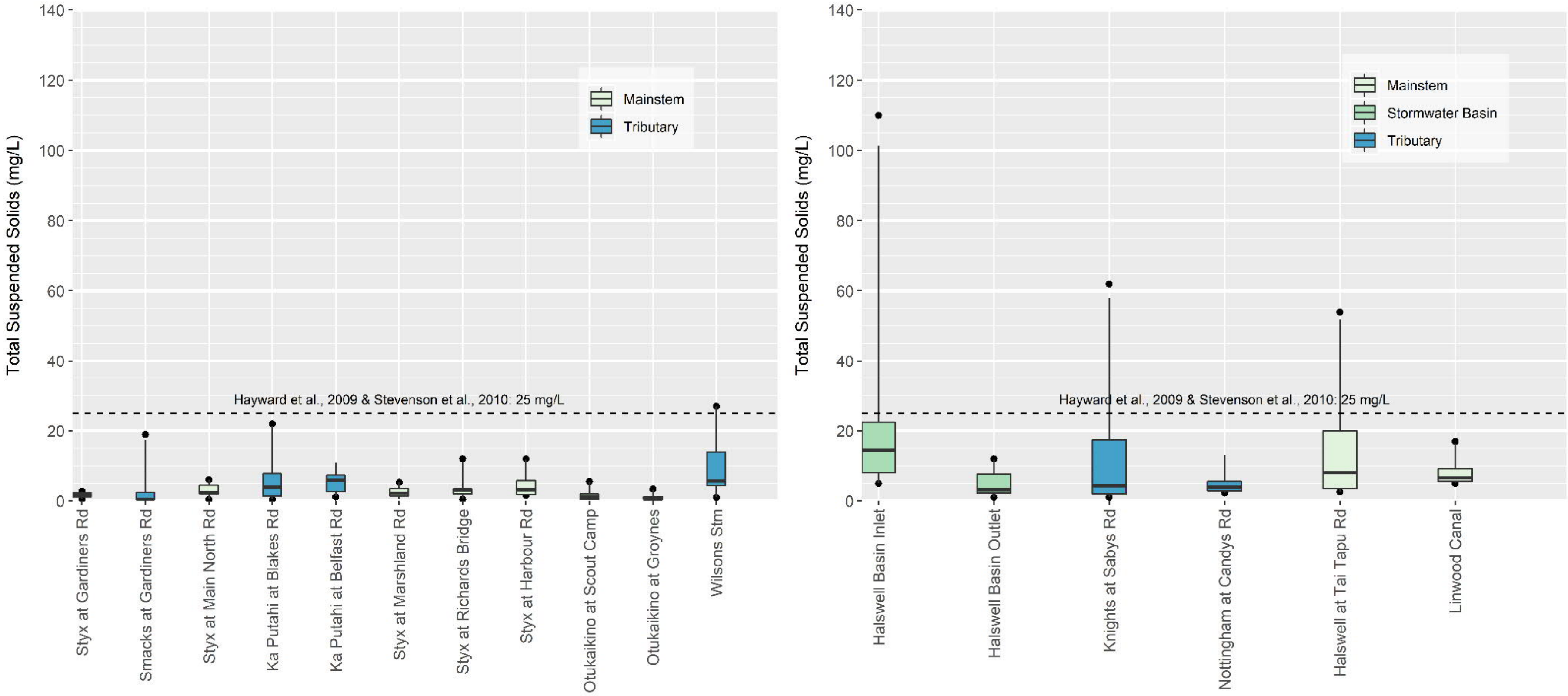


Figure vi (b). Total Suspended Solid (TSS) concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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 1.0 mg/L – analysed as half this value (0.5 mg/L) to allow statistics to be undertaken.

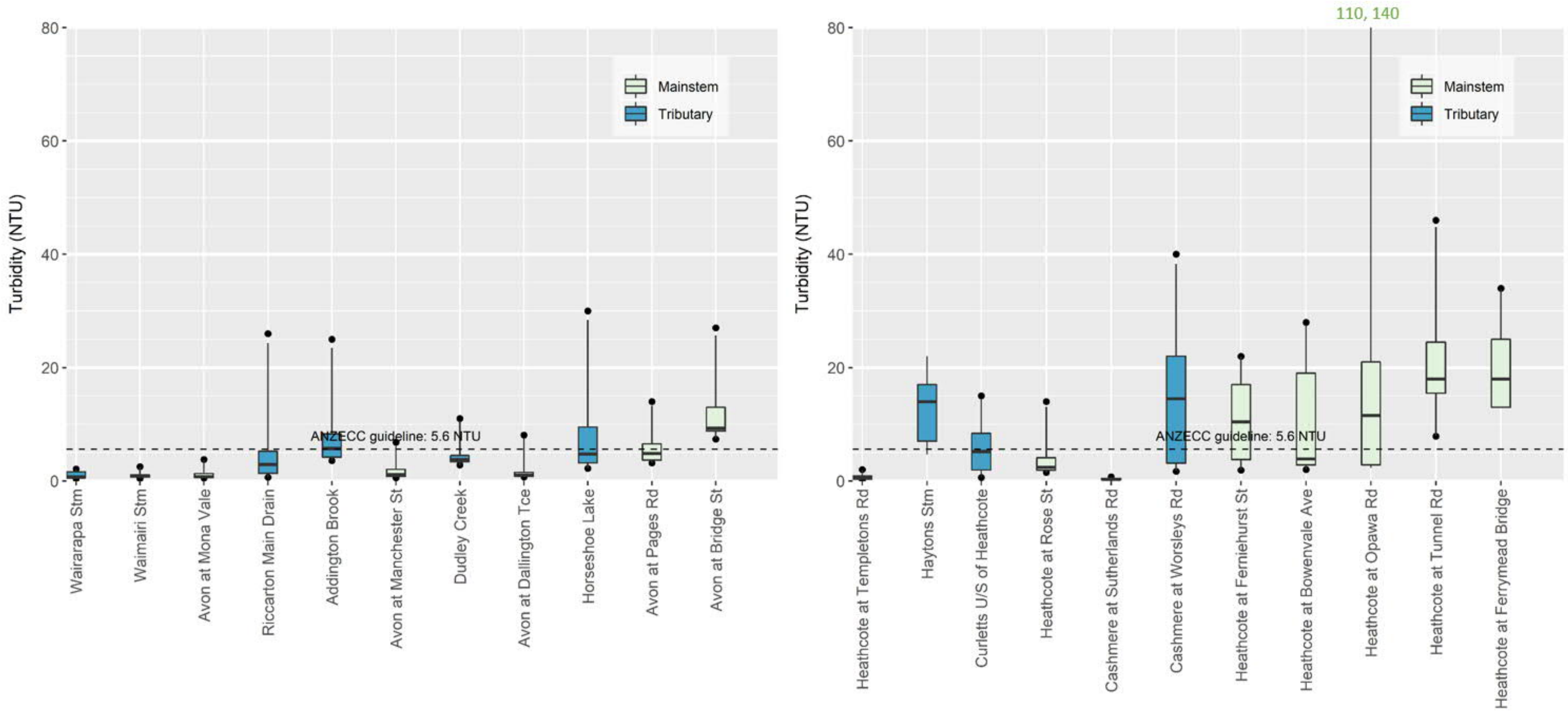


Figure vii (a) .Turbidity concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. The 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).

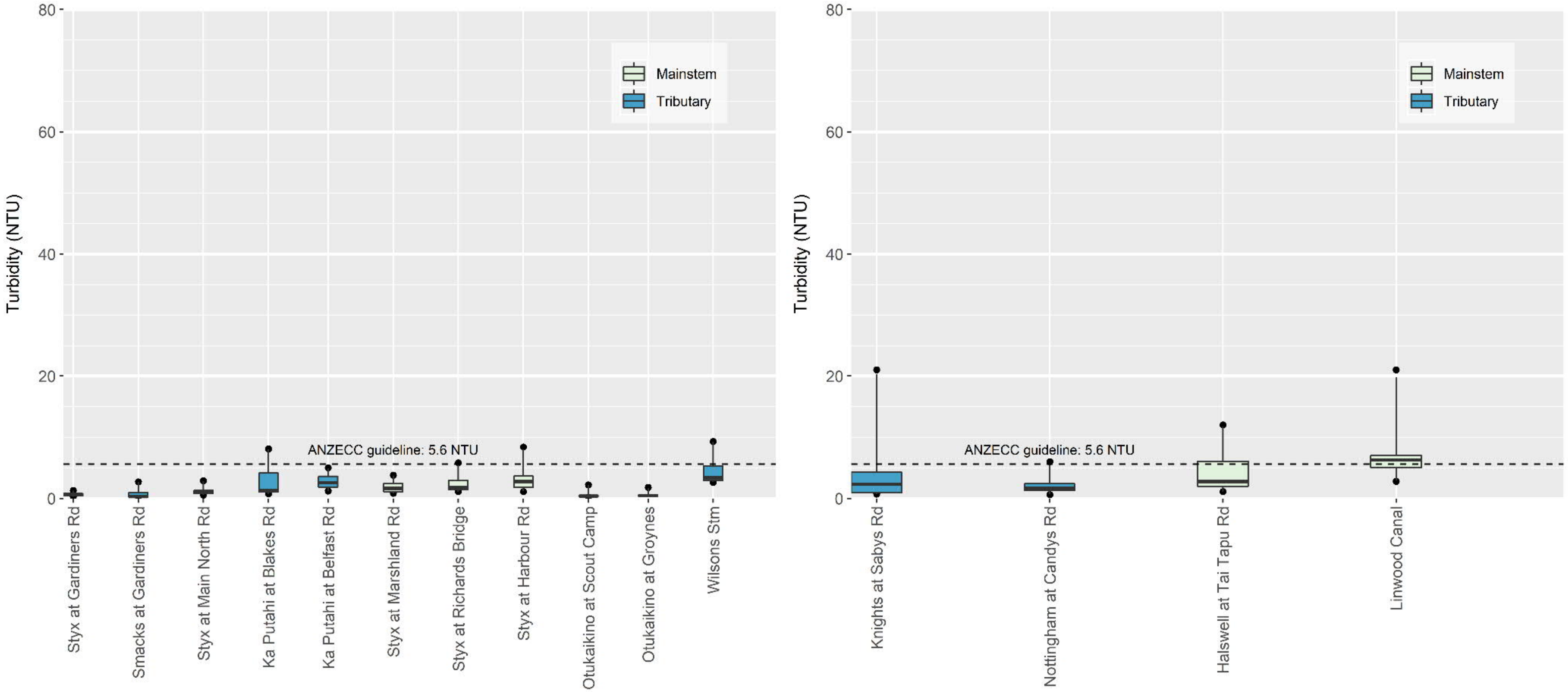
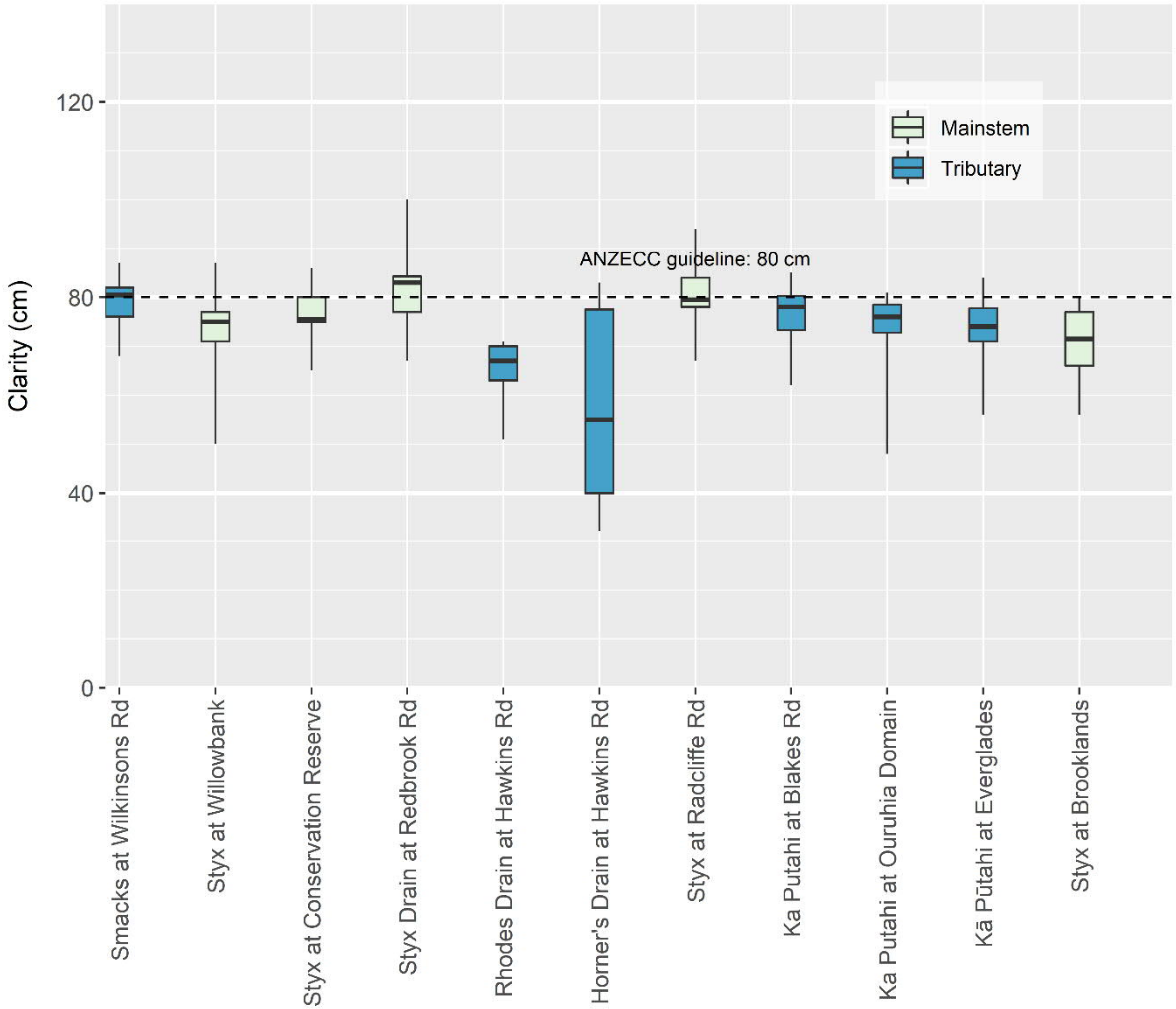


Figure vii (b). Turbidity concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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).



Clarity (cm)
120
80
40
0
ANZECC guideline: 80 cm
Mainstem
Tributary
Smacks at Wilkinsons Rd
Styx at Willowbank
Styx at Conservation Reserve
Styx Drain at Redbrook Rd
Rhodes Drain at Hawkins Rd
Horner's Drain at Hawkins Rd
Styx at Radcliffe Rd
Ka Putahi at Blakes Rd
Ka Putahi at Ouruhia Domain
Kā Pūtahi at Everglades
Styx at Brooklands

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 2019 (n = 6–10 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.

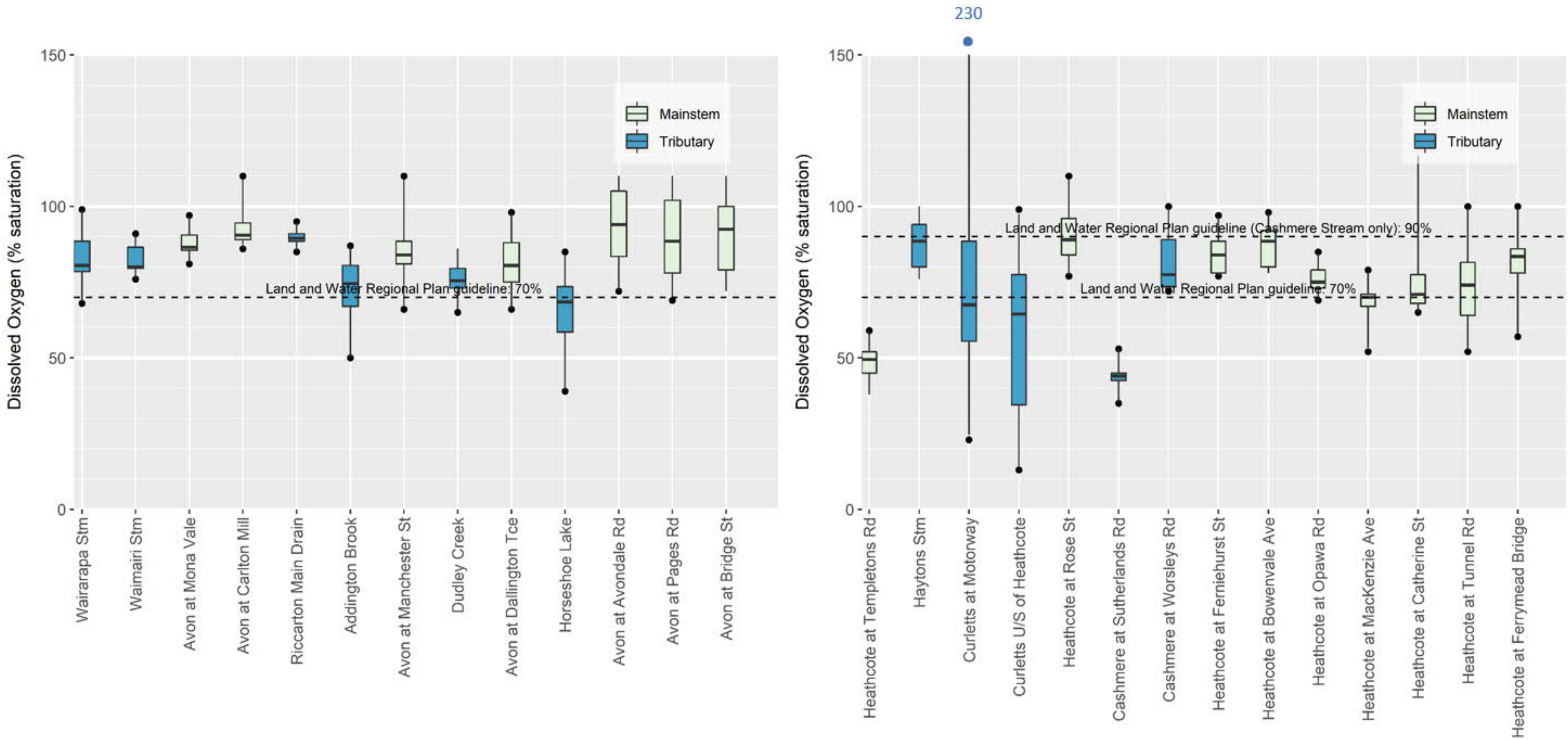
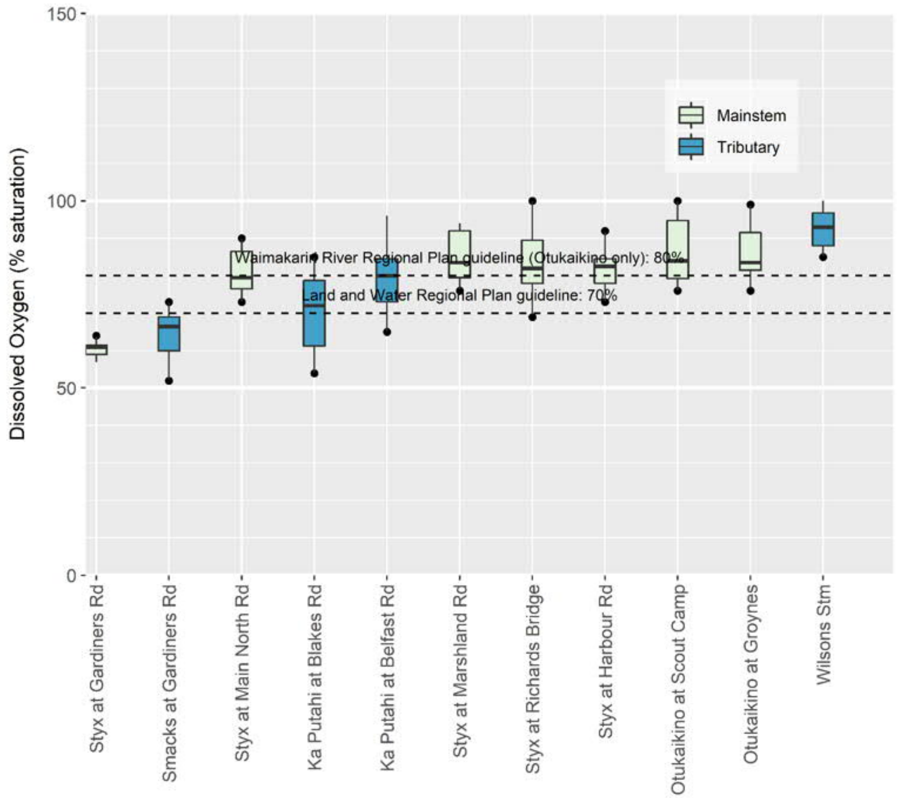


Figure ix (a). Dissolved oxygen concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. 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, 2019).



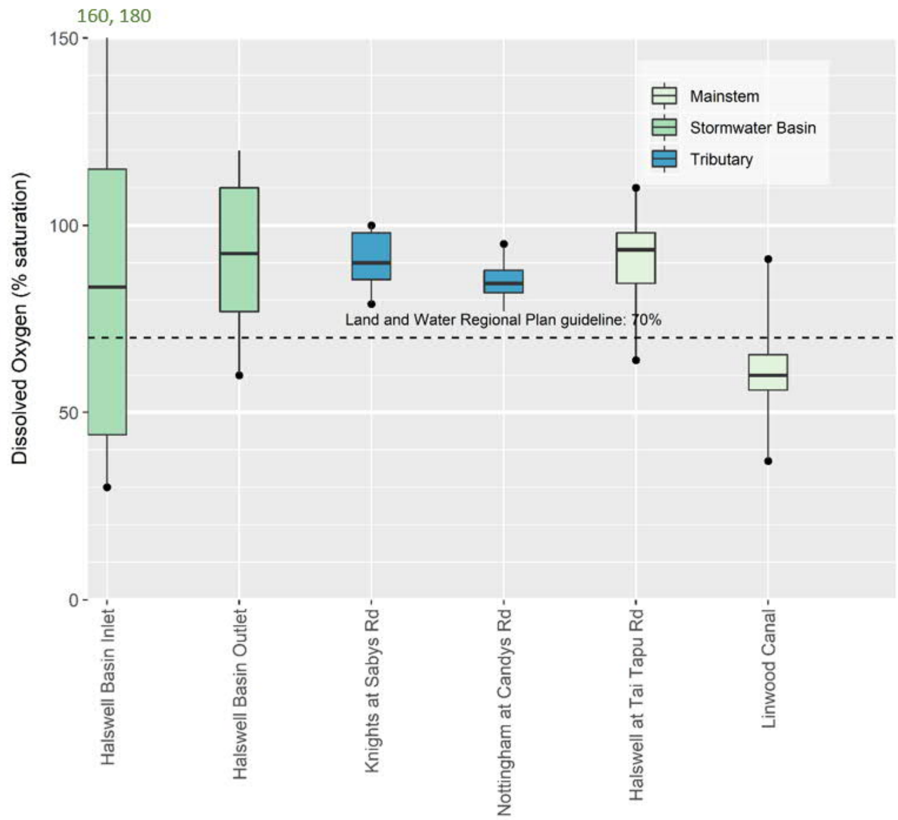


Figure ix (b). Dissolved oxygen concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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, 2019). The upper dotted line represents the Waimakariri River Regional Plan minimum guideline value for all Ōtūkaikino sites (80%, Environment Canterbury, 2011).

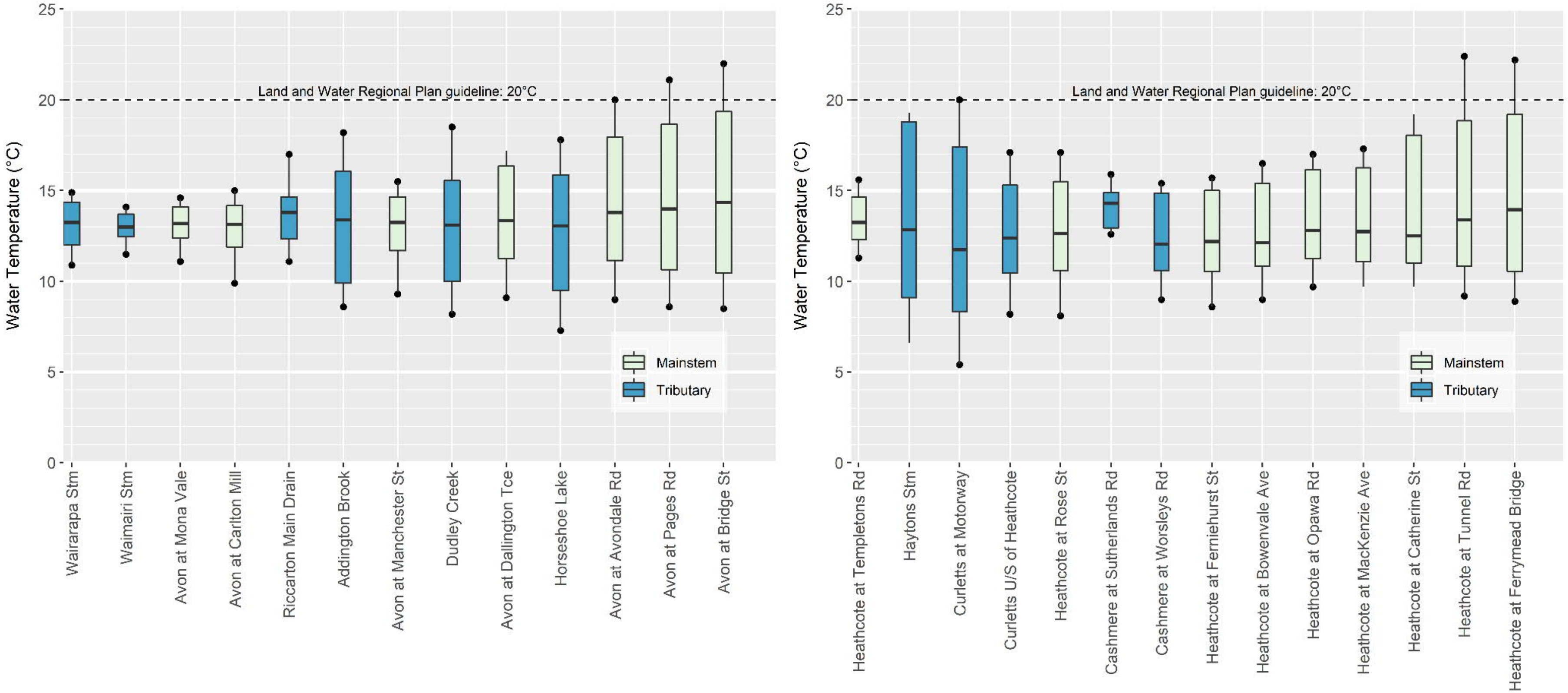
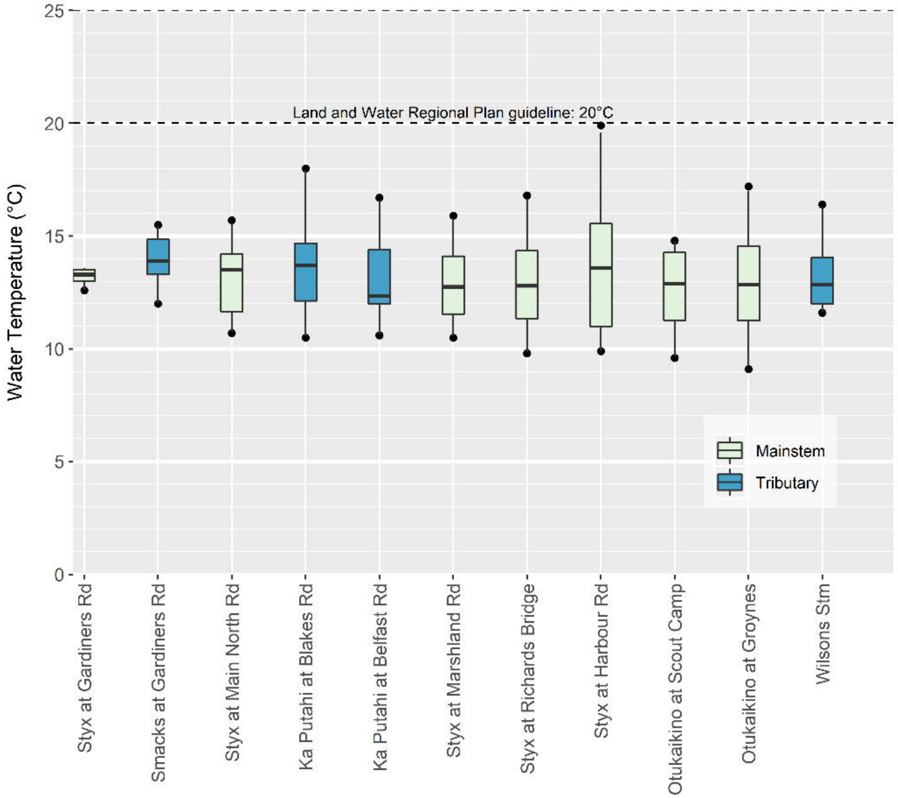


Figure x (a). Temperature of the water at the time of sampling at the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed line represents the Land and Water Regional Plan maximum guideline value (20ºC, Environment Canterbury, 2019).



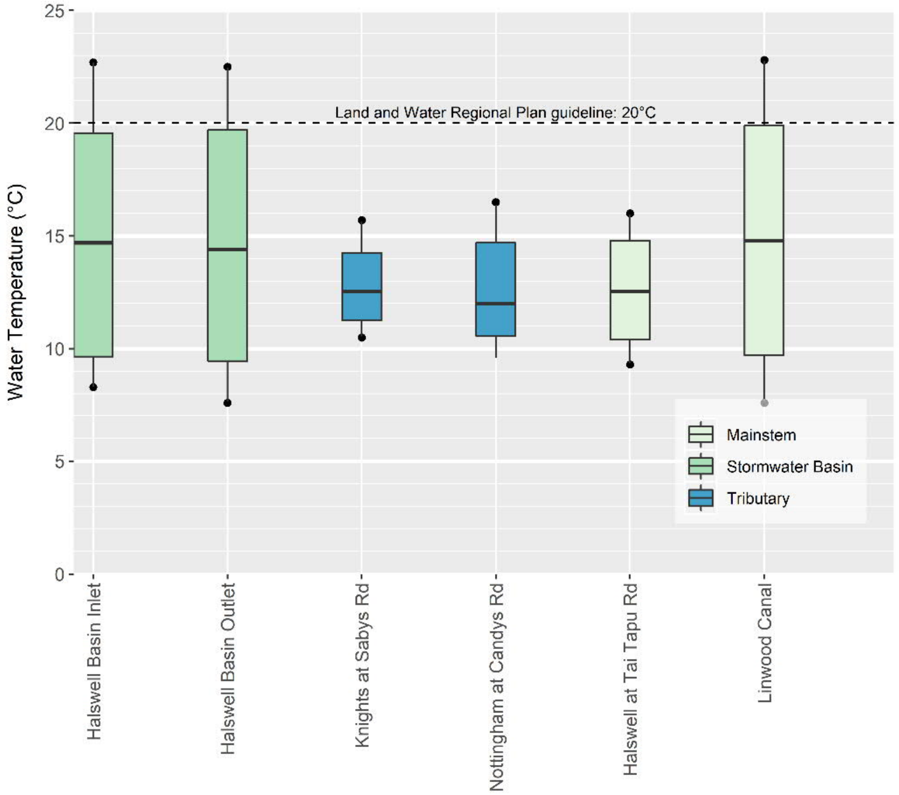
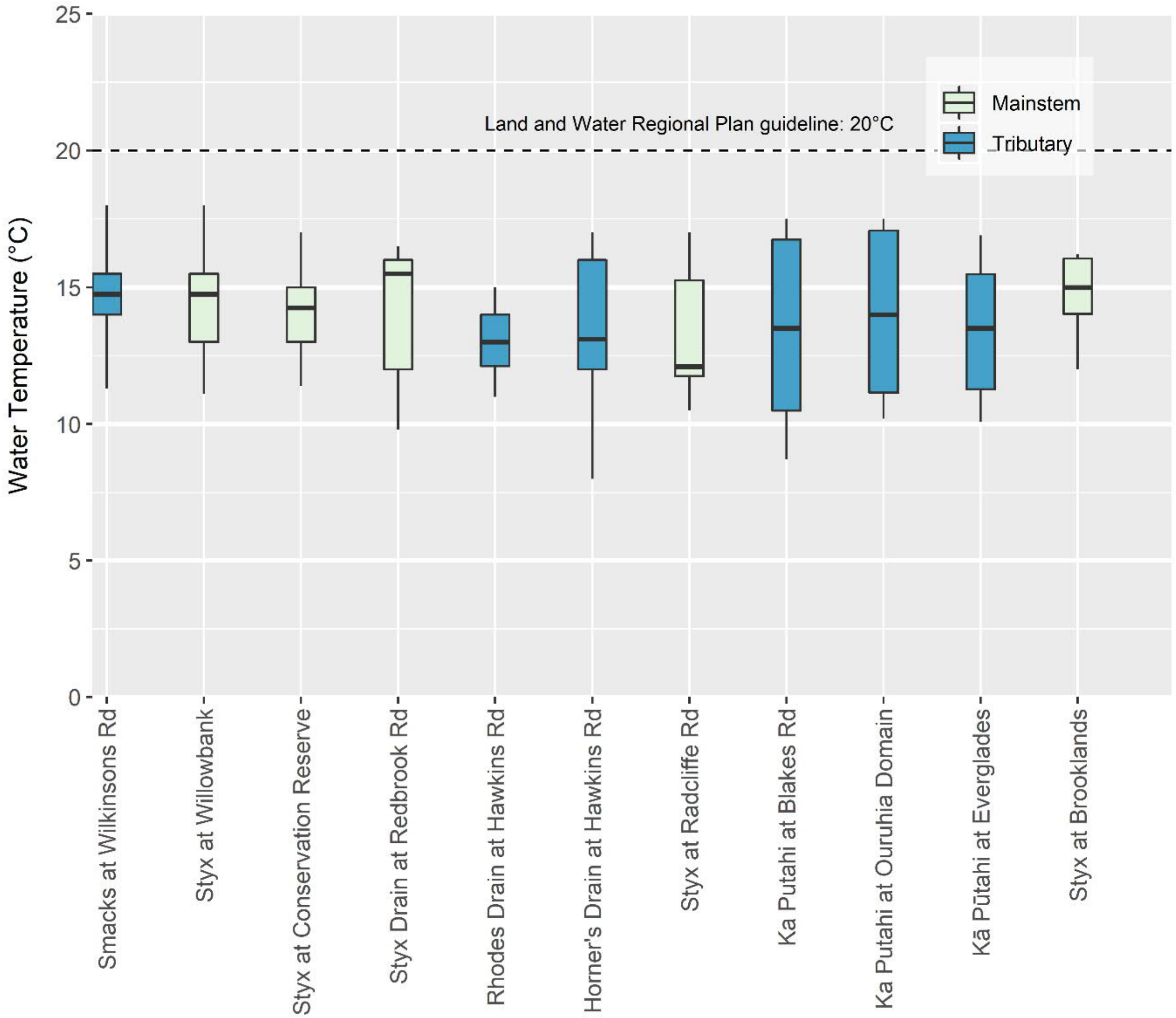


Figure x (b). Temperature of the water at the time of sampling at the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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, 2019). The Waimakariri River Regional Plan maximum guideline value for all Ōtūkaikino sites is 25ºC (Environment Canterbury, 2011).



Water Temperature (°C)
25
20
15
10
5
0
Land and Water Regional Plan guideline: 20°C
Mainstem
Tributary
Smacks at Wilkinsons Rd
Styx at Willowbank
Styx at Conservation Reserve
Styx Drain at Redbrook Rd
Rhodes Drain at Hawkins Rd
Horner's Drain at Hawkins Rd
Styx at Radcliffe Rd
Ka Putahi at Blakes Rd
Ka Putahi at Ouruhia Domain
Kā Pūtahi at Everglades
Styx at Brooklands

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 2019 (n = 6–10 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, 2019).

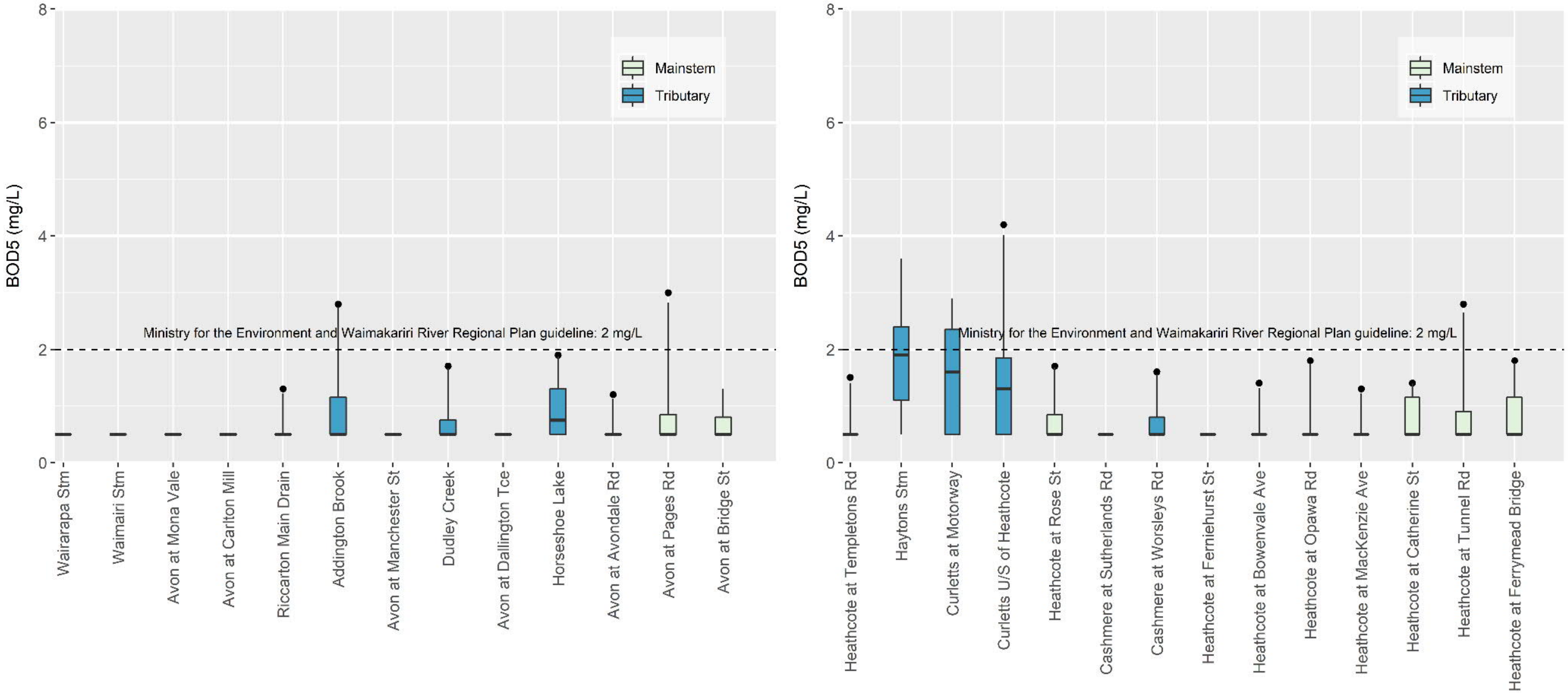


Figure xi (a). Biochemical Oxygen Demand (BOD_5) concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. 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.

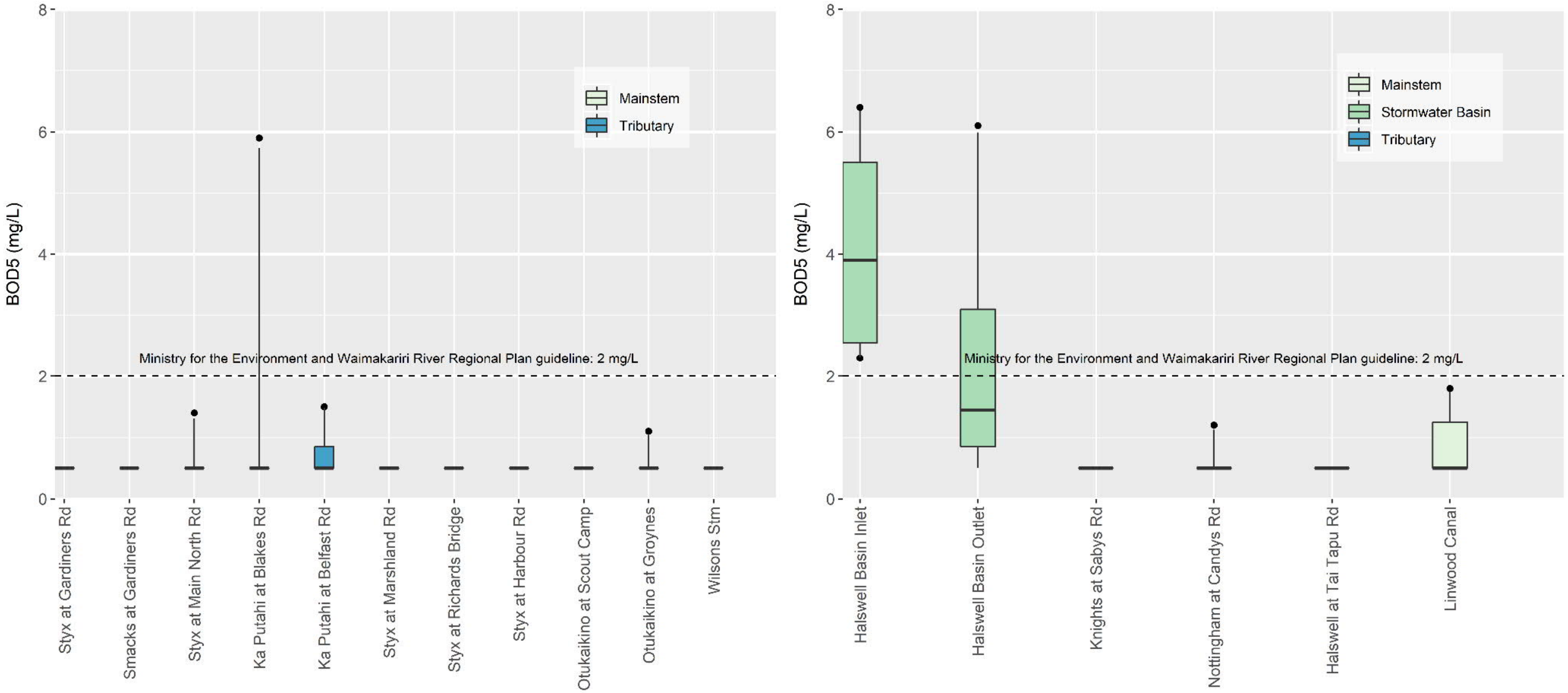


Figure xi (b). Biochemical Oxygen Demand (BOD_5) concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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.

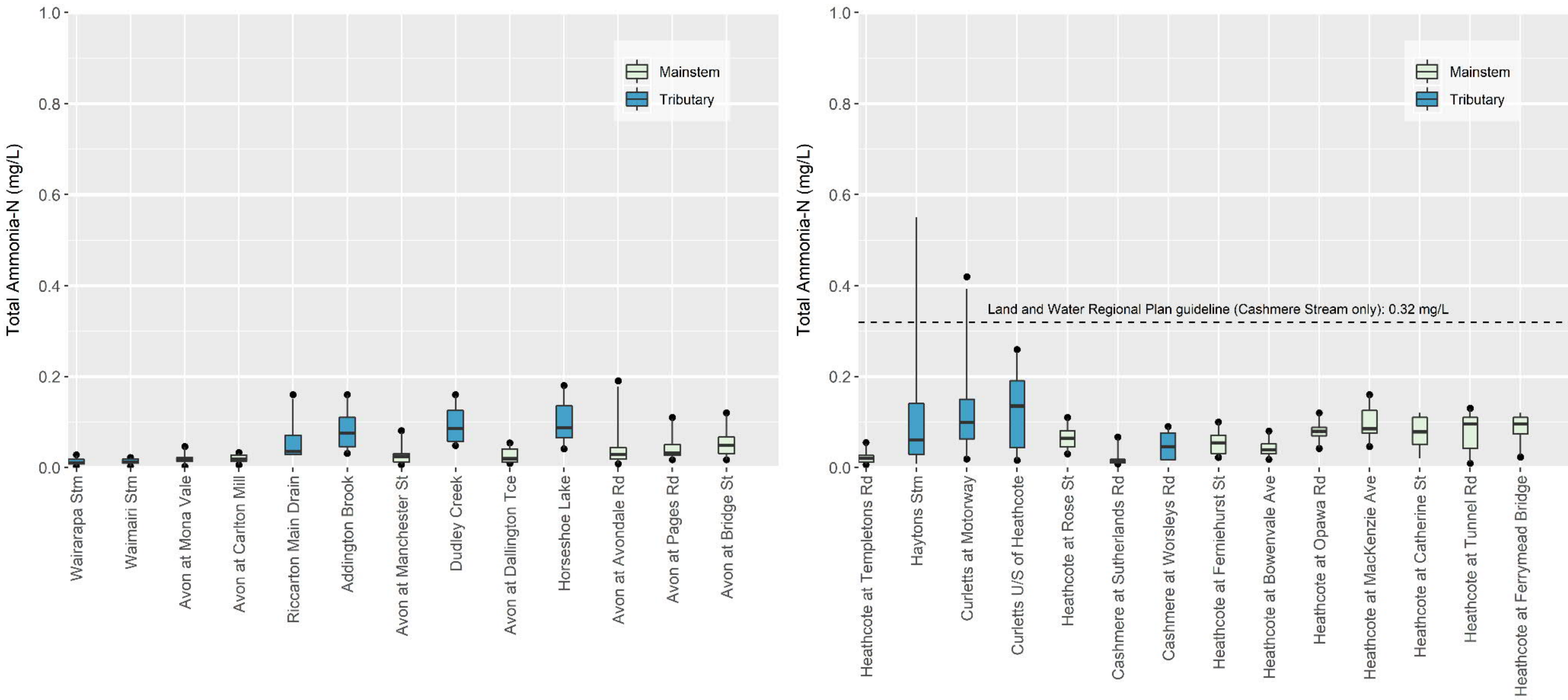


Figure xii (a). Total ammonia concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The Land and Water Regional Plan guideline value (Ōtākaro/ Avon catchment: 1.88 mg/L, Ōpāwaho/ Heathcote: 1.75 mg/L,; Environment Canterbury, 2019), which has been adjusted in accordance with median pH levels for the monitoring period (Ōtākaro/ Avon catchment: 7.3, Ōpāwaho/ Heathcote catchment: 7.4), are not presented on the graph as they are 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, 2019). 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.

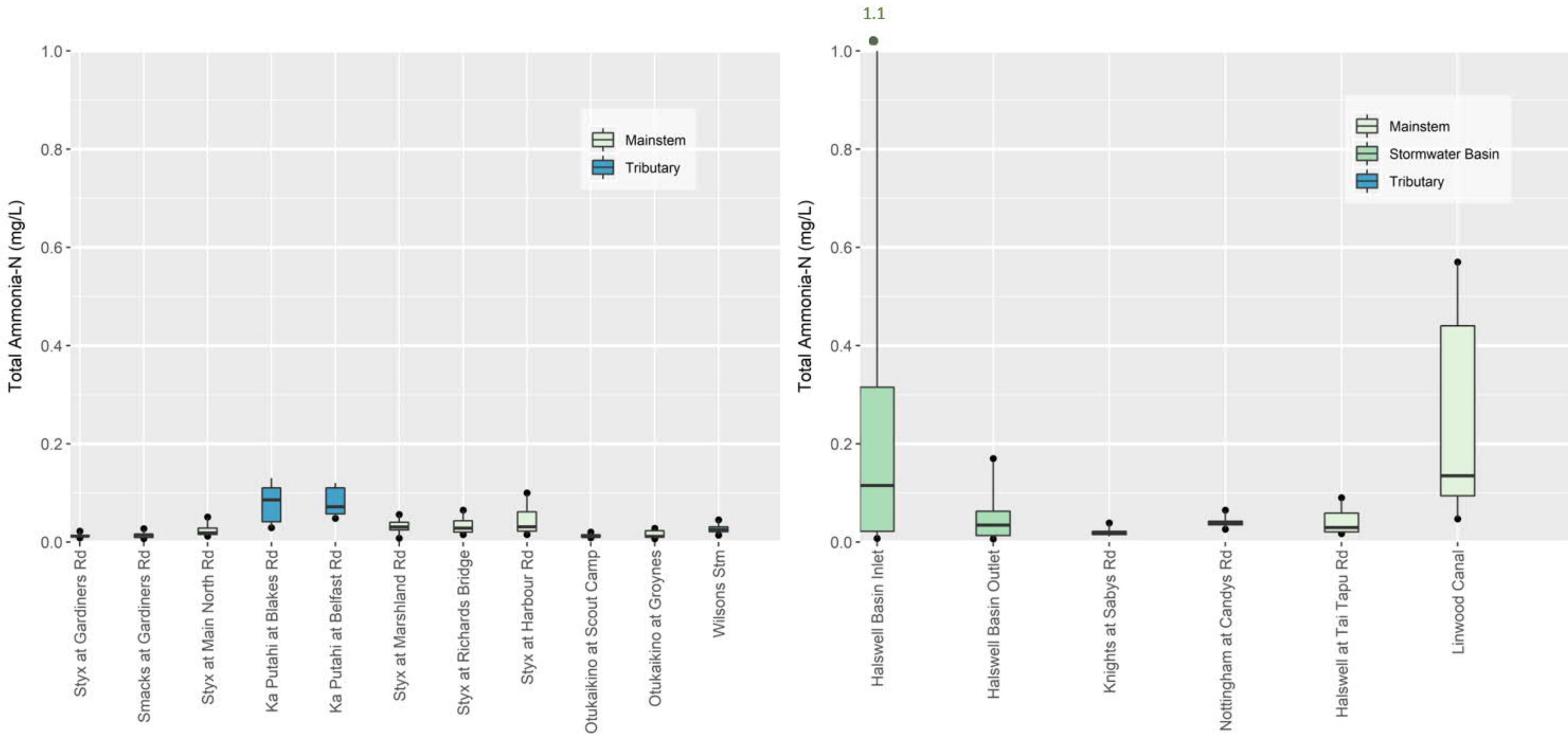


Figure xii (b). Total ammonia concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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: 1.99 mg/L, Huritini/ Halswell catchment: 1.61 mg/L, Linwood Canal: 1.61 mg/L,; Environment Canterbury, 2019), adjusted in accordance with median pH levels for the monitoring period (Pūharakekenui/ Styx catchment: 7.2, Ōtūkaikino catchment: 7.2, Huritini/ Halswell catchment: 7.5, 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.

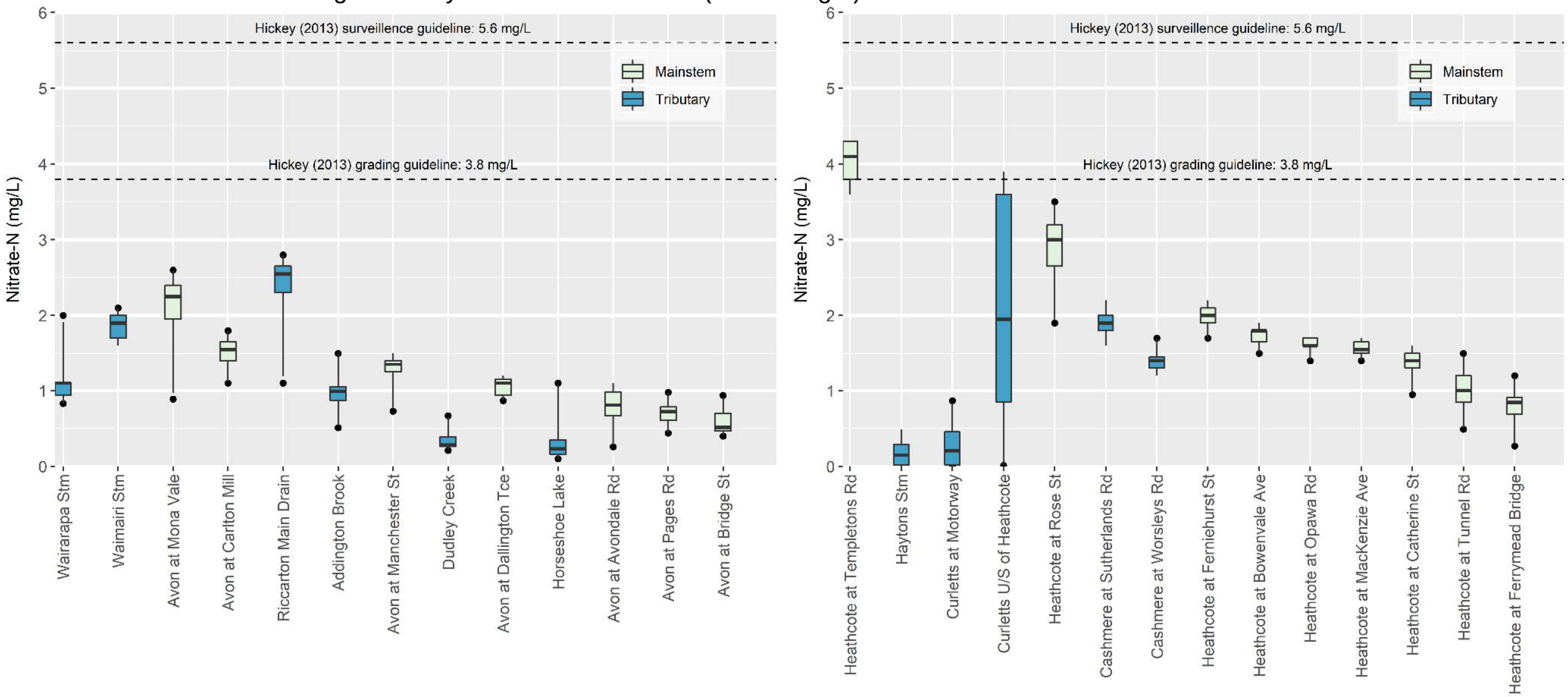


Figure xiii (a). Nitrate-nitrogen concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. 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 0.002 mg/L – analysed as half this value (0.001 mg/L) to allow statistics to be undertaken.

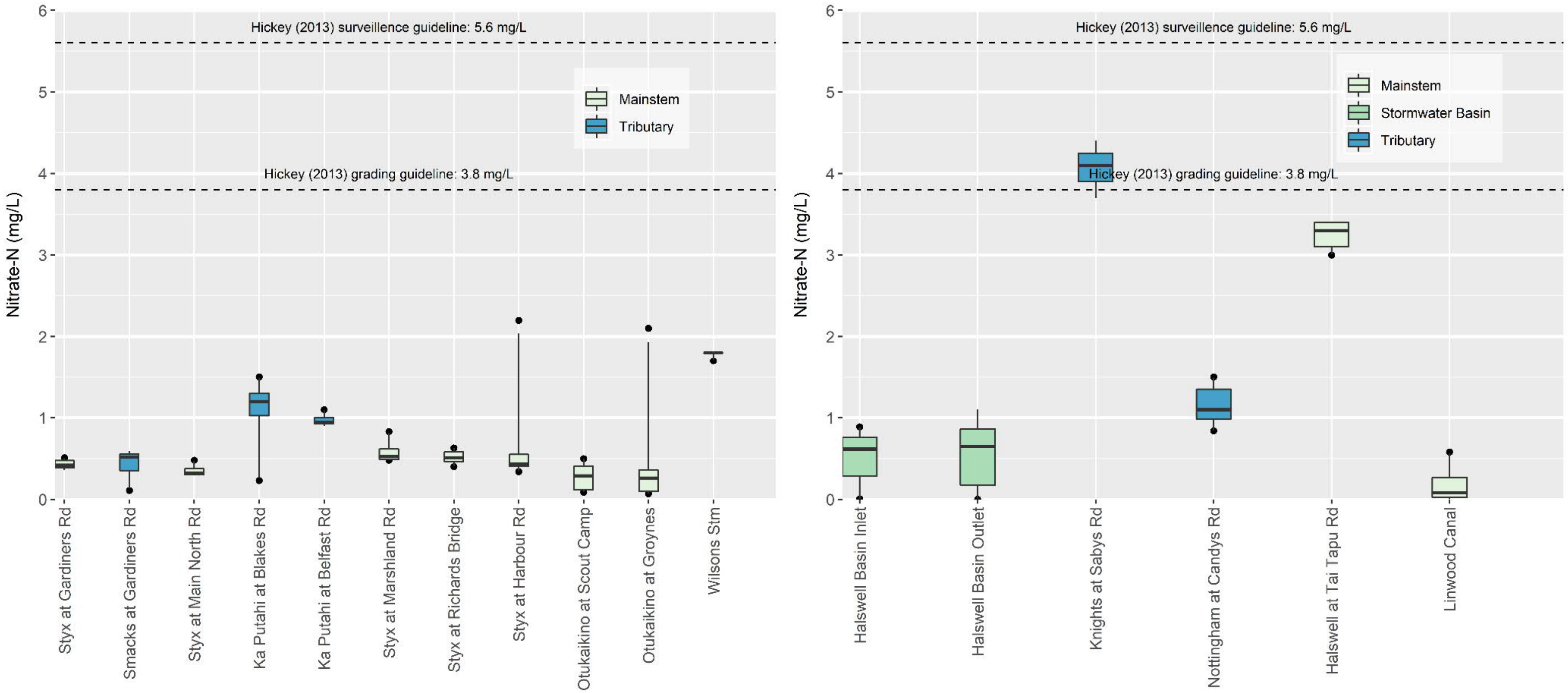


Figure xiii (b). Nitrate concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino Rivers (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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 0.002 mg/L – analysed as half this value (0.001 mg/L) to allow statistics to be undertaken.

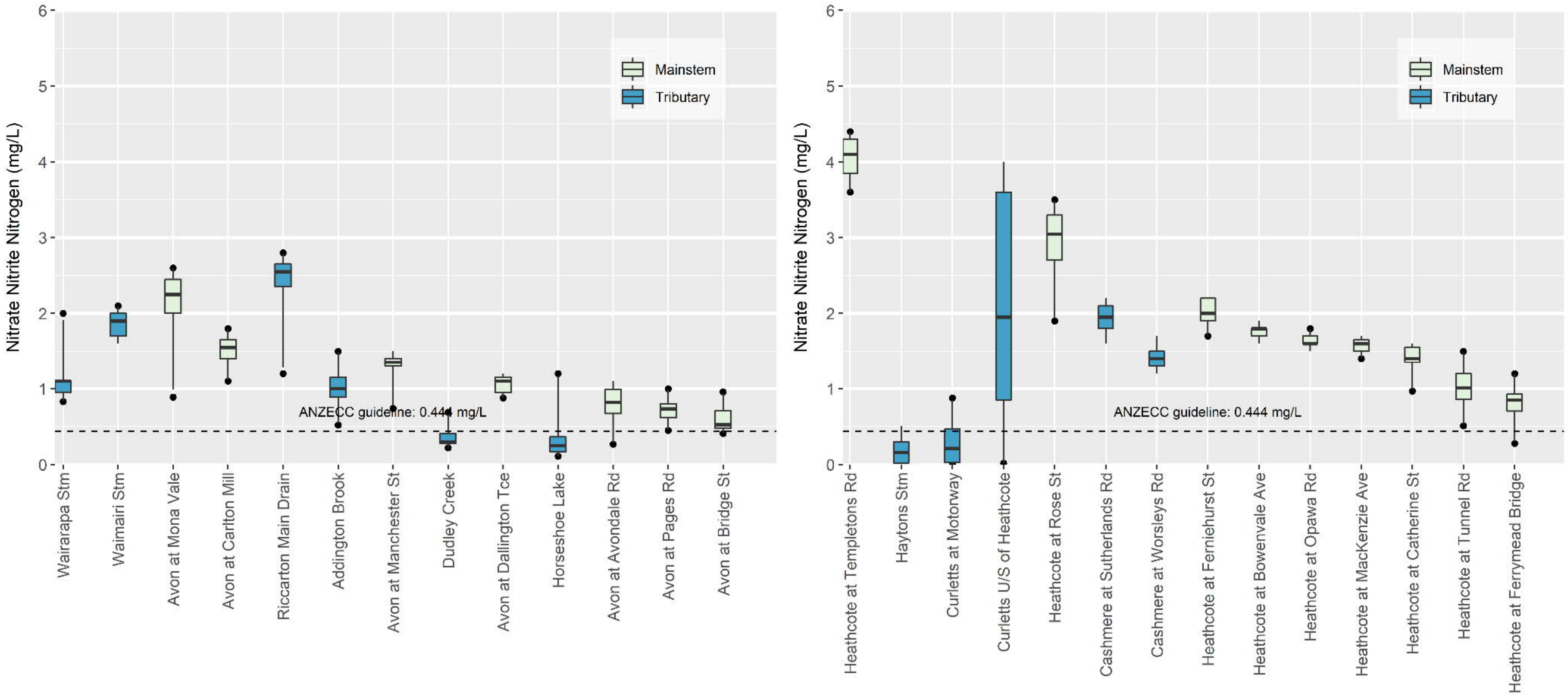


Figure xiv (a). Nitrate Nitrite Nitrogen (NNN) in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. 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 0.002 mg/L – analysed as half this value (0.001 mg/L) to allow statistics to be undertaken.

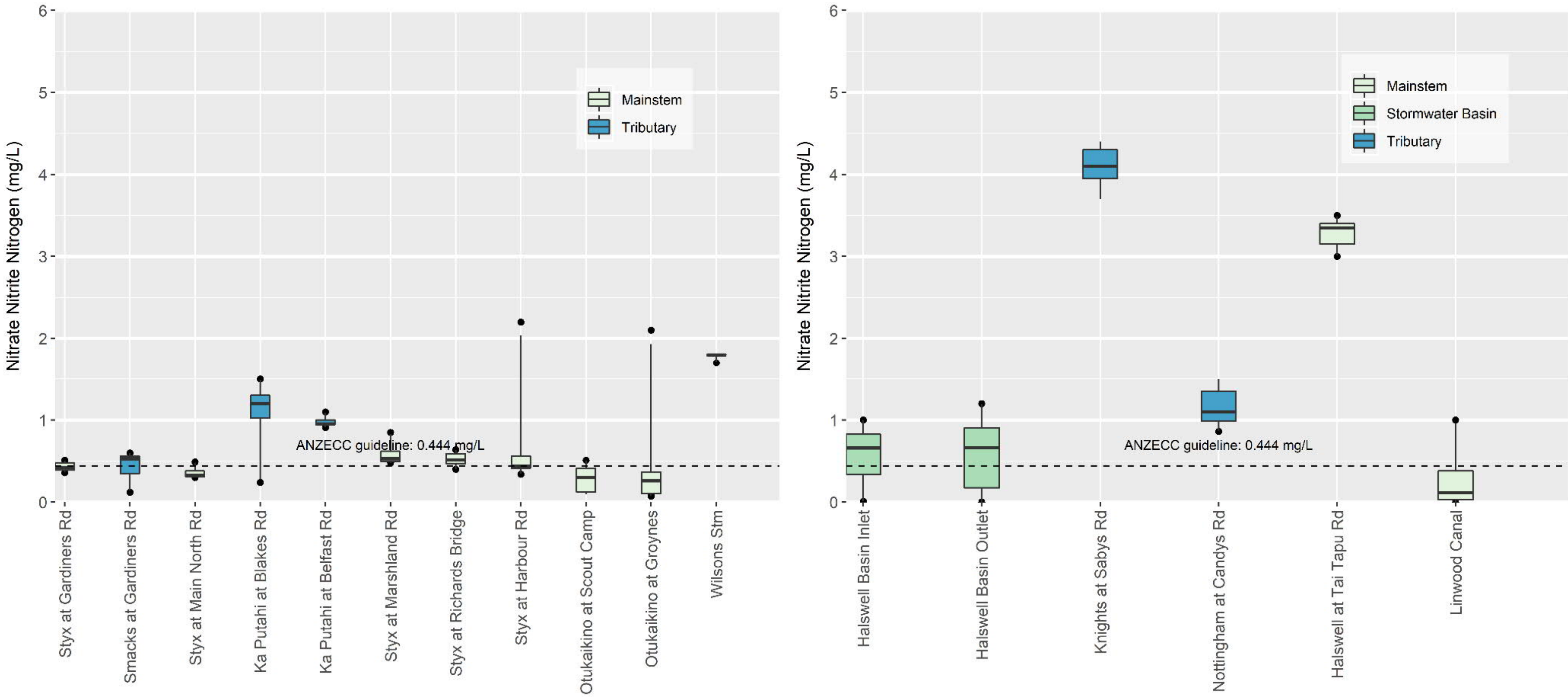


Figure xiv (b). Nitrate Nitrite Nitrogen (NNN) concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. 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 0.002 mg/L – analysed as half this value (0.001 mg/L) to allow statistics to be undertaken.

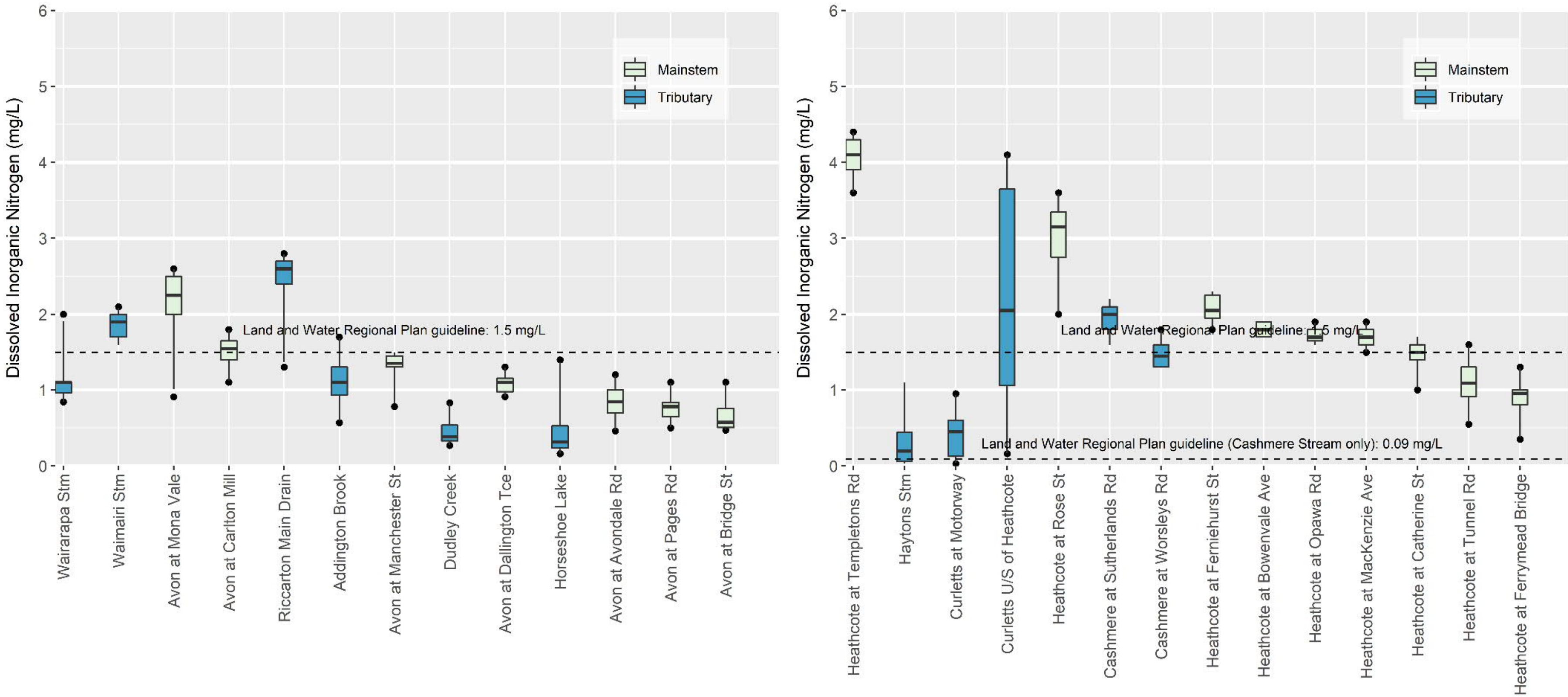


Figure xv (a). Dissolved Inorganic Nitrogen (DIN) concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline 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, 2019).

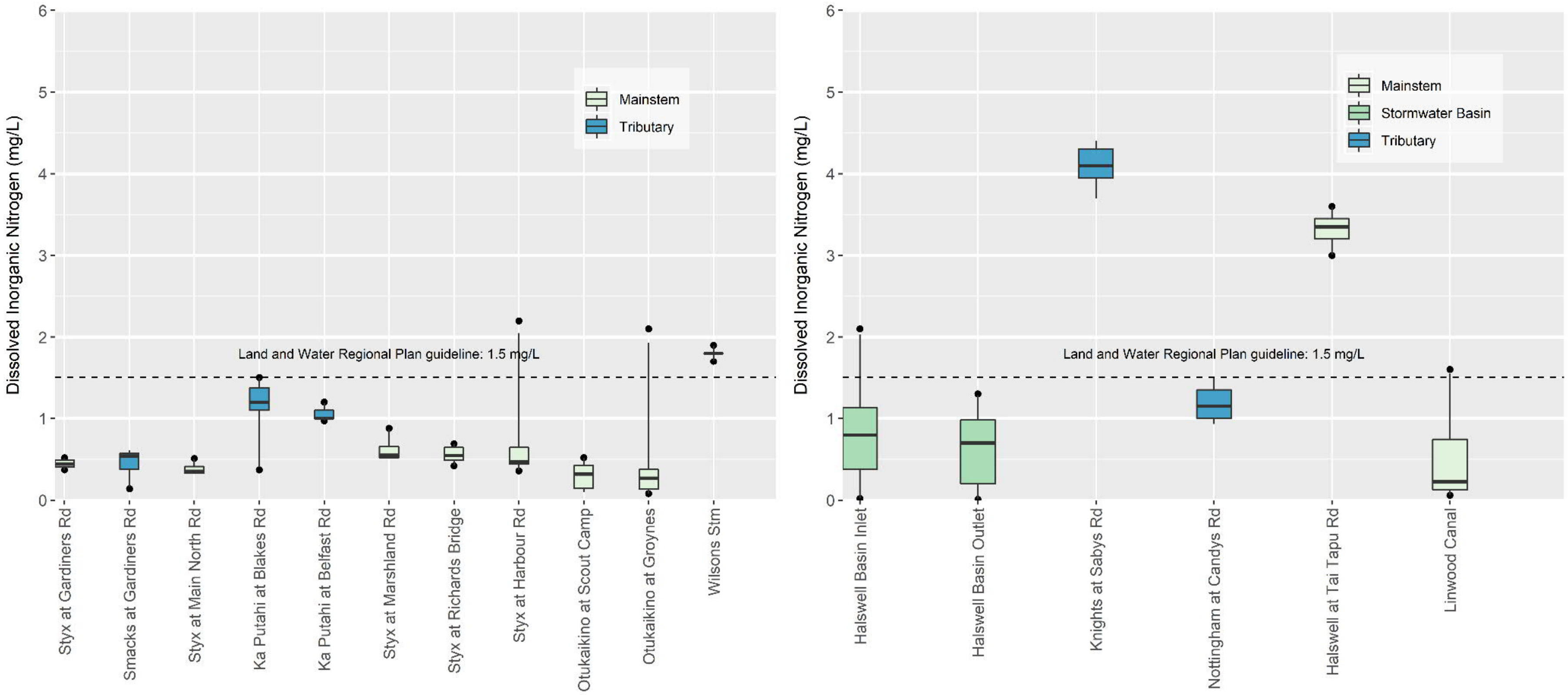


Figure xv (b). Dissolved Inorganic Nitrogen (DIN) concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline value for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways of 1.5 mg/L (Environment Canterbury, 2019).

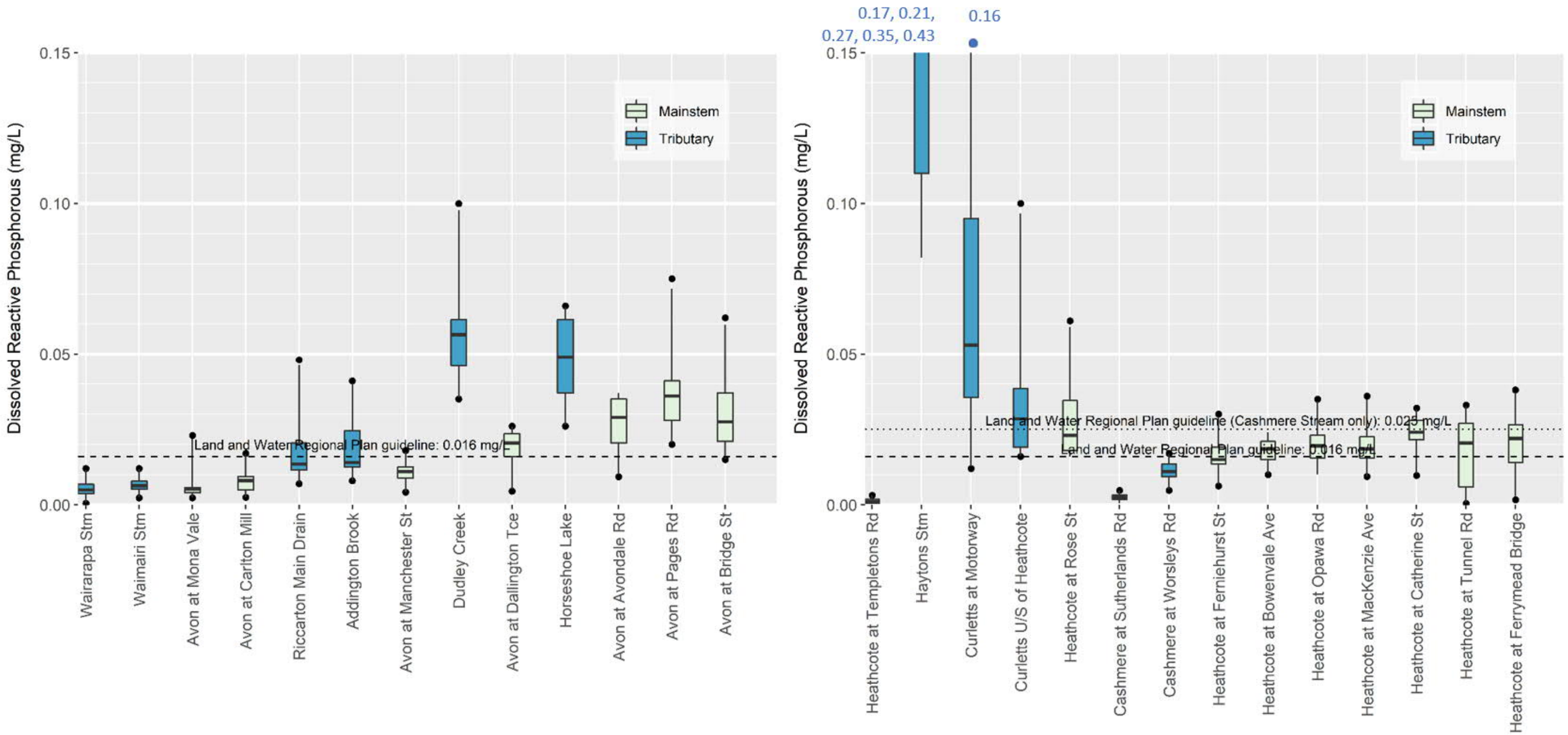


Figure xvi (a). Dissolved Reactive Phosphorus (DRP) concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019. No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline 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 guideline value of 0.025 mg/L for Banks Peninsula waterways (Cashmere Stream only), (Environment Canterbury, 2019). The Laboratory Limit of Detection was 0.001 mg/L, analysed as half this value (0.0005 mg/L) to allow statistics to be undertaken.

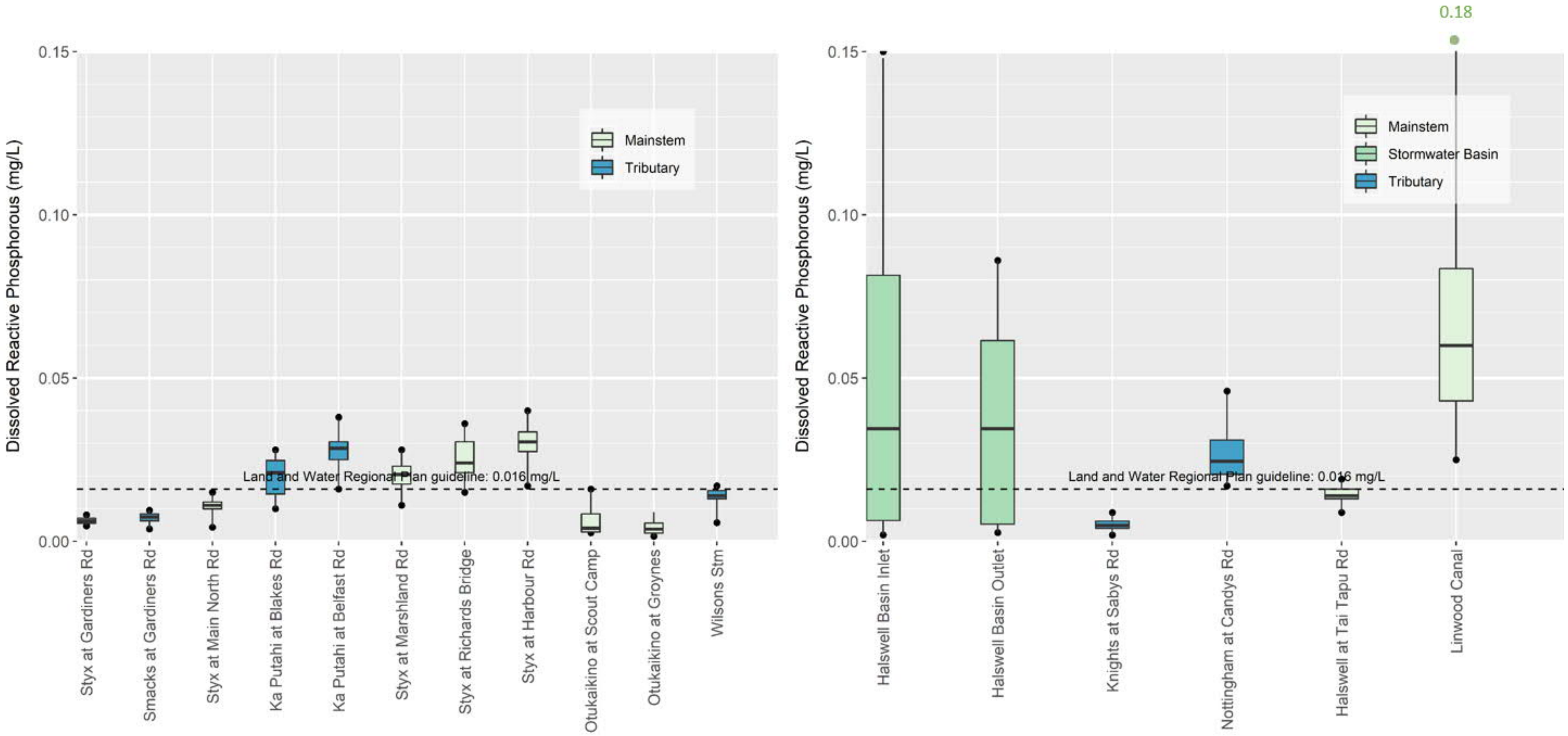


Figure xvi (b). Dissolved Reactive Phosphorus (DRP) concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline value of 0.016 mg/L for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (Environment Canterbury, 2019). The Laboratory Limit of Detection was 0.001 mg/L, analysed as half this value (0.0005 mg/L) to allow statistics to be undertaken.

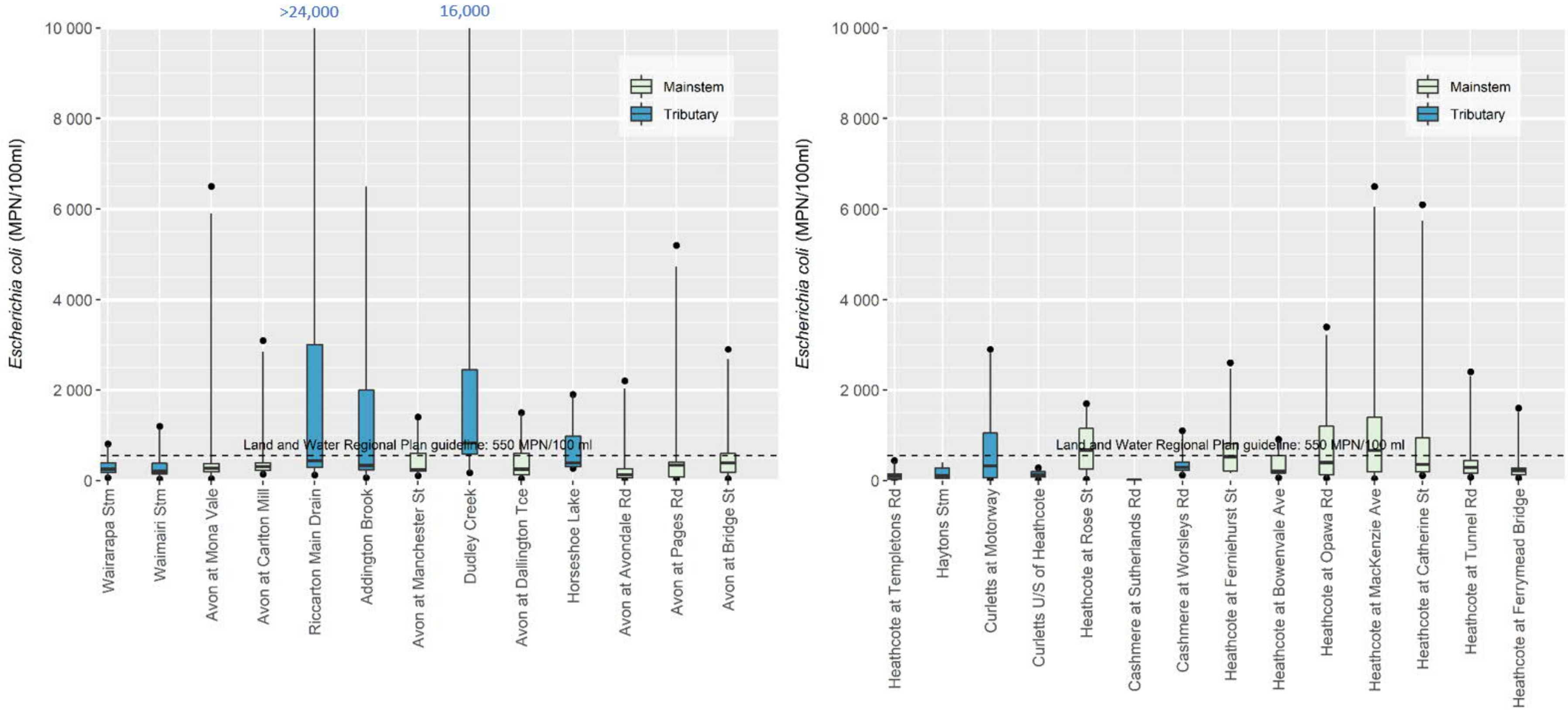


Figure xvii (a). *Escherichia coli* concentrations in water samples taken from the Ōtākaro/ Avon (left graph) and Ōpāwaho/ Heathcote (right graph) River sites, for the monitoring period January to December 2019.No monitoring was undertaken at the Haytons Stream site in March and June as the site was dry. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline value of 550 MPN/100ml for 95% of samples for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (Environment Canterbury, 2019). 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.

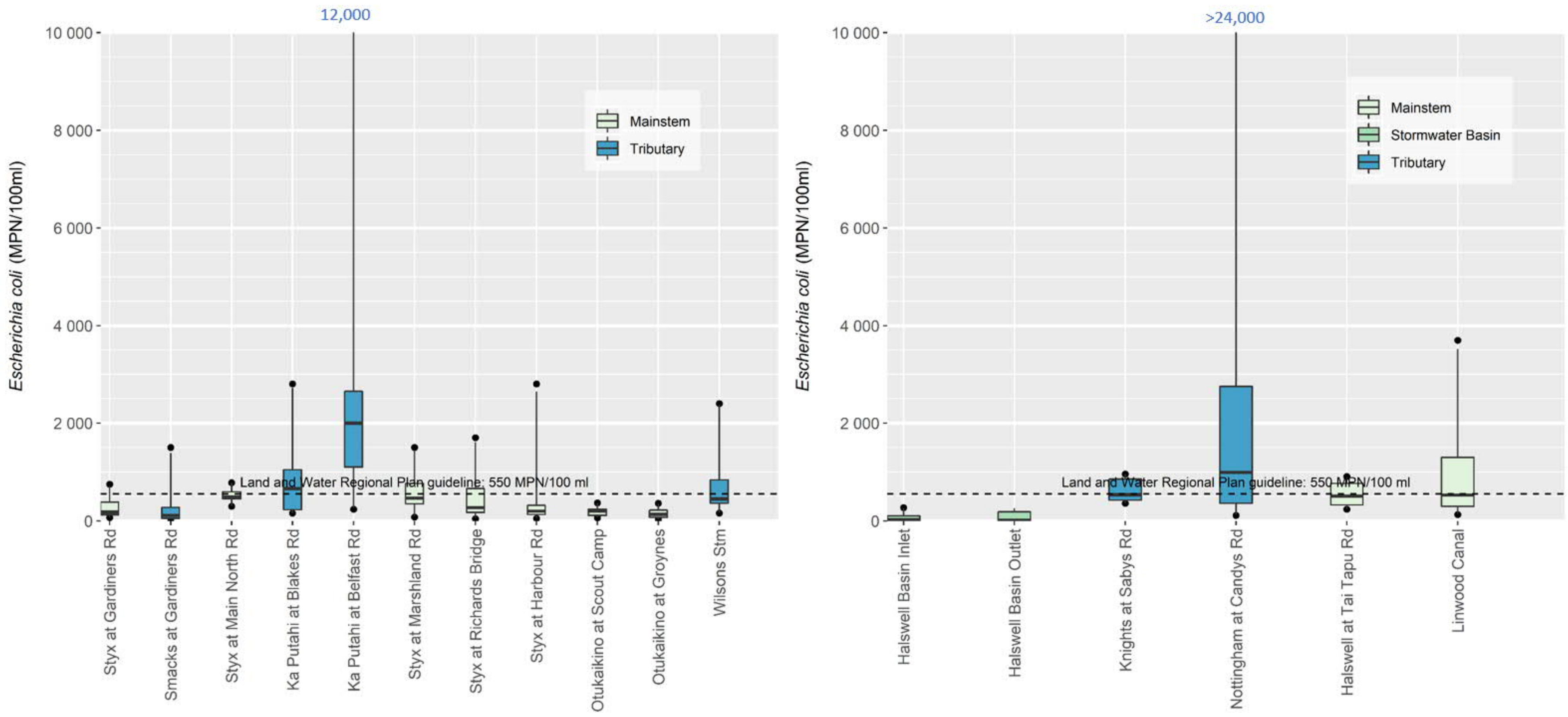


Figure xvii (b). *Escherichia coli* concentrations in water samples taken from the Pūharakekenui/ Styx and Ōtūkaikino River (left graph), and the Huritini/ Halswell River and Linwood Canal sites (right graph) for the monitoring period January to December 2019. No monitoring was undertaken at the Kā Pūtahi Creek at Blakes Road site in August and the Ōtūkaikino Creek at Omaka Scout Camp site in February, as these sites could not be accessed. Sites are ordered from upstream to downstream (left to right). The dashed lines represent the Land and Water Regional Plan guideline value of 550 MPN/100ml for 95% of samples for 'spring-fed – plains – urban' and 'spring-fed – plains' waterways (Environment Canterbury, 2019). 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.