River Water Quality State and Trends in Tāmaki Makaurau / Auckland 2010-2019. State of the Environment Reporting

R Ingley

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Technical Report 2021/07

Research and Evaluation Unit
RIMU

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Vaughan Stream at Long Bay by Rhian Ingley

Executive summary

This report is one of a series of publications prepared in support of the *State of the environment report* for the Auckland region. River water quality is monitored monthly at 36 streams across the Auckland region using a range of physical, chemical, and microbiological variables or attributes. Water quality can be affected by land use activities, point and diffuse source discharges, and land and instream erosion.

River water quality is assessed in relation to national and regional objectives, and how water quality has changed over the past 10 years in relation to the current state, such as where water quality is good but declining, poor but improving, or poor and getting worse.

The current state was assessed in relation to the national objectives framework under the National Policy Statement for Freshwater Management (NPS-FM) 2020 which came into effect on 3 of September 2020. Trends were assessed for the 10-year period from January 2010 to December 2019. Trend assessment includes two parts, the assessment of the probability of the direction of the trend, and where there is a high probability of a trend (very likely) we can also estimate the magnitude of that trend. Where a specific attribute is below the minimum state or *national bottom line*, the NPS-FM requires that council must work towards improving the state over time for those water bodies and/or freshwater management units.

Key regional issues were highlighted including instream nutrient enrichment and potential effects of eutrophication, declining visual clarity (based on turbidity), and generally high levels of *E. coli*. Regionally, there are risks (below the national bottom line) of nitrate toxicity in rural streams in the Franklin area, and risks of ammonia toxicity in almost half of our monitored urban streams, with many of these streams continuing to degrade. Over a third of our monitored streams had moderate impacts of suspended sediment and these impacted streams had a higher proportion of degrading trends. Most monitored urban streams are contaminated with zinc to levels below the proposed regional bottom line, however many were very likely improving. While no streams were below the proposed regional bottom line for copper, many rural and urban streams returned very likely degrading trends in relation to copper.

The assessment of *E. coli* undertaken here is **not** in relation to identified primary contact sites or the bathing season. However, the national objectives framework also provides for an assessment of *E. coli* in relation to potential human contact risk for all lakes and rivers. While most rural and urban streams had very high levels of *E. coli* (band E), over half of the monitored streams were found to be improving over the most recent 10-year period.

Several site-specific issues were also identified where there was a high rate of change and/or multiple attributes were poor or changing within a single stream site or spatial area. A follow-on discussion paper is planned to provide further information on these streams and their contributing catchments in relation to known pressures, planned interventions, and requirements for further actions.

The information presented here, in combination with matauranga Māori knowledge, can be used to support Māori in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water). This reporting also forms part of the knowledge base supporting the future work necessary to develop the long-term vision for Auckland rivers and streams and to set effective freshwater objectives, limits and/or targets to meet that vision as Auckland Council responds to the requirements set out in the National Policy Statement for Freshwater Management (2020).

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1.0 Introduction

Auckland's freshwater environments are valued by the people of Auckland. Water holds special significance to Māori. Mana whenua whakapapa to significant water bodies and have kaitiaki obligations to protect them. This is part of the customary practice of taonga tuku iho (protecting treasures or taonga passed down from previous generations).

The aesthetics, human use and health of our rivers are influenced by their water quality. Auckland Council monitors river water quality monthly at 36 streams across the Auckland region using a range of physical, chemical, and microbiological variables or attributes, that can be affected by land use activities, point and diffuse source discharges, and land and instream erosion. The analyses in this report were aligned, where possible, with attributes incorporated in the National Policy Statement for Freshwater Management 2020 (NPS-FM, (Ministry for the Environment, 2020)). This information can be added to matauranga Māori knowledge to support Māori in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water).

Many of Auckland's rivers are small and drain directly to the coast before they can merge with others to form larger river systems, but collectively, there are over 19,000km of permanently flowing rivers across the region, and many more intermittent and ephemeral streams that feed into these rivers (Auckland Council GeoMaps V 3.2.1.1). Auckland's topography is predominantly gentle in comparison to other regions of New Zealand. This strongly influences the nature of Auckland's rivers, along with the underlying geology, typically resulting in slow flowing, low gradient rivers with predominantly soft substrate beds. High gradient rivers with hard stony substrates are mostly restricted to catchments that drain the Waitākere Ranges, Hunua Ranges and Aotea/Great Barrier Island. River water quality varies seasonally, and through long-term and interdecadal climatic changes. It is well established, both within New Zealand, and within Auckland, that river water quality is intrinsically related to how the land is used, and where land use change occurs.

This report provides technical information describing how river water quality within Auckland has changed over the past 10 years (2010-2019). This forms part of a series of technical reports collectively addressing river, groundwater, lake, and coastal water quality, and ecological condition over the same time frames.

The current state of river water quality (based on 2015-2019) is described fully in the 2019 Annual Water Quality Report but is also summarised here to provide further context on trend directions (i.e. where water quality is good but declining, or poor but improving). This is part of the feedback loop necessary to assess whether Auckland Council's management strategies are effective in sustaining ecosystem functions, and to identify opportunities for improved future sustainable use of our valued rivers and streams.

1.1 Purpose and objectives

Auckland Council's river water quality monitoring programme supports the following objectives:

- Meet council's obligations under section 35 of the Resource Management Act 1991 (as amended) to monitor and report on the state of the environment, with specific regard to river water quality.
- Provide evidence of how the council is maintaining and enhancing the quality of Auckland's river environments (Local Government Act, 2002). Provide evidence for the Environment and Cultural Heritage component of the Auckland Plan 2050. A key direction for the region is to manage the effects of growth and development on our natural environment.
- Help inform the efficacy and efficiency of council policy initiatives and strategies.
- Assist with the identification of large scale and/or cumulative impacts of contaminants associated with different land uses and disturbance regimes and correlative links to particular activities.
- Provide baseline, regionally specific data to underpin sustainable management through resource consenting and associated compliance monitoring for river/stream environments.
- Help identify the possible standard of future river water quality in Auckland.
- Continuously increase the knowledge base for Aucklanders and promote awareness of regional river quality issues and their subsequent management.

1.2 National Policy Statement for Freshwater Management

The National Policy Statement for Freshwater Management 2020 (NPS-FM) provides guidance to regional councils and unitary authorities toward achieving nationally consistent goals for managing freshwater resources under the Resource Management Act. The NPS-FM sets out high level objectives and policies for freshwater management and requires that freshwater systems are maintained or enhanced through time (MfE, 2020).

The national objectives framework (NOF) within the NPS-FM was developed to support councils to set effective freshwater objectives, limits and/or targets. River and stream monitoring information is required to communicate/evidence NPS-FM baseline water quality state (as at 2017), or some more recent state (utilising the most recent data available) and via ongoing assessment of state to support the objective setting process, and to monitor progress towards these river management objectives through time. Councils need to:

- understand the current state of each attribute as baseline information for setting river/stream objectives

- use models where applicable to demonstrate how land use change and mitigation methods will influence these river water quality states through time, and the costs of suggested mitigations
- be able to demonstrate to their community through instream monitoring that they have achieved freshwater objectives over time.

This report presents results of monitoring undertaken prior to the notification of the NPS-FM 2020 in relation to river water quality only and consequently focuses on the state and trends for four compulsory limit setting attributes: nitrate and ammonia toxicity, *Escherichia coli* (*E. coli*) bacteria, and suspended fine sediment (as visual clarity), as well as the action plan setting attribute, dissolved reactive phosphorus (DRP).

The regionally important attributes copper and zinc are also included. Copper and zinc are given a provisional grading using the proposed draft attribute bands developed by NIWA for Auckland Council (Gadd et al., 2019).

Three compulsory NOF attributes are not reported on here. Dissolved oxygen is monitored at all river water quality sites on a discrete monthly sampling basis; however, these sites are not specifically associated with point source discharges, and continuous monitoring is necessary to identify daily minimum concentrations. Periphyton is also not included, however, a periphyton monitoring programme is currently being initiated by Auckland Council and a minimum of three years of data is required to assess compliance with the periphyton, trophic state NOF attribute for hard bottom streams. The planktonic cyanobacteria attribute is not applicable as there are no lake fed rivers within the region. *Escherichia coli* bacteria in relation to specific primary contact sites is not presented within this report or reporting series.

Other aspects of freshwater ecosystem health including water quantity, river habitats and aquatic life are currently reported separately (see section 1.3), however it is important to recognise that all these components contribute to the healthy functioning of our rivers and other freshwater systems as part of the fundamental concept of Te Mana o te Wai.

1.3 Supporting reports

Previous reports can be obtained from Auckland Council's Knowledge Auckland website, www.knowledgeauckland.org.nz.

Supplementary data files of the trend analysis outputs presented in this report are also available on Knowledge Auckland. For further enquiries and data supply, email environmentaldata@aucklandcouncil.govt.nz.

Microbiological contamination of beaches and recreational water quality are monitored through the Safeswim programme, www.safeswim.org.nz.

This report is one of a series of publications prepared in support of the State of the Environment report for Tāmaki Makaurau / Auckland. Reports on aspects of freshwater and coastal water quality and ecology include:

- *Auckland river water quality: annual reporting and National Policy Statement for Freshwater Management current state assessment, 2019* – TR2021/11
- *Coastal and estuarine water quality 2019 annual report* – TR2020/016
- *Coastal and estuarine water quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/02
- *Groundwater quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/03
- *Lake water quality state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/04
- *Marine ecology state and trends in Tāmaki Makaurau / Auckland to 2019. State of the environment reporting* – TR2021/09
- *Marine sediment contaminant state and trends in Tāmaki Makaurau / Auckland 2004-2019. State of the environment reporting* – TR2021/10
- *Rainfall, river flow, and groundwater level state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/06
- *River ecology state and trends in Tāmaki Makaurau / Auckland 2010-2019. State of the environment reporting* – TR2021/05

2.0 Methods

2.1 River water quality monitoring programme design

Auckland Council's river water quality monitoring programme was primarily designed for detecting long-term changes in water quality across the region. The network aims to be regionally representative by including a range of river and catchment sizes, stream orders, catchment locations, and catchment land cover composition (see section 2.1.2). This enables Auckland Council to present a region-wide perspective on water quality and infer the likely water quality of other rivers in the region that are not monitored.

The river water quality monitoring programme currently includes 36 sites. The programme has evolved over time, with sites added or removed according to varying regional management priorities. The programme was last reviewed internally in 2008 and subsequent changes were described in the 2009 annual report (Neale, 2010).

The 36 sites are grouped into five sampling runs and each run is carried out within the same week each month. Sites on each run are visited in the same order each time to ensure sampling occurs at approximately the same time of day each month. Each site is sampled monthly by council's Research and Evaluation Unit (RIMU), except the Hoteo River, which is monitored exclusively by the National Institute for Water and Atmospheric Research (NIWA) as part of the National River Water Quality Network (NRWQN). Rangitopuni River was also historically monitored by NIWA, and was incorporated into the Auckland Council programme in 2016. For consistency of laboratory analysis methods over the 10-year period reported here, only the data collected by NIWA from 2010 to 2019 was included in this analysis.

Physical parameters (such as temperature, salinity, dissolved oxygen) are measured in the field, and river water samples are collected for further laboratory analysis of nutrients, metals, sediments, and other chemical properties of water. Further details on data collection and management, and analytical methods for each parameter are provided in Appendix A.

2.1.1 Site locations

Monitored site location details are outlined in Table 2-1, including the year river water quality sampling was initiated, third-level river environment classes (REC) (climate, topography, and geology), and the contributing catchment size upstream of the sampling point (Snelder et al. 2010). In the Auckland region there are two relevant climate classes: warm wet (WW) and warm dry (WD; one relevant topography class (low elevation); and three relevant geology classes (based on the NPS-FM 2020 aggregation of classes): soft sedimentary (SS), hard sedimentary (HS), and volcanic (VA). Sites are mapped in Figure 2-1.

Table 2-1: Auckland Regional River Water Quality Programme site locations.

Site No.	Site name	NZTM X	NZTM Y	Year started	REC Class	Stream order (REC)	Catchment area (ha)
8019	Avondale Stream	1750600	5912264	2012	WW_Low_SS	3	339
44603	Cascades Stream (Waitakere)	1735628	5916378	1986	WW_Low_VA	3	1388
74701	Cascades Stream (Waiheke)	1785942	5923254	2013	WD_Low_HS	1	64
45703	Hoteo River	1735254	5972546	1986	WW_Low_SS	5	26917
45415	Kaukapakapa River	1735833	5944978	2009	WW_Low_SS	1	6157
45313	Kumeu River	1739252	5928781	1993	WW_Low_SS	4	4566
7830	Lucas Creek	1751468	5934510	1993	WD_Low_SS	3	616
6811	Mahurangi River (Forestry)	1747750	5965035	1993	WW_Low_SS	2	490
6804	Mahurangi River (Warkworth)	1748864	5970457	1993	WW_Low_SS	4	4844
45505	Makarau River	1736150	5953126	2009	WW_Low_SS	4	4834
6604	Matakana River	1753500	5976481	1986	WW_Low_SS	4	1385
43829	Ngakoroa Stream	1775164	5881624	1993	WW_Low_VA	3	466
7171	Nukumea Stream	1749411	5951400	2012	WW_Low_SS	2	99
8110	Oakley Creek	1751963	5917636	1994	WW_Low_SS	3	1129
7502	Okura Creek	1751405	5938716	2003	WW_Low_SS	3	553
8249	Omaru Creek	1766268	5916749	2009	WD_Low_SS	2	515
74401	Onetangi Stream	1786243	5926204	2013	WD_Low_HS	2	68
7904	Opanuku Stream	1742086	5915581	1986	WW_Low_SS	3	1566
8219	Otaki Creek	1764306	5907216	1992	WD_Low_SS	2	117
8214	Otara Creek (South)	1767422	5907535	1985	WD_Low_VA	3	880
8205	Otara Creek (East)	1768335	5908376	1992	WD_Low_SS	3	1828
7811	Oteha River	1751325	5933519	1986	WD_Low_SS	3	1221
8217	Botany Creek	1770686	5913036	1992	WD_Low_SS	3	665
8215	Pakuranga Creek	1769473	5910813	1992	WD_Low_VA	2	216
1043837	Papakura Stream (Upper)	1774247	5902648	2012	WW_Low_HS	4	2324
43856	Papakura Stream (Lower)	1771240	5900290	1993	WW_Low_HS	4	4716
43807	Puhinui Stream	1766440	5904295	1994	WD_Low_SS	3	1304
7805	Rangitopuni River	1744450	5932301	1986	WW_Low_SS	5	8366
45373	Riverhead Stream	1737125	5933216	2009	WW_Low_SS	2	410
7506	Vaughan Stream	1755414	5938729	2001	WD_Low_SS	2	239
8568	Wairoa Tributary	1786700	5892817	2009	WW_Low_HS	2	227
8516	Wairoa River	1782682	5901720	1986	WW_Low_HS	5	14885
43601	Waitangi Stream	1754343	5878534	2009	WW_Low_VA	3	1897
7104	Waiwera Stream	1748628	5953665	1986	WW_Low_SS	4	3023
7206	West Hoe Stream	1748314	5950610	2002	WW_Low_SS	2	53
438100	Whangamaire Stream	1763578	5884625	2009	WW_Low_VA	2	814

Figure 2-1: River water quality monitoring site location map.

(Area shaded in red shows the extent of urban area in 2019 (Hoffman, 2019)

2.1.2 Land cover representativeness

A geospatial assessment of land cover changes over time was carried out for the specific catchment area upstream of each site using the New Zealand Land Cover Database V5.0 (Manaaki Whenua – Landcare Research). Land cover in the upstream catchment has been shown to explain more variation in stream contaminant concentrations than land cover in the riparian zone at a reach scale (Larned et al., 2019). The upstream catchment areas were defined using natural drainage topography and the existing Auckland Council permanent streams network layer.

Catchments upstream of the sites in the river water quality monitoring programme included a range of different land cover types. Detailed land cover types defined by the LCDB 5 were further aggregated into broad level categories (see Appendix B for aggregation). An overview of how the programme sites reflect this broad land cover is provided in Figure 2-2. The proportion of each broad level category within the upstream catchment of each monitoring site is outline in Figure 2-3.

The dominant land cover type for the upstream catchment of each site was assigned based on the broad land cover categories as of summer 2018/2019 following the approach of Snelder & Biggs 2002 (as applied in Larned et al., 2018). The dominant land cover type is described as 'urban' when urban cover exceeds 15 per cent, and 'rural' when rural cover exceeds 25 per cent. If both urban and rural land cover exceed these thresholds, then 'urban' is considered the dominant land cover. These definitions take into account the disproportionate influence that these land cover categories have on river water quality. If neither of these thresholds are exceeded, then the dominant land cover category is defined by the greatest percentage of land cover type.

Two sites within the 'native' land cover type are impacted by more than 10 per cent of rural or urban land cover. The remaining four sites are referred to as 'reference' streams that are relatively unimpacted by anthropogenic land use.

Overall, the monitoring programme is representative of proportions of dominant land cover type that approximate the distribution of land cover across the Auckland region with a greater representation of urban streams (LCDB 5.0).

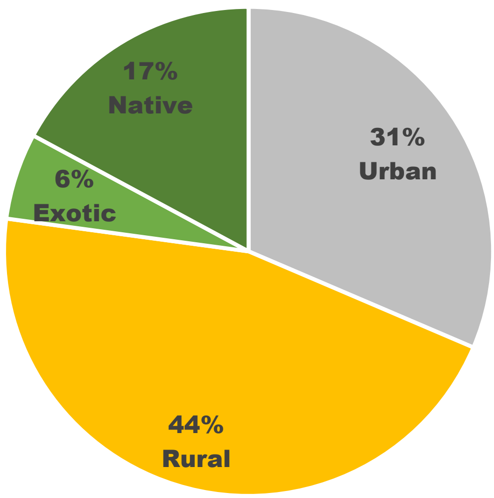


Figure 2-2: Percentage of monitored catchments per dominant land cover.

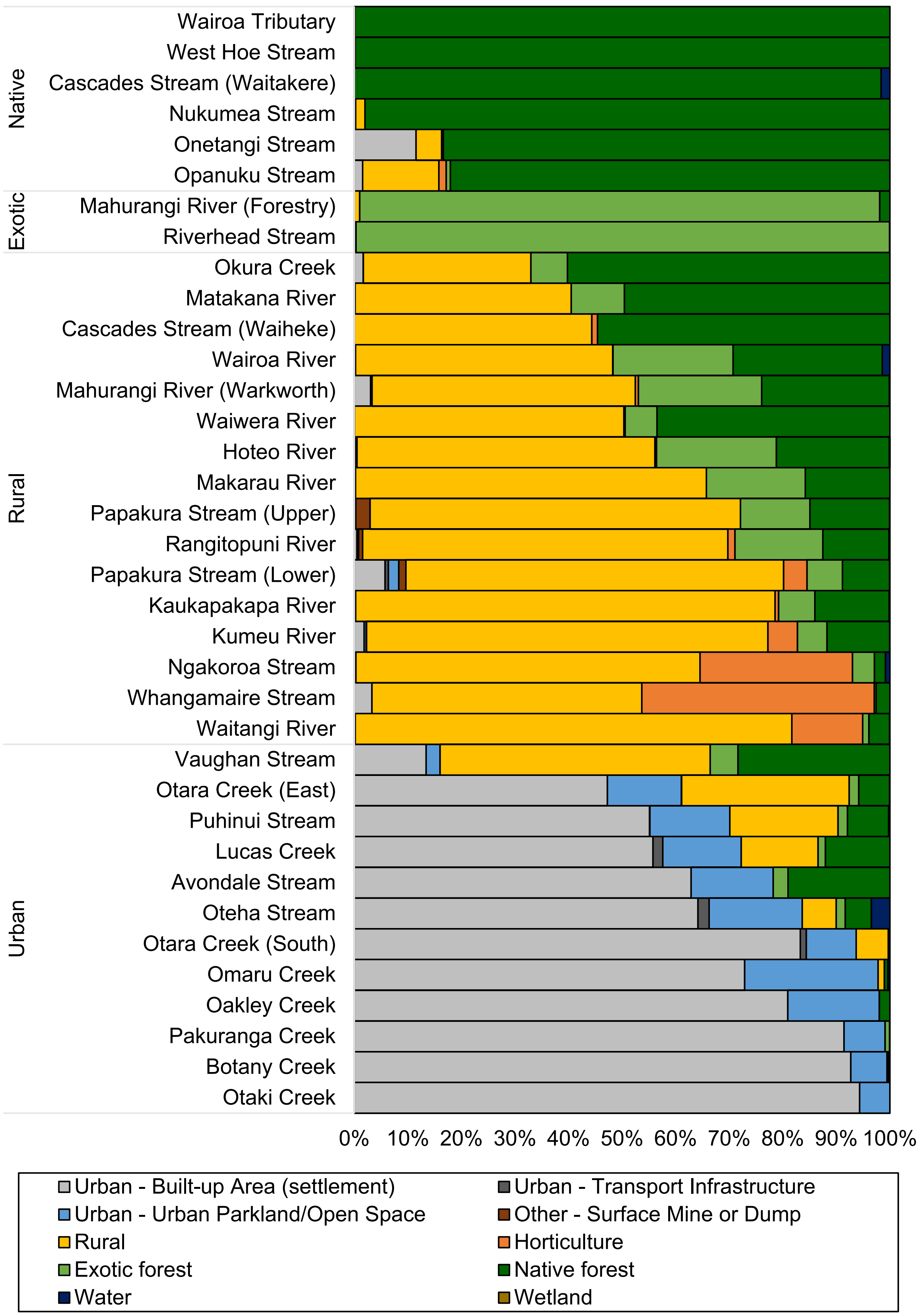


Figure 2-3: Summary of land cover in upstream catchments at 2018/2019 (LCDB5).

2.1.3 Modifier adjustments

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) recommend that soluble copper is adjusted for dissolved organic carbon (DOC) to 0.5 mg/L and that soluble zinc be adjusted to a hardness (as $CaCO_3$) of 30 mg/L and a pH of 8.0 (Warne et al., 2018).However, because Auckland Council has only been gathering data on DOC and hardness since 2018, no adjustment has been made when assessing against regional draft copper and zinc guidelines, as per the approach outlined in Gadd et al. (2019). This will be possible in future reports.

Total ammoniacal nitrogen refers to two chemical species that are in equilibrium in water – toxic ammonia (NH_3) and the relatively non-toxic ammonium ion (NH_4^+). The proportion of the two varies, particularly in response to pH and temperature. The NOF toxicity guidelines for ammoniacal nitrogen are standardised to a pH of 8.0. Total ammoniacal nitrogen results are adjusted for pH following a conversion table, as prescribed by the Ministry for the Environment (MfE, 2017b) for comparison to NOF guidelines only. Trend analyses were undertaken on total ammoniacal nitrogen concentrations rather than on adjusted ammonia toxicity.

All water quality state and trends analyses were undertaken **without flow adjustment**. In recent national analysis, flow adjustments were applied only to site and variable combinations where reliable water quality to flow relationships existed and otherwise carried out without flow adjustment (Larned et al., 2019). It would be possible to undertake flow adjustment for only nine of the 36 monitored sites, where there are paired flow monitoring records. For consistency of analyses across the regional monitoring network, flow adjustment was not undertaken.

2.2 River water quality state

The current state of river water quality at 2019 is based on the median, 95th percentile[1], or maximum values recorded over the preceding five years (2015-2019 inclusive) in accordance with the national objectives framework under the National Policy Statement for Freshwater Management 2020 (NPS-FM, Appendix 2A and 2B), and proposed draft Auckland specific attributes for metals (Gadd et al., 2019). These objectives are summarised in Table 2-2, Table 2-3, and Table 2-4 below.

The NOF identifies a core group of attributes which councils must use to grade the quality of river environments. The state of each attribute is graded into specific bands (using various statistical metrics) per water body type (e.g. lakes or rivers). Each numeric band (A – best, B, C, D/E – worst) is associated with a narrative description

[1] Hazen percentiles have been used as per NOF guidelines

which describes the expected ecological outcome of interest. The '*National Bottom Line'* refers to the minimum state for each attribute that councils must meet or work towards meeting over time.

The NOF nitrate toxicity assessment is reported here using the proxy total oxidised nitrogen (nitrate + nitrite nitrogen). This assumes the nitrite fraction is almost always a negligible proportion of the total oxidised nitrogen (see Ingley and Groom, 2021).

The NOF suspended fine sediment attribute allows for turbidity measurements to be converted to visual clarity. This was undertaken with reference to the technical memo prepared by NIWA for the Ministry for the Environment identifying a national regression relationship between site median visual clarity and site median turbidity (Franklin et al., 2020; Franklin et al., 2019). Briefly, median turbidity values were natural log transformed and the national regression relationship equation was applied and then transformed via the exponential function as the inverse of the natural logarithm.

$$\ln(\text{CLAR}) = 1.21 - 0.72 \ln(\text{TURB})$$

At this time, it is not possible to derive NOF bands for dissolved oxygen from the discrete monthly monitoring undertaken. In the interim, ANZ default guidelines (2018) for the relevant REC class are referred to for dissolved oxygen, and pH (see Table 2-5). A site median that exceeds the ANZ trigger values does not necessarily signify that effects will occur, it indicates that further analysis, and consideration of the appropriateness of the default guideline is recommended for management purposes.

High surface water temperatures are also recognised as an issue affecting water quality in Auckland streams. Regional reference values for temperature, based on streams within native forested catchments, as applied within the Auckland regional river Water Quality Index (Ingley and Groom, 2021), are also considered here.

Further details on methods for the assessment of water quality state are provided in the 2019 Annual River Water Quality data report (Ingley and Groom, 2021).

Table 2-2: NPS-FM (2020) NOF Attribute Bands.

(Red line depicts the national bottom line (NBL) for each attribute, red shading depicts bands failing the NBL)

NOF River Attribute	Ammonia (Ecosystem Health – toxicity)		Nitrate (Ecosystem Health – toxicity)		Suspended fine sediment (Ecosystem Health)		*Escherichia coli* (Human Contact)			
Metric	**Median**	**Annual Maximum**	**Annual Median**	**Annual 95th %ile**	**Median Class 1**	**Median Class 2**	**% > 540**	**% > 260**	**Median**	**95th %ile**
Unit	mg NH_4-N/L pH adjusted		mg NO_3-N/L		Visual clarity (m)		cfu/100mL			
A	≤ 0.03	≤ 0.05	≤ 1.0	≤ 1.5	≥ 1.78	≥ 0.93	< 5%	≤ 20%	≤ 130	≤ 540
B	> 0.03 and ≤0.24	> 0.05 and ≤ 0.40	> 1.0 and ≤ 2.4	> 1.5 and ≤ 3.5	< 1.78 and ≥1.55	< 0.93 and ≥0.76	5-10%	20-30%	≤ 130	≤ 1000
C	> 0.24 and≤1.30	> 0.40 and≤2.20	> 2.4 and ≤ 6.9	> 3.5 and ≤ 9.8	< 1.55 and >1.34	< 0.76 and >0.61	10-20%	20-34%	≤ 130	≤ 1200
D	> 1.30	> 2.20	> 6.9	> 9.8	< 1.34	< 0.61	20-30%	> 34%	> 130	≤ 1200
E							> 30%	> 50%	> 260	> 1200

Table 2-3: NPS-FM (2020) Action Plan Attribute Bands.

NOF River Attribute	DRP	
Metric	**Median**	**95th %ile**
Unit	mg/L	
A	≤ 0.006	≤ 0.021
B	> 0.006 and ≤ 0.01	> 0.021 and ≤0.030
C	>0.01 and ≤0.018	> 0.030 and ≤0.054
D	> 0.018	> 0.054

Table 2-4: Proposed Auckland Attribute Bands for dissolved metal contaminants (Gadd et al., 2019).

NOF River Attribute	Soluble Copper		Soluble Zinc	
Metric	**Annual Median**	**Annual 95th %ile***	**Annual Median**	**Annual 95th %ile***
Unit	**mg/L**		**mg/L**	
A	≤ 0.001	≤ 0.0014	≤ 0.0024	≤ 0.008
B	>0.001 and ≤ 0.0014	>0.0014 and ≤ 0.0018	>0.0024 and ≤ 0.008	>0.008 and ≤ 0.015
C	>0.0014 and ≤ 0.0025	>0.0018 and ≤ 0.0043	>0.008 and ≤ 0.031	>0.015 and ≤ 0.042
D	> 0.0025	> 0.0043	> 0.031	> 0.042

** Amended metric from annual maxima to annual 95th percentile*

Table 2-5: ANZ Default Guidelines (2018).

REC Class	Dissolved Oxygen	pH
Metric	**Annual Median**	**Annual Median**
Unit	**(%saturation) Daytime only**	**Daytime only**
Warm wet – Low	>92 and <103	>7.26 and <7.7
Warm dry – Low	>82 and <100	>7.27 and <7.8

2.3 Trend analysis

As a first step, data was assessed for seasonality using the Kruskal-Wallis test which determined the type of test used for subsequent trend analysis. Seasonal tests compare river water quality observations within each month over time while non seasonal tests compare all observations over time. Data were also inspected for minimum data requirements, and changes in detection limits over time prior to analysis (see sections 2.3.1 and 2.3.2).

Monotonic trends across sites were analysed by assessing the direction of a trend, i.e. how likely is it that parameter is increasing or decreasing? The confidence in the trend direction is calculated using the Kendall (or seasonal Mann-Kendall) test based on the probability that the trend was decreasing. An overarching assumption of the first step of the trend analysis is that there are always differences between observations (McBride, 2019). The calculated probability is interpreted based on the categories used by the Intergovernmental Panel on Climate Change and further aggregated to five categories for simplicity as per LAWA (Cawthron Institute 2019; Snelder and Fraser 2018) (see Table 2-6).

For most parameters, a decreasing trend is interpreted as an improvement in water quality, and an increasing trend is a degradation in water quality. For physical parameters such as temperature and salinity we have referred to the likelihood of the direction of the trend as increasing or decreasing and have not assigned this as either improving or degrading. A trend is classified as indeterminate when there is insufficient evidence to determine if the data is trending in a particular direction.

Table 2-6: Trend confidence category levels used to determine the direction of trends.

Trend categories		Probability (%)
Very likely improving	Very likely decreasing	90-100
Likely improving	Likely decreasing	67-90
Indeterminate	Indeterminate	33-67
Likely degrading	Likely increasing	10-33
Very likely degrading	Very likely increasing	0-10

Where water quality is found to be degrading further assessment is critical to understand what actions may be necessary to improve water quality. This includes assessment of the likelihood of the trend, the magnitude of the trend, the risk of adverse ecological outcomes (in relation to the known current state), and consideration of whether the current state reflects naturally occurring processes.

The magnitude of the trend is characterised by the slope of the trend line using the Sen slope estimator (SSE) (or the seasonal version (SSSE)). The SSE is the median of all possible inter-observation slopes. The 90 per cent confidence intervals of this median estimate are also calculated.

While a trend may be ‘very likely’ improving or degrading, the smaller the Sen slope, or rate of change, the longer it would take to be reflected in assessments of the current state assuming a linear rate of change. Trend magnitude is further considered in this report relative to the limit of precision (i.e. the measurement resolution[2]) for each parameter following the approach in Fraser and Snelder (2018). Trend magnitude can only be estimated *with confidence* for ‘very likely’ trends.

Trend magnitudes were discussed in previous Auckland Council water quality trend reports in terms of the relativised Sen slope or per cent change per annum relative to the median concentration over 10 years. This per cent annual change approach is useful for comparing between different parameters as it standardises the rate of change to the same units. However, this approach can mask interpretation of trends if there are large differences in median values of a parameter between sites. For example, where sites have high concentrations of contaminants (poor water quality), concentrations may be changing by a large amount but when divided by the median value, the trend magnitude appears small. Conversely, where a site has a very low median concentration (such as at reference sites), a small magnitude of change would be amplified to a high percentage per annum.

Analyses were undertaken using purpose-written script designed for undertaking the trend analysis as described in Larned, et al. (2018) in the R statistical package (R Core Team, 2020). The script was obtained from Land Water People (LWP-Trends library Version 1901: LWPTrends_v1901.r.) and is readily available at https://landwaterpeople.co.nz/pdf-reports/.

[2] Where the measurement resolution varied over time (such as due to changes in detection limits), the most common value was used.

2.3.1 Data requirements and time periods for analyses

Monotonic trends were assessed for the 10-year period from January 2010 to December 2019.

A minimum of 90 per cent of samples across all site per parameter per year (or season) combinations were required for analysis. For example, over a 10-year period of monthly monitoring, this is equivalent to at least 10 samples per year in at least nine of the 10 years. Any sites or parameters that did not meet these data requirements were not analysed and therefore no trends were reported.

On numerous occasions Ōtaki Creek was tidally influenced, as evidenced by high salinity concentrations not consistent with a freshwater stream environment. Where salinity was greater than 0.5 ppt, all data were excluded from analysis (Buckthought et al. 2020). This resulted in an insufficient number of observations to assess the current state, or trends at Ōtaki Creek in relation to freshwater guidelines.

Five sites were added to the network within the last 10 years (in 2012 or 2013) (see Table 2-1). For these sites, interim trends were calculated where there was a minimum of 90% of samples across the seven or eight years available.

Some discrepancies have been observed in long-term trends particularly for dissolved reactive phosphorus coinciding with laboratory analytical changes from automated, to flow injection analysis (July 2017)[3].

2.3.2 Detection limits and censored values

Values that are less than the detection limit for a parameter are referred to as 'left censored' values. For trend analysis, censored values are replaced with a value half the detection limit. This ensures that any measured value that is equal to the detection limit, is treated as being larger than a value that is less than the detection limit i.e. a measured concentration of 0.2 mg/L is larger than a value recorded as <0.2 mg/L, and that the difference between two censored values is not measurable and treated as zero.

The evaluation of the confidence in trend direction is highly reliable, even with a high percentage of censored values. However, the estimation of the magnitude of the trend (Sen slope) decreases in reliability as the proportion of censored values increases. The LWP script specifically identifies where the trend slope was calculated from data with censored observations. In these instances, the magnitude of the trend is

[3] Note that ammoniacal N, total oxidised nitrogen, and nitrite analyses changed from automated to flow injection analyses in August 2016 however no clear step changes were observed and these results are assumed to be comparable over time.

considered to be imprecise and is not reported here. Specifically, trend magnitudes were excluded where the Sen slope was based on two censored values or tied non-censored values. Where the Sen slope was influenced by one censored value these trend magnitudes were retained. Therefore, it is not necessary to apply an arbitrary limit of no more than 15 per cent censored values within the data set (Larned et al. 2018).

The face value of all detection limits was used for this analysis where there were differences in detection limits over time, rather than replacing all lower detection limit values with the highest detection limit. This ensures that observations obtained with more sensitive laboratory analytical measurements are not lost under an 'umbrella' of water quality observations with poor resolution. However, this can induce 'improving' trends where observations are lower than were able to be recorded previously, or alternatively induce 'degrading' trends where observations were historically lower than current detection limits. Where there is a risk of induced trends influencing results reported here, they have been clearly identified.

3.0 River water quality results and discussion

3.1 Summary of changes in land cover for monitored streams

Land cover refers to the general spatial distribution of structures and vegetation types on land and does not necessarily capture differences in land use or management practices. However, land cover provides a clear overview of large-scale changes over time at intervals that are relevant for river water quality trend analysis.

Across all catchment areas upstream of monitored river sites, the overall proportion of land cover types has been relatively consistent over time, with a two per cent increase in urban land cover and three per cent reduction in rural land cover over the last 11 years (summer 2008/09-2018/19). However, at the scale of the individual upstream catchments of monitored streams, there have been considerable changes over time.

The greatest changes in land cover over this time period were associated with urban growth in the upstream catchments of Otara Creek East (Flat Bush), Omaru Creek (Tamaki), and Vaughan Stream (Long Bay) (Table 3-1). At Otara Creek East the percentage of urban land cover in the catchment increased from 31 per cent to 47 per cent, while the Vaughan Stream catchment more than doubled in urban land cover from 6 per cent to 13 per cent. Stage 1 of the Flat Bush Structure Plan was released in 2001, and staged development has continued over the period assessed. Construction commenced in 2012 at Long Bay. The Omaru Creek catchment was already highly urbanised but further increased over the last 11 years. Lucas Creek also saw a small increase in urban area.

The two streams monitored within predominantly exotic forest catchments were also in different phases within the past 10-year period. Mahurangi River (Forestry) went through a harvest phase between 2012 and 2018 where the harvested area increased from zero to 38 per cent of the catchment, prior to land being set aside for the development of the Puhoi to Warkworth Motorway Corridor. Conversely Riverhead Forest Stream was still within a growth phase following a harvest cycle approximately prior to 1996.

All other monitored streams had less than three per cent change in broad land cover classes in the upstream catchments over the past 11 years.

Table 3-1: Percentage of built-up area within the upstream catchment for selected sites with large scale urban growth (LCDB 5.0).

	Prior to trend assessment period		Within trend assessment period		
Site	**1996/97**	**2001/02**	**2008/09**	**2012/13**	**2018/19**
Botany Creek	88%	93%	93%	93%	93%
Pakuranga Creek	15%	91%	91%	91%	91%
Otara Creek (South)	69%	79%	83%	83%	84%
Otara Creek (East)	9%	21%	**31%**	**32%**	**47%**
Omaru Creek	58%	59%	**65%**	**70%**	**73%**
Oteha Stream	53%	64%	66%	66%	66%
Lucas Creek	19%	39%	51%	53%	58%
Vaughan Stream	6%	6%	**6%**	**9%**	**13%**

3.2 Overview of water quality current state (2015-2019)

A summary of water quality state is outlined here collectively across the region (Figure 3-1), and per dominant land cover class (Figure 3-2). Overall NOF grades (compared to the NPS-FM 2020 national objectives framework) and provisional grades for metals (Gadd, et al., 2019), per site are shown in maps in Figure 3-3 and Figure 3-4. The '*National Bottom Line'* refers to the minimum state for each attribute. Grades below the national bottom line mean that there are high concentrations of contaminants, and there are risks of adverse effects on the health of our waterways. Refer to the 2019 Annual River Water Quality Data report (Ingley and Groom, 2021) for further information on current water quality state.

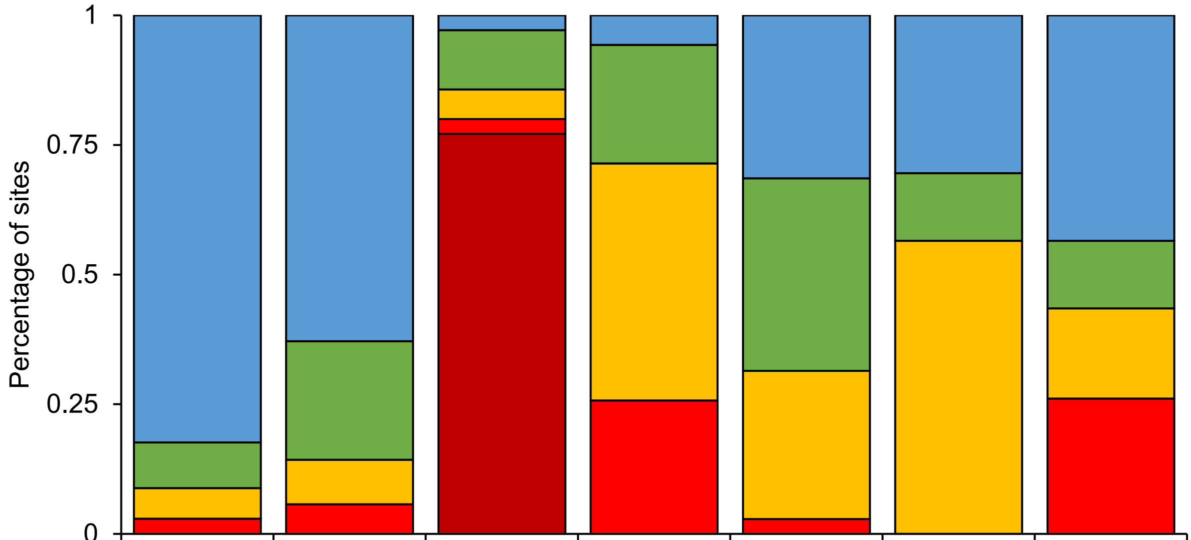
There is a very low risk of nitrate or ammonia toxicity effects even for the most sensitive species. Over 90 per cent of monitored river water quality sites are above the national bottom line for nitrate toxicity, and over 80 per cent are above the national bottom line for ammonia toxicity. However, the adverse effects of nutrient enrichment can occur at concentrations far lower than nutrient levels that cause toxicity. The limiting nutrient in rivers potentially driving excessive plant and algal growth, is most commonly phosphorus (McDowell, et al., 2009). Less than 30 per cent of monitored streams were in bands A and B for dissolved reactive phosphorus (DRP) indicating that phosphorus levels are elevated within Auckland, however, none of the four reference sites monitored are in band A, which suggests that phosphorus levels may be naturally elevated within parts of the region, and further interpretation will be required to understand the natural condition state across the region.

Only one monitored site was below the national bottom line for suspended fine sediment (turbidity), however, nearly 30% of monitored sites were in band C where sensitive native fish species may be lost.

All monitored sites had soluble copper concentrations above the proposed regional bottom line, however 26% of sites failed the proposed regional bottom line for soluble zinc where effects instream may approach acute impact levels for sensitive species[4]. All stream sites in bands C and D for zinc were in urban areas except for one site in exotic forestry with high concentrations of zinc (Figure 3-2).

Pollution by faecal contamination is a widespread issue across the Auckland region particularly within urban, and rural areas (Figure 3-2) and has implications for human contact with rivers and streams.

The percentage of catchment area in urban or pastoral land use has been found to be consistently, positively correlated with contaminant concentrations in freshwater rivers/streams and negatively correlated with ecological health indicators (Snelder, et al. 2017; Larned, et al., 2019; Gadd et al., 2020). Regionally, overall water quality state follows a similar distribution with urban streams in the poorest condition and streams with catchments dominated by native forest in the best condition (Figure 3-2).



	Nitrate (n=34)	Ammonia (n=35)	E.coli (n=35)	DRP (n=35)	Turbidity (n=35)	Cu(n=23)	Zn(n=23)
A	82%	63%	3%	6%	31%	30%	43%
B	9%	23%	11%	23%	37%	13%	13%
C	6%	9%	6%	46%	29%	57%	17%
D	3%	6%	3%	26%	3%	0%	26%
E			77%				

Figure 3-1: Summary of the proportion of all river sites within each overall band across NPS-FM 2020 NOF and proposed Auckland specific water quality attributes (2015-2019).

[4] Grading for metals is provisional only.

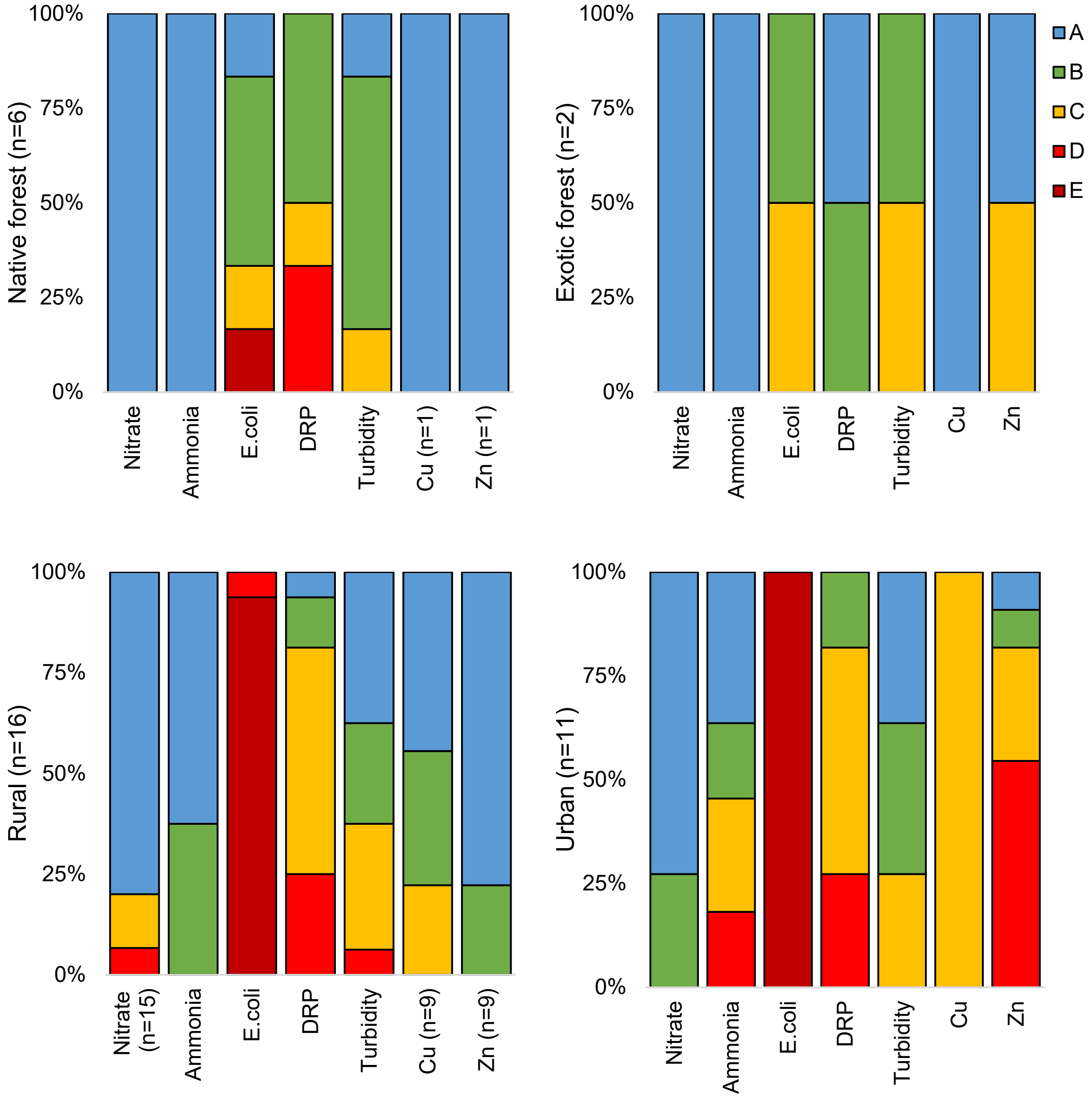


Figure 3-2: Summary of the proportion of sites per dominant land cover class within each overall band across NPS-FM 2020 NOF and proposed Auckland specific water quality attributes (2015-2019).

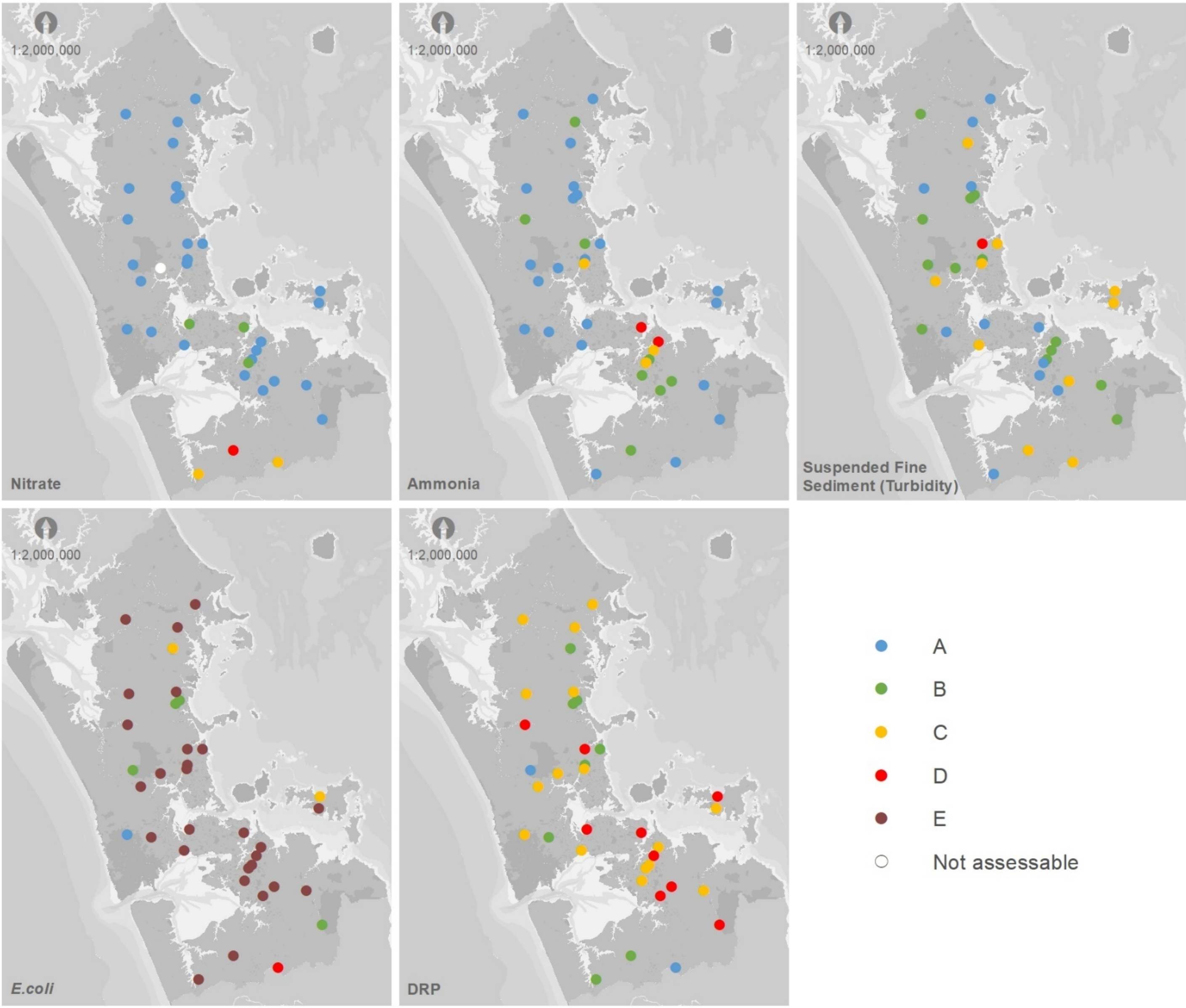


Figure 3-3: Auckland region summary maps of current state (2015-2019) for NPS-FM 2020 overall NOF attribute band per site.

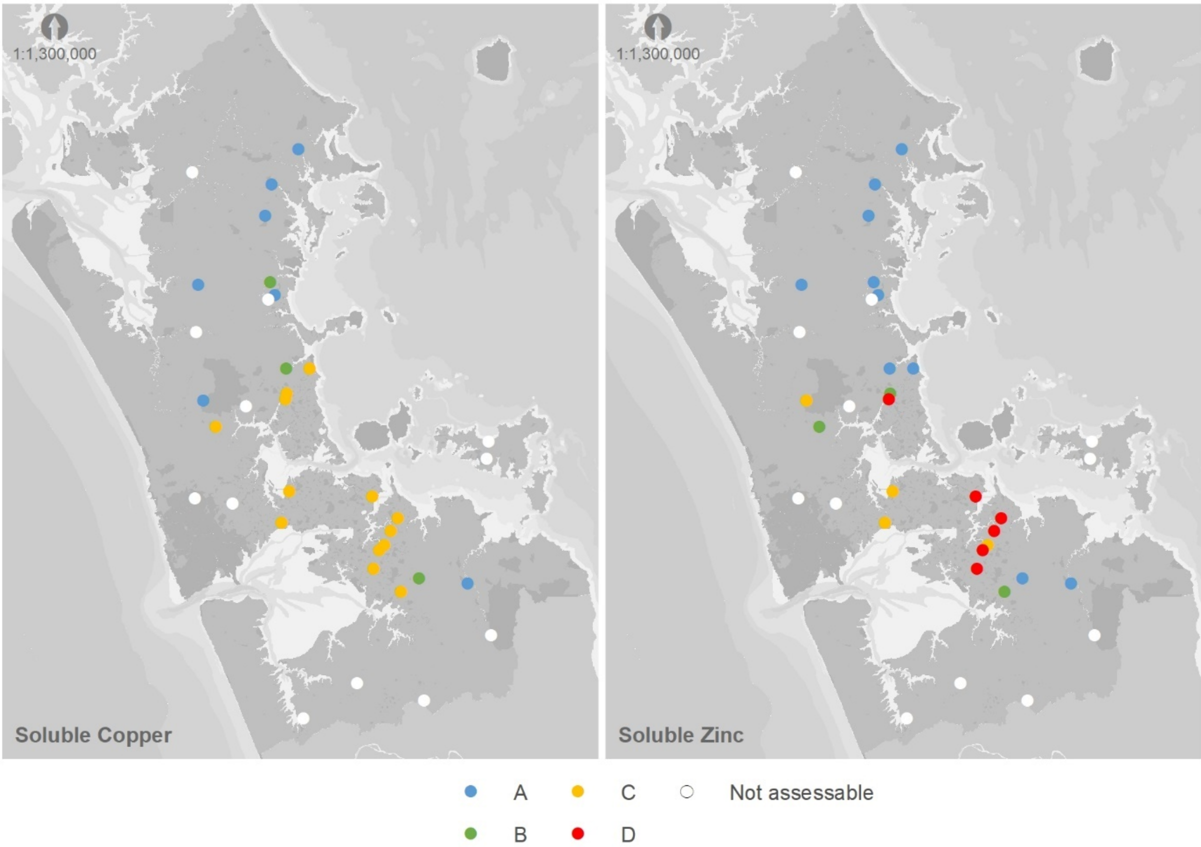


Figure 3-4: Auckland region summary maps of current state (2015-2019) provisional bands for proposed regional zinc and copper guidelines.

3.3 Overview of 10-year trends (2010-2019)

Trends in river water quality are first assessed from a regional perspective to decipher if trends are following similar patterns across all monitored sites in the Auckland region. Figure 3-5 displays the 10-year trends for the key NPS-FM national objectives framework (NOF), and proposed Auckland specific attributes summarised across the region. Figure 3-6 displays the 10-year trends for key physical parameters. Trend directions per site and per parameter are shown in maps in Figure 3-7 and Figure 3-9. Further discussion on each set of parameters, is provided section 3.4.

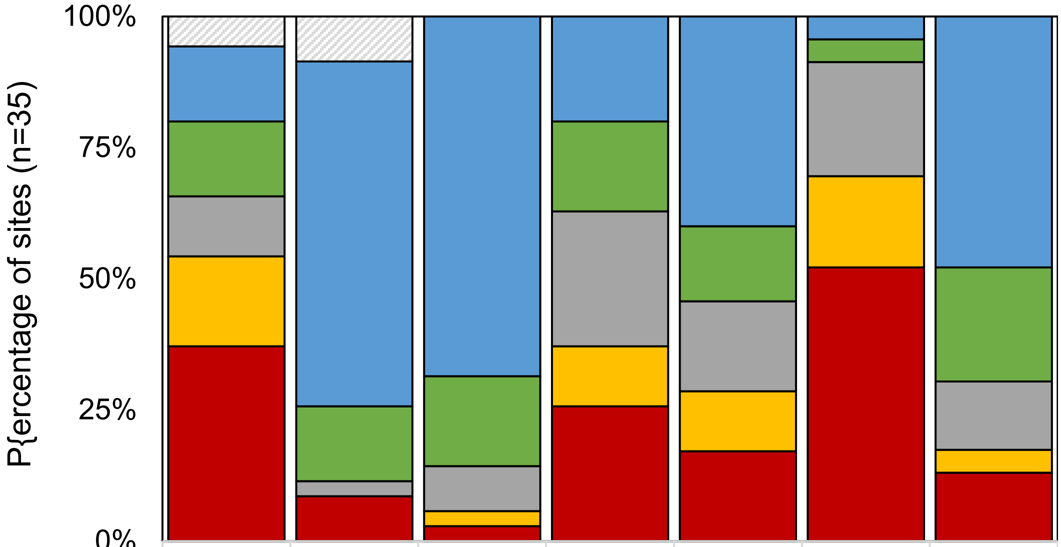
In the previous Auckland river water quality state and trend analysis, regional trend assessment was undertaken by pooling all data across sites and assessing the overall trend through this pooled data set (Buckthought and Neale, 2016). The value of this approach was questioned as large changes at one or two sites skewed the overall analysis (Buckthought and Neale, 2016). It was recommended that subsequent trend analysis should focus more on site-specific trends (Buckthought and Neale, 2016). The approach taken here aggregates individual site trends to obtain a regional picture of the proportion of trends that were improving or degrading which enables assessment of overall water quality changes that may be difficult to identify from only examining individual site trends (Snelder and Fraser, 2018). Where water quality trend is improving, we can assume that water quality is at least being maintained in the current state (McBride, 2019).

The NPS-FM national objectives framework (NOF) focuses on soluble, rather than total (soluble and particulate) forms of nutrients. Soluble forms are considered to be more bioavailable. There are different pathways that soluble and total forms follow from land to water and complex relationships and cycling between both forms. In most instances, trend directions at each monitored site were the same between soluble and total forms however there were differences in the likelihood or probability of those trends. Notable differences in trends between soluble and total forms are discussed further in sections 3.4.4, 3.4.5, and 3.4.8 below.

Across the region, over 80 per cent of monitored streams returned improving trends for the nutrients ammoniacal-N and dissolved reactive phosphorus, although more than 50 per cent returned degrading trends for total oxidised nitrogen (nitrate). Over 50 per cent of monitored streams were improving for the faecal indicator bacteria *E. coli.* There were roughly equal proportions of improving and degrading trends in suspended fine sediment (turbidity) and a higher proportion of indeterminate trends. Over 50 per cent of sites returned improving trends for dissolved zinc (Zn), and over 50 per cent had degrading trends for dissolved copper (Cu). However, application of higher detection limits for these metals from 2017 potentially influenced the trend assessment particularly where concentrations are currently low (A band) or where there is a high proportion of values below the detection limit.

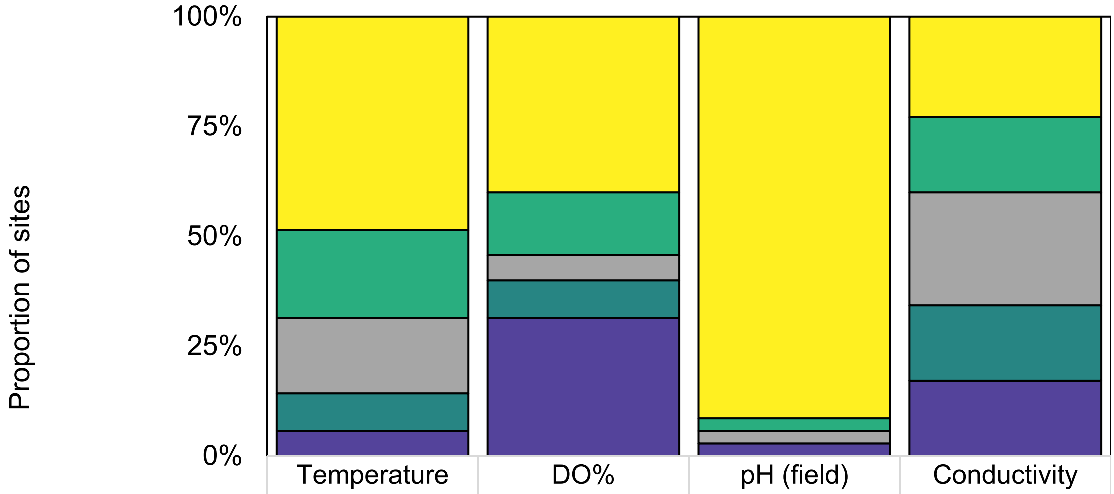
It is important to also consider the magnitude of these trends, or how rapidly, or slowly water quality has changed over the past 10 years. The magnitude can be estimated for 'very likely' trends, i.e. the trends we have most confidence in. Very likely trends in nitrate and ammoniacal N, *E. coli*, turbidity, and soluble metals, tended to be greater than the precision of our monitoring (i.e. the measurement resolution for each parameter), while very likely trends in dissolved reactive phosphorus tended to be less than the precision limit for that parameter.

Across the region, nearly 70 per cent of sites had increasing temperatures and more than 50 per cent had increasing dissolved oxygen saturation. Almost all sites returned increasing trends in pH. There were similar proportions of increasing to decreasing trends for conductivity, with a high proportion of indeterminate trends (Figure 3-6).



	Total oxidised nitrogen	Ammonia cal N	DRP	Turbidity	E.coli	Cu (n=23)	Zn (n=23)
NA	6%	9%					
Very likely improving	14%	66%	69%	20%	40%	4%	48%
Likely improving	14%	14%	17%	17%	14%	4%	22%
Indeterminate	11%	3%	9%	26%	17%	22%	13%
Likely degrading	17%	0%	3%	11%	11%	17%	4%
Very likely degrading	37%	9%	3%	26%	17%	52%	13%

Figure 3-5: Summary of the proportion of sites within each trend category across NPS-FM 2020 NOF and proposed Auckland specific water quality attributes.



	Temperature	DO%	pH (field)	Conductivity
	Physical			
Very likely increasing	49%	40%	91%	23%
Likely increasing	20%	14%	3%	17%
Indeterminate	17%	6%	3%	26%
Likely decreasing	9%	9%	0%	17%
Very likely decreasing	6%	31%	3%	17%

Figure 3-6: Auckland region summary of the proportion of sites within each trend category across physical water quality parameters.

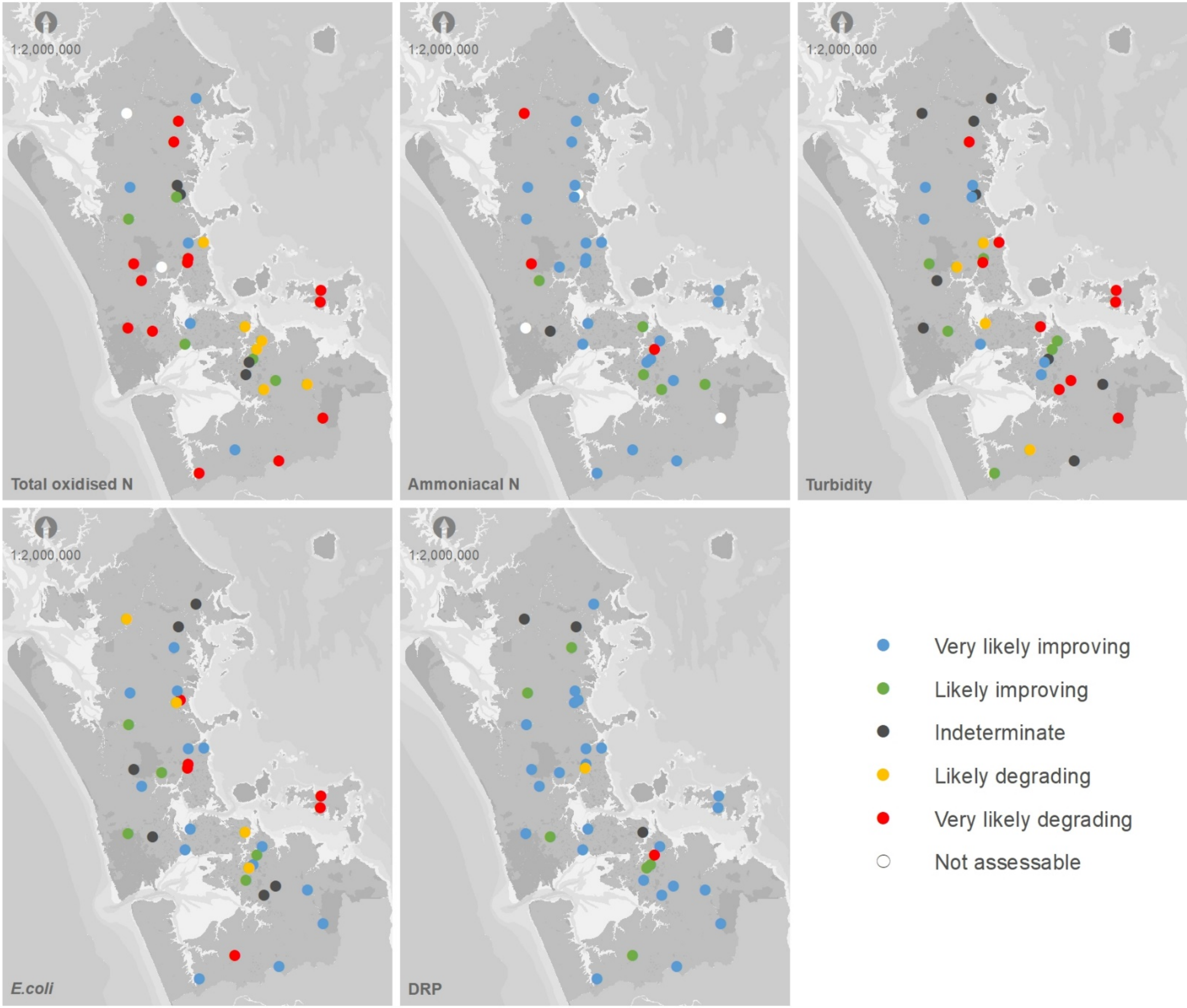


Figure 3-7: Auckland region summary maps of 10-year trends (2010-2019) in river water quality parameters per site.

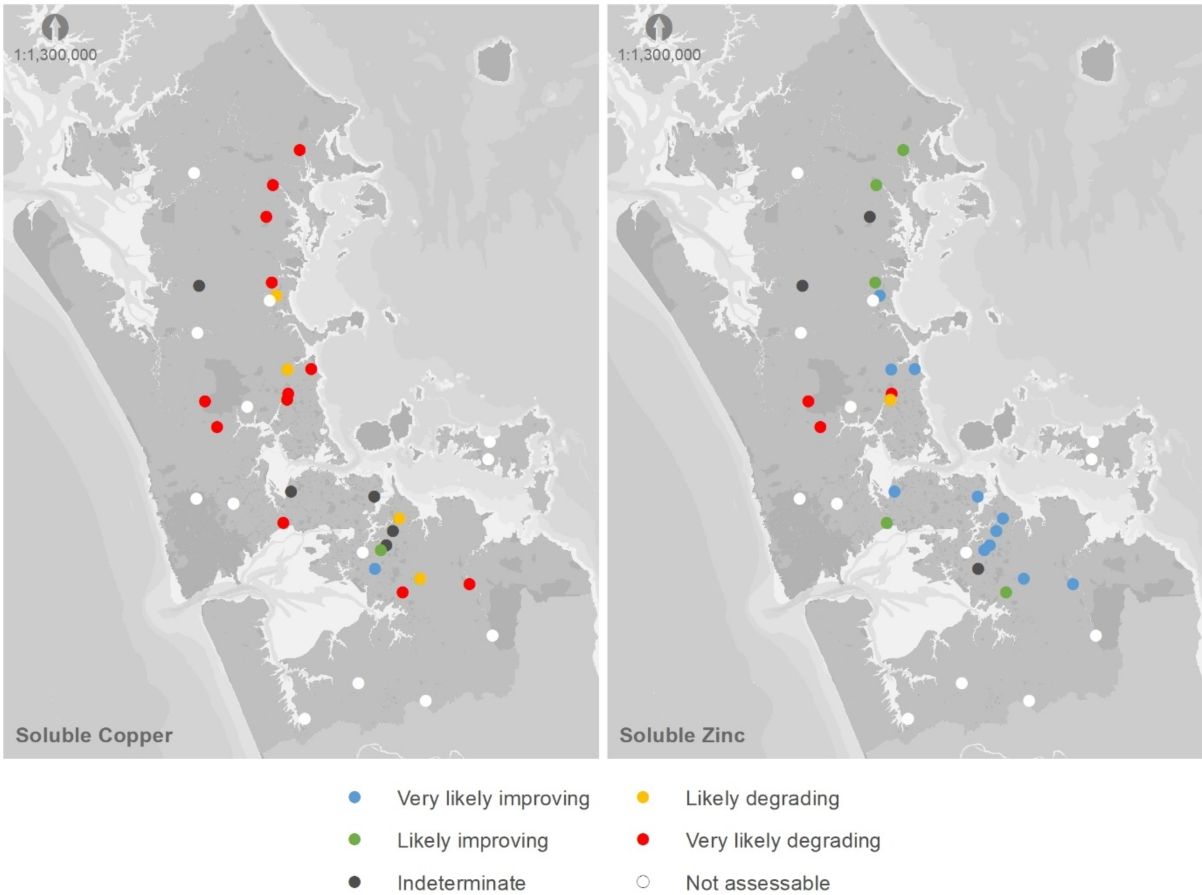


Figure 3-8: Auckland region summary maps of 10-year trends (2010-2019) in river water quality metal parameters per site.

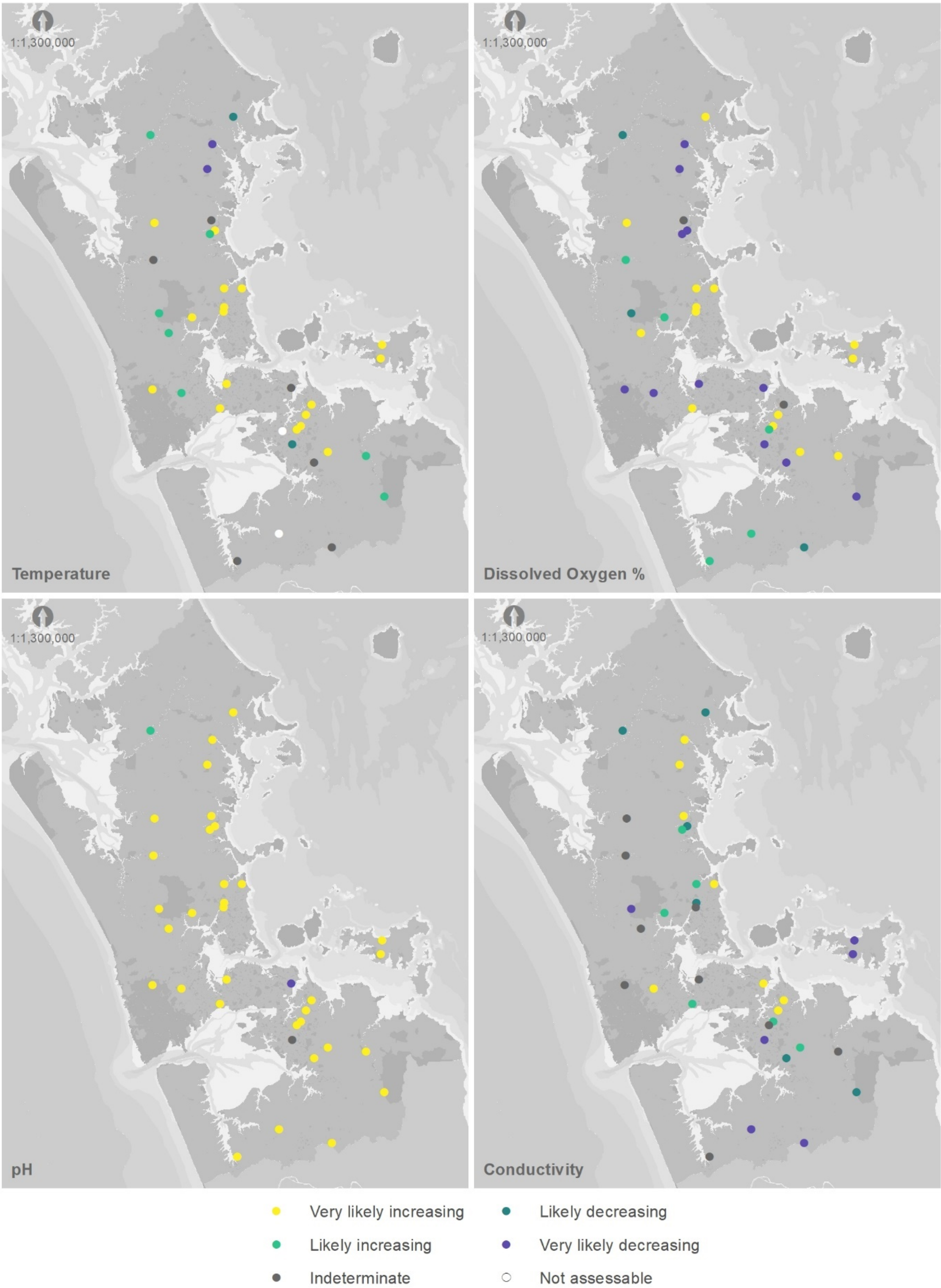


Figure 3-9: Auckland region summary maps of 10-year trends (2010-2019) in physical river water quality parameters per site.

3.4 Water quality trends relative to current state

Trends are typically presented aggregated by the water quality state for that parameter based on the relevant NOF band, or ANZ default guidelines (dissolved oxygen and pH), or regional reference values (temperature) within each dominant land cover class. Aggregated summaries are presented as the total number of sites, rather than the percentage within each band or grade.

The magnitude of change is presented for individual sites where there are **very likely** improving or degrading trends. Sites are also ordered by the relevant water quality state assessment, nested within each dominant land cover class. Because of differences in water quality state between different parameters, and differences in the likelihood of trends, sites are not necessarily displayed in the same order between different sections.

3.4.1 Temperature

Water temperature indirectly affects a range of other water quality parameters such as dissolved oxygen, or the toxicity of ammonia. High water temperatures can also cause direct stress to aquatic fauna, and rapid changes in temperature can cause lethal effects. River water temperature is highly correlated with air temperature but is not 1:1 or linear in all streams (Young et al., 2013; Foley and Carbines, 2019). Lack of overarching stream shading, and stormwater runoff from impervious services can also increase stream temperatures (Young et al., 2013). Smaller, shallow streams tend to be more vulnerable to changes in temperature than larger streams/rivers. River water temperatures are projected to increase because of increases in air temperature predicted under all climate change scenarios for the Auckland region particularly in urban and poorly shaded streams (Foley and Carbines, 2019; Pearce et al., 2020).

The national objectives framework does not currently include guidelines for river temperatures. The Auckland regional river water quality index guidelines are referred to here to provide an indication of the current state of thermal stress in our monitored streams.

The temperatures in forested, reference streams are typically below 17.65 ^{o}C (Buckthought et al., 2020). Temperatures instream are expected to be higher than this reference value at poorly shaded rural and urban streams over the summer months (December to March). Analysis against the regional water quality index showed that, within 2017-2019, temperatures were elevated more than seasonally for most urban streams (moderate frequency of values higher than 17.65 ^{o}C) and elevated for most of the year (high frequency of values higher than 17.65 ^{o}C) at urban, and heavily modified concrete lined streams at Otara Creek (south), Pakuranga Creek, and Botany Creek (Ingley and Groom, 2021) (Figure 3-10).

The trend direction for river water temperature was influenced by a change in monitoring programme logistics in 2016 for nine sites that resulted in the timing of sampling changing by more than three hours. This difference in diurnal instream temperature regime sampled is expected to be greater than long-term climatic or catchment management influences on temperature. All sites that were sampled more than three hours earlier in the day had decreasing trends while almost all sites that were sampled more than three hours later in the day had increasing trends (Figure 3-10 (b)).

The majority of monitored sites, not subject to major diurnal changes (<2 hours difference), had likely to very likely increasing trends in surface water temperatures over the past 10 years, including all four reference stream sites (Figure 3-10 (a)). Streams in predominantly rural catchments had a higher proportion of indeterminate trends. Avondale Stream was cooler than most other urban streams (only occasionally warmer than reference temperatures), but this site also had very likely increasing temperatures.

Only two sites, not subject to major sampling time changes, had likely decreasing trends in stream temperature; Puhinui Stream (urban) and Whangamaire Stream (rural).

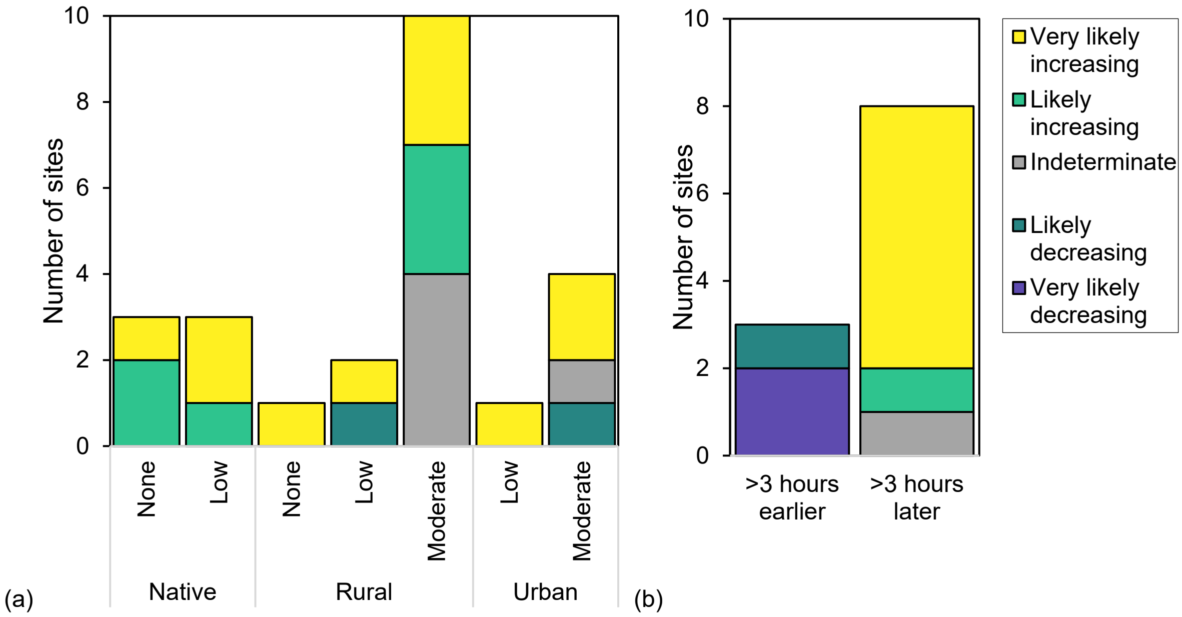


Figure 3-10: Summary of 10-year (2010-2019) trends in river temperature at each site.

(a) Not subject to timing changes in monitoring. Sites are ordered by dominant land cover, and temperature state as assessed against the frequency of temperatures >17.65 °C (None, Low, Moderate) (2017-2019) (Ingley and Groom, 2021).

(b) Subject to changes in timing of site monitoring (> 3 hr either side of original time).

3.4.1.1 Magnitude of trends in river temperature

The estimated magnitude of increase in temperatures was similar across all urban, rural, and native forested sites with very likely trends where the time of sampling was consistent (<2 hours difference) (Figure 3-11). This suggests that the change is likely climatic rather than driven by changes in point source discharges, stormwater inputs, or riparian, or catchment vegetation and shading.

The percentage of urban land cover in the catchment contributing to Vaughan Stream doubled over the 10-year period assessed (see section 3.1). It was very likely that temperatures were increasing at this site, however the rate of change was comparable with native forested and other rural sites, with no clear indication of increased stream water temperature from the increasing urban footprint within the catchment.

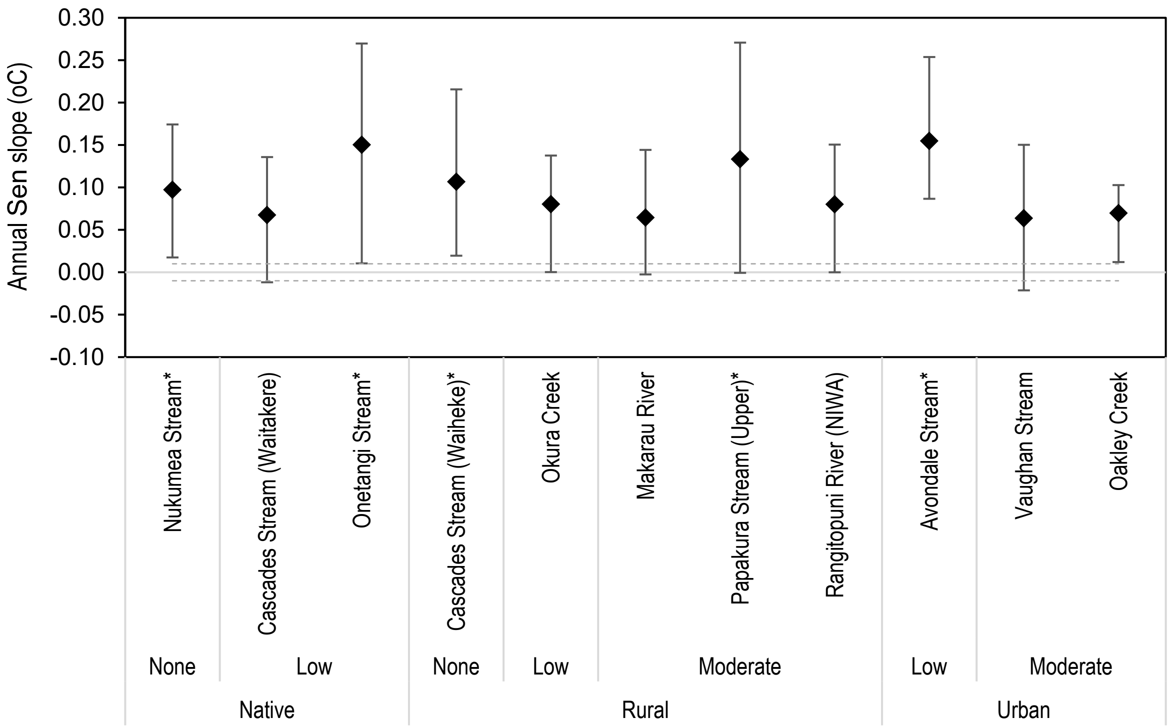


Figure 3-11: Magnitude of annual change for 'very likely' trends in temperature at each site not subject to changes in monitoring time. Sites are ordered by dominant land cover and temperature state as frequency of temperatures >17.65 °C (2017-2019).
Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
* Shorter time period available for trend analysis.

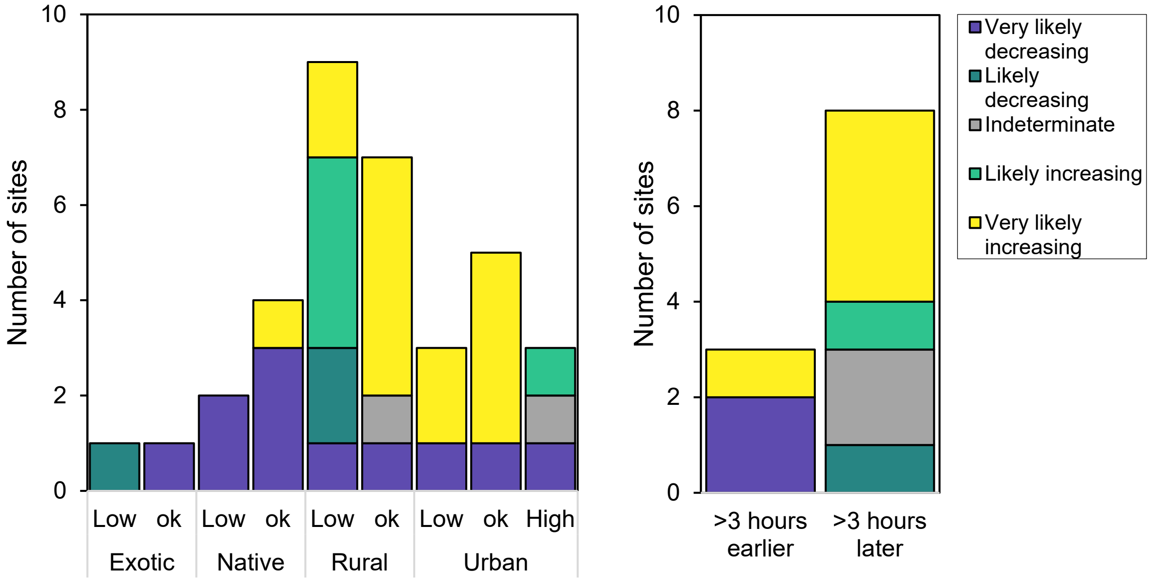
3.4.2 Dissolved oxygen

Dissolved oxygen is a fundamental aspect of the life-supporting capacity of water. Low dissolved oxygen or hypoxia can have adverse effects on aquatic fauna from reduced growth rates, to death in anoxic conditions (Davies-Colley et al., 2013). Dissolved oxygen varies seasonally and over the course of the day (diurnally) as plants and algae release oxygen into the water during the day via photosynthesis and consume it at night (Davies-Colley et al., 2013. The lowest levels of oxygen saturation therefore typically occur in the early morning before dawn, and maximum levels later in the afternoon. Where very high dissolved oxygen saturation occurs in the day closer to the diurnal maxima, this can indicate low concentrations may occur overnight where this is driven by abundant macrophytes or algae. Water temperature, organic matter, and physical turbulence also affect the saturation of dissolved oxygen.

Median dissolved oxygen saturation across 2015-2019 was lower, or higher than ANZ guidelines for 51 per cent of monitored sites (Figure 3-12). Despite the limitations of monthly sampling, this suggests that hypoxic conditions are likely to be common across the region. Further analysis of the frequency of low, or high dissolved oxygen levels relative to regional water quality index guidelines has suggested that at least three urban (Omaru Stream, Otara Creek (South), Botany Creek), and four rural monitored streams (Papakura Stream, Rangitopuni River, Riverhead Stream, Kaukapakapa River) frequently experience hypoxic conditions (Buckthought et al., 2020; Ingley and Groom 2021).

As outlined in section 3.4.1, a change in the timing of monitoring occurred in 2016 for some sites. The majority of sites with catchments in native forest, not subject to changes in monitoring time, had very likely decreasing trends in dissolved oxygen, including all four reference sites, whist the majority of rural sites had very likely increasing trends in dissolved oxygen (Figure 3-12 (a)). At urban sites, not subject to major timing changes, dissolved oxygen levels were typically improving, with decreasing trends where oxygen was supersaturated (high DO) and increasing where DO was low (Figure 3-12 (a)).

As expected, most sites that were sampled more than three hours earlier in the day had decreasing trends while almost all sites, particularly in urban areas, that were sampled more than three hours later in the day had increasing trends (Figure 3-12 (b)). One site (Riverhead Stream) had low median dissolved oxygen saturation and likely decreasing trends despite sampling later in the day (Figure 3-12 (b)). The upstream catchment is dominated by exotic forestry that was primarily in a growth phase over the 10-year period, it is possible that increased or high shading may have limited algal or macrophyte growth or increased organic matter inputs may have increased instream oxygen consumption.



(a) (b)

Figure 3-12: Summary of 10-year (2010-2019) trends in dissolved oxygen (%) at each site: Sites are ordered by dominant land cover, and dissolved oxygen state based on exceedances of ANZ lower (low), neither guideline exceeded (ok), and upper (high) guidelines (2015-2019).

(a) Not subject to timing changes in monitoring.
(b) Subject to diurnal changes in monitoring.

3.4.2.1 Magnitude of trends in dissolved oxygen saturation

The estimated rate of change in dissolved oxygen saturation was greater than the limit of measurement precision for this parameter (>0.01%) across all sites with very likely trends.

Sites with predominantly native forested catchments exhibited a small rate of change less than 0.3% saturation per annum except at Onetangi Stream on Waiheke Island which was very likely increasing at an estimated rate of 2.2 per cent saturation per annum (Figure 3-13).

The estimated rate of change across rural sites, that were not subject to diurnal changes in monitoring, was between 0.3 to 0.65 per cent saturation per annum except at upper Papakura Stream site which was very likely increasing at an estimated rate of 1.32 per cent saturation per annum (Figure 3-13, Appendix C). The water quality index analysis indicated that this stream is currently frequently subjected to hypoxic conditions (Ingley and Groom, 2021), however increasing oxygen saturation through time suggests a considerable improvement at this site.

As noted above, Omaru Creek frequently experiences hypoxic conditions (Ingley and Groom, 2021) and oxygen saturation has been decreasing over the past 10 years at an estimated rate of 1.2 per cent saturation per annum (Figure 3-13, Appendix C).

Pollution incidents, and wet weather wastewater overflows are known to occur in this stream and projects are currently underway targeting the reduction of contaminants at Omaru Creek.

Median oxygen saturation was below ANZ guidelines at Vaughan Stream but DO saturation has increased over the past 10 years at an estimated rate of 1.9% saturation per annum (Figure 3-13, Appendix C). It is possible that high abundances of instream macrophytes at Vaughan Stream are increasing diurnal oxygen levels.

Puhinui Stream currently experiences high dissolved oxygen levels during the day and therefore decreasing dissolved oxygen saturation over time likely represents an improvement at this site relative to the upper guideline value (Figure 3-13, Appendix C).

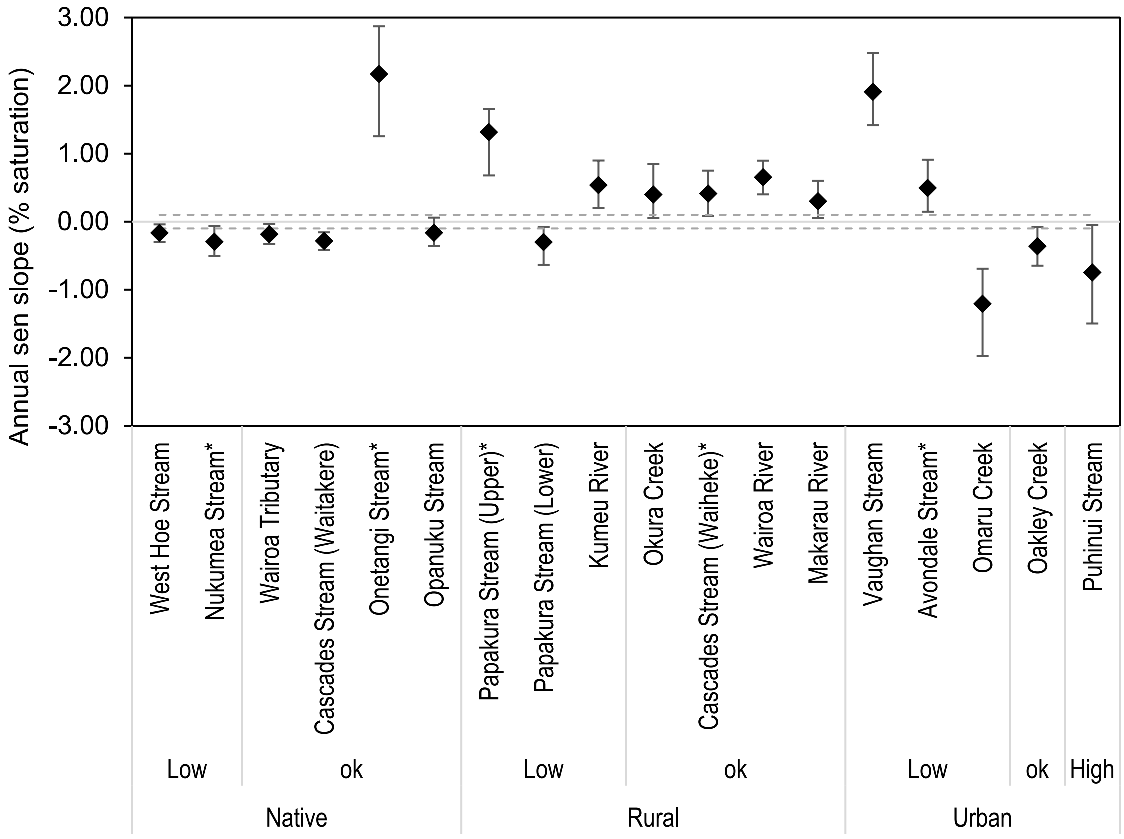


Figure 3-13: Magnitude of 'very likely' trends in dissolved oxygen (%) at each site not subject to diurnal changes in monitoring. Sites are ordered by dominant land cover and state as exceedances of ANZ DO lower and upper guidelines (2015-2019).
Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
* Shorter time period available for trend analysis.

3.4.3 pH

pH is a measure of how acidic or alkaline the river water is. River waters are usually slightly alkaline (Davies-Colley et al., 2013). pH also varies over daily cycles, particularly where there is abundant instream vegetation or algae, and is typically highest in the afternoon (Davies-Colley et al., 2013). High, or low pH can have adverse effects on the growth or survival of aquatic animals, and it is also an important modifier of other water quality parameters. The overall toxicity of ammoniacal N increases with higher pH. The national objectives framework does not currently include guidelines for river pH. The ANZ upper and lower guidelines are referred to here to provide an indication of the current state of pH at our monitored sites.

Median pH levels over 2015-2019 are within the ANZ guidelines at the majority of monitored streams, however 43% of monitored sites, including two reference sites, had median pH levels lower the ANZ guidelines which suggests that these guidelines may not be entirely appropriate for the Auckland region. Median pH is higher than the ANZ guideline at one urban stream and further analysis against regional water quality index guidelines suggests that pH levels are elevated at several other urban streams particularly within the Tāmaki watershed (Ingley and Groom, 2021).

Over 90% of monitored sites had very likely increasing trends in pH. The change in sampling time discussed above, does not appear to have influenced the trend direction despite expected diurnal variation (Figure 3-14).

Given the strong consistency in trend direction across the region, the three sites that did not follow the same pattern are notable. Omaru Creek was the only site that was very likely decreasing (Figure 3-14, Figure 3-9). Whangamaire Stream was likely increasing, and there was no clear trend direction (indeterminate) at Puhinui Stream (Figure 3-14).

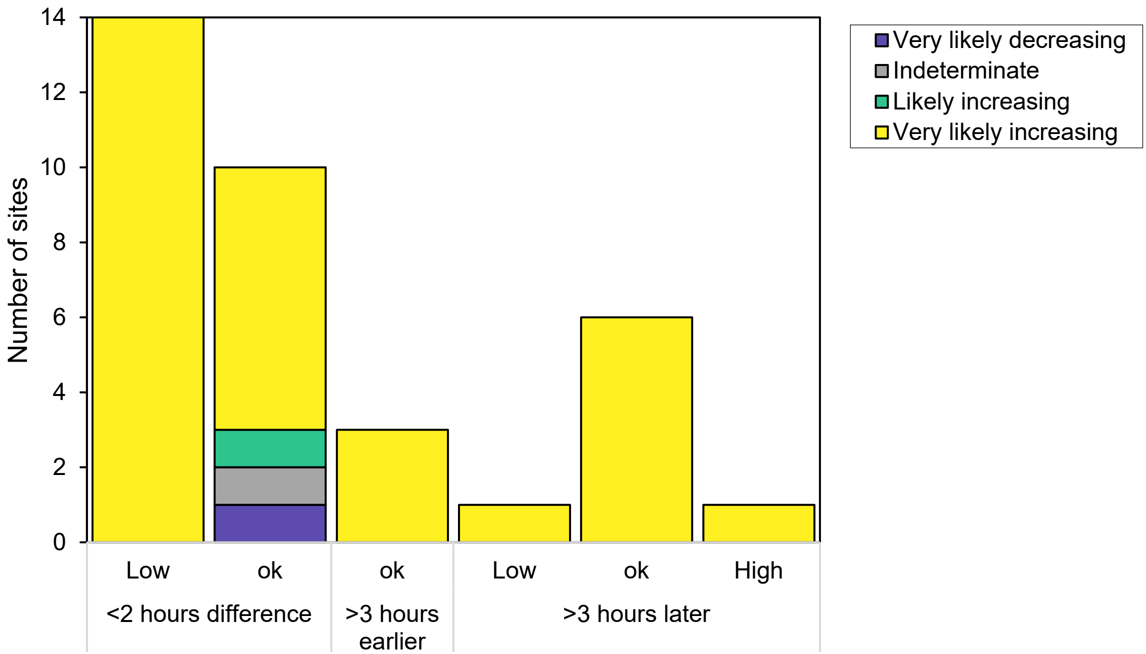


Figure 3-14: Summary of 10-year (2010-2019) trends in pH at each site ordered by monitoring timing changes, and exceedances of ANZ pH upper (High) neither guideline exceeded (ok) and lower (Low) guidelines.

3.4.3.1 Magnitude of trends in pH

The estimated rate of change in pH was greater than the limit of measurement precision for this parameter (>0.01) across all sites with very likely trends.

The estimated rate of increase across all streams with catchments dominated by native forest or rural land use was ≤0.06 per annum and this magnitude of change may therefore be associated with natural or climatic variation, or improvements in equipment accuracy and calibration over time.

The greatest magnitude of increase in pH was at Otara Creek and Vaughan Stream. Both Otara Creek (East) and (South) increased at an estimated rate of ≥0.1 pH units per annum over the past 10 years (Figure 3-15, Appendix C). Vaughan Stream had the next greatest increase with an estimated rate of change of 0.08 pH units per annum (Figure 3-15, Appendix C). Increasing alkalinity of these urban streams may increase the overall toxicity of ammoniacal N over time.

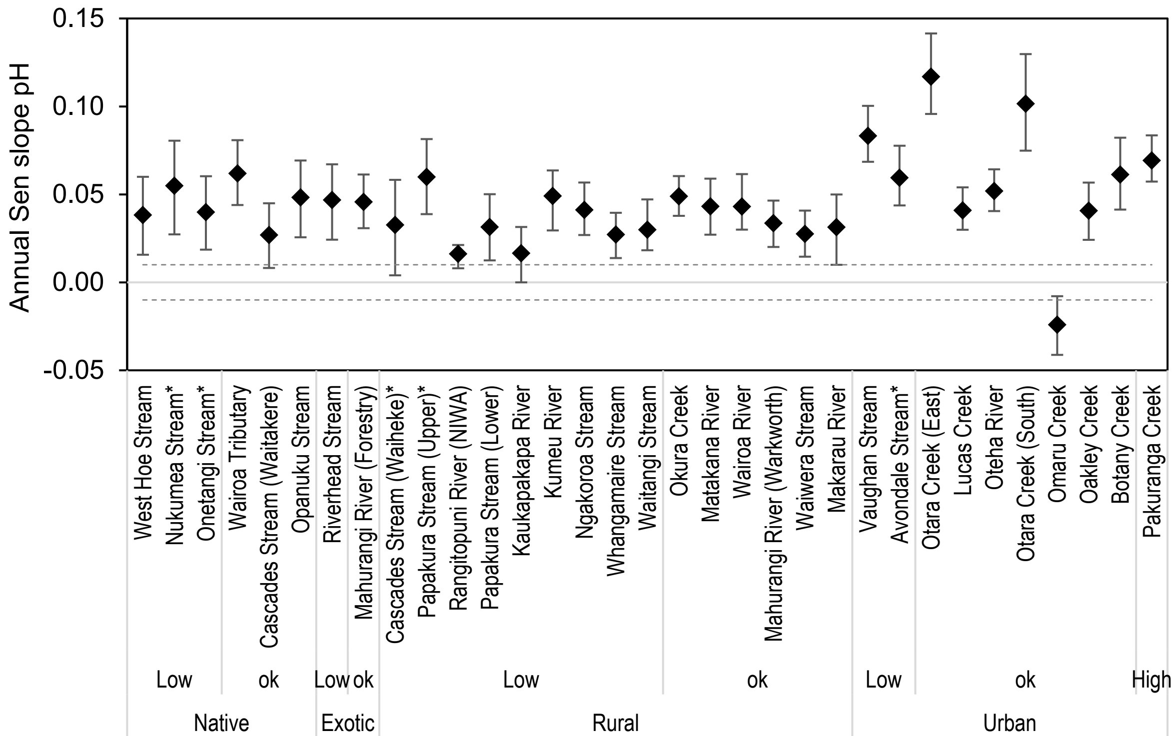


Figure 3-15: Magnitude of 'very likely' trends in pH at each site ordered by dominant land cover, and exceedances of ANZ pH guidelines.

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)

* Shorter time period available for trend analysis.

3.4.4 Nitrogen

Nitrogen is a key nutrient that contributes to the growth of aquatic plants and algae. However, high concentrations of nutrients can cause excessive plant growth that can lead to low dissolved oxygen levels and have adverse effects on aquatic faunal communities. Two forms of nitrogen, ammonia and nitrate, can also be toxic to sensitive aquatic animals (fish). Effects of nutrient enrichment (eutrophication) on instream organisms can occur at nitrogen levels far lower than those that cause toxicity effects. The NOF nitrate toxicity assessment is reported here using the proxy total oxidised nitrogen (nitrate + nitrite nitrogen).

The majority of monitored streams across the region have nitrate and ammonia levels that are above the national bottom line and 95 per cent of species would be protected from chronic toxicity effects. However over 60 per cent of monitored sites had likely to very likely degrading trends in nitrate (total oxidised nitrogen (nitrate+nitrite)) while, over 70 per cent of monitored sites had likely to very likely improving trends in ammoniacal nitrogen. The dominant transport pathway for organic and ammoniacal N is via overland flow and benthic sediment associated N. The dominant transport pathway for total oxidised N (consisting mainly of nitrate-N) in streams is via leaching through slow sub surface or groundwater flow processes (McDowell et al., 2009). For both nitrate and ammonia, the national bottom line is below band B. In band C, the survival of sensitive fish species is at risk, and in band D, concentrations are approaching acute impact levels. Several sites that are currently below the national bottom line for either nitrate or ammonia, were very likely degrading over the past 10 years (Figure 3-16). However the most impacted sites, in band D, were likely to very likely improving over the past 10 years (Figure 3-16).

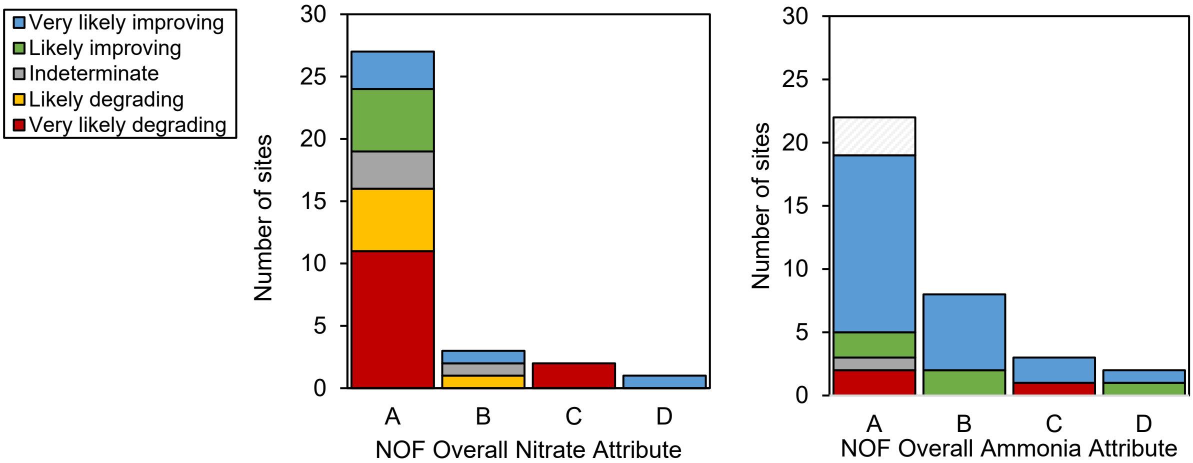


Figure 3-16: Summary of 10-year trends (2010-2019) within each NPS-FM NOF attribute band for nitrate and ammonia toxicity (2015-2019).

3.4.4.1 Magnitude of trends in nitrate and ammonia

The estimated rate of change in total oxidised nitrogen was typically greater than the limit of measurement precision for this parameter (>0.001 mg/L per annum).

Sites that are currently in band A for nitrate toxicity across all dominant land cover types had a low estimated rate of change of approximately <0.01 mg/L per annum. This is equivalent to one per cent of the difference between the A/B to B/C band thresholds for the median attribute metric. Three sites in band A were an exception to this pattern, Onetangi Stream, Cascades Stream (Waiheke Island) and Mahurangi River (Forestry). These sites were very likely degrading at an estimated rate of 0.02±0.004 mg/L over the past 10 years (Figure 3-17(a), Appendix C).

The greatest rate of change was at the four sites (with very likely trends) that were in bands B, C and D (Figure 3-17(b)). Oakley Creek (band B) was very likely improving at an estimated rate of 0.037±0.025 mg/L per annum. All three sites in the Franklin nitrate area are below the national bottom line (bands C and D). Both sites currently in band C were very likely degrading, most notably at Waitangi Stream, at an estimated rate of 0.068mg/L per annum (+0.031, -0.033). The greatest rate of change overall was at Whangamaire Stream (band D) which was very likely improving at an estimated rate of 0.177 mg/L per annum but with a very wide range of variability in the rate of change (confidence intervals of +0.127,-0.107 mg/L per annum) (Figure 3-17, Appendix C). Median concentrations of nitrate at this site are more than five times the national bottom line and despite these indications of improvement, meaningful change in water quality is likely to take several decades. These Franklin stream sites receive baseflow from volcanic aquifers, with Ngakoroa Stream baseflow sourced from the Bombay volcanic aquifer, Whangamaire Stream from the Pukekohe volcanic aquifer, and Waitangi Stream from the Glenbrook volcanic aquifer. Two of these volcanic aquifers, Bombay and Pukekohe, are monitored for groundwater quality. Trends in groundwater nitrate concentrations were consistent with the patterns observed for both Ngakoroa Stream and Whangamaire Stream, with very likely degrading trends observed in the Bombay Volcanic aquifer, and very likely improving nitrate concentrations in the Pukekohe Central Volcanic aquifer across the same 10-year period (Table 5-1 within Foster and Johnson 2021).

The overall pattern, and magnitude of trends, was very similar between total oxidised N and Total N. Trends in Total N were typically in the same direction as for total oxidised N but with lower confidence i.e. likely instead of very likely. Ngakoroa Stream in Franklin presented the most notable exception to this pattern. Total oxidised nitrogen was very likely improving at this site however total nitrogen was very likely degrading. Several inconsistencies in trends between these two parameters had been noted in previous regional trend analysis however, this was previously attributed to the different time periods assessed for these two parameters (Buckthought and Neale, 2016).

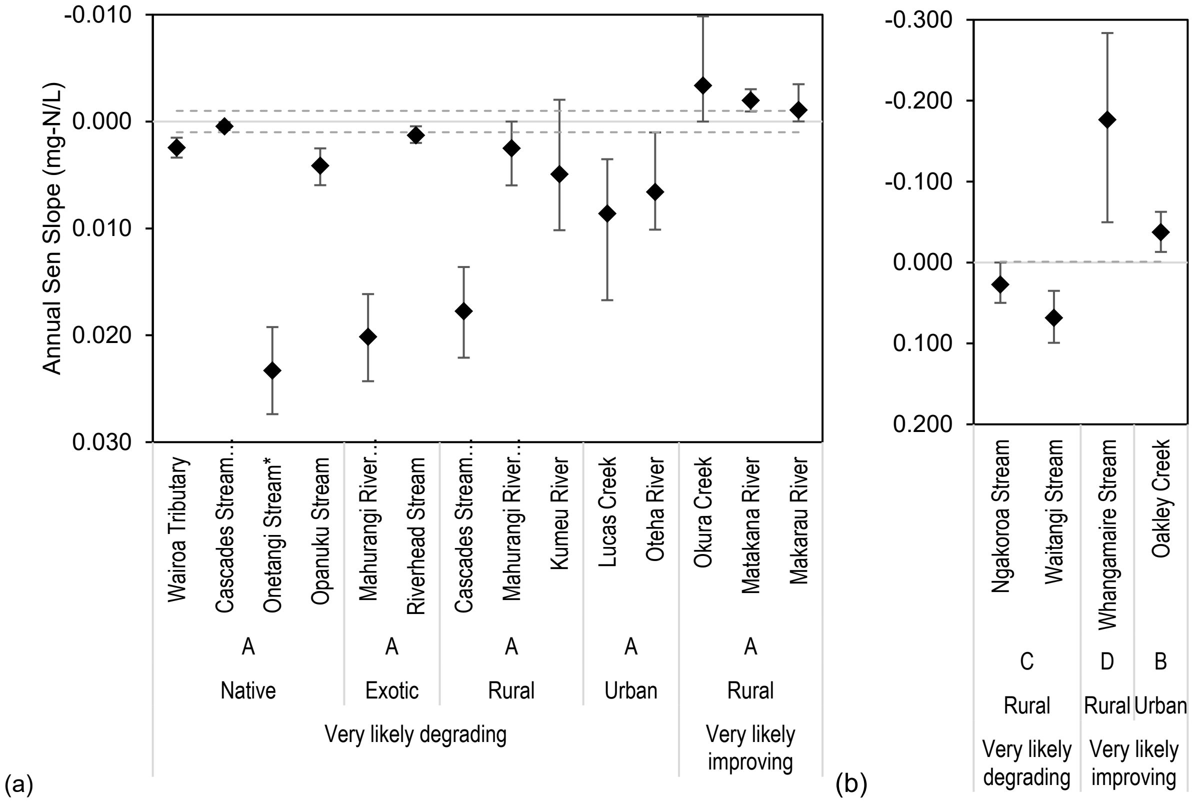


Figure 3-17: Magnitude of 'very likely' trends in total oxidised N at each site ordered by dominant land cover and overall NOF nitrate toxicity band (2015-2019).

(a) NOF Band A only (note different Y axis).

(b) NOF Bands B, C, and D (note different Y axis).

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)

* Shorter time period available for trend analysis.

The estimated rate of change, either improving or degrading, in ammoniacal N at sites was less than or equal to the measurement precision limit for this parameter across all sites in band A with predominantly native forest, exotic forestry, or rural catchments, except for Riverhead Stream, and Onetangi Stream (Figure 3-18). The measurement precision limit (0.001mg/L) is equivalent to three per cent of the threshold between bands A and B for the median attribute at pH 8.0.

The estimated annual rate of improvement across urban sites, below the national bottom line (bands C and D) was <0.002mg/L per annum. This is equivalent to less than one per cent of the B/C, or C/D threshold which suggests that water quality in relation to ammonia toxicity is at least being maintained at the current level across most of the region although this does not necessarily account for occasional discharges were maximum concentrations differ from the median state.

The estimated annual rate of degradation in ammoniacal N at Pakuranga Creek, an urban stream in the Tāmaki watershed, was an order of magnitude greater than all other trends (Figure 3-18 – inset). This site is below the national bottom line (band C) across both the median and maximum concentration metrics, where the survival of sensitive species is assumed to be at risk. The rate of degradation in ammoniacal N concentrations at this site was estimated at 0.016 ±0.01mg/L/annum (Figure 3-18, Appendix C). This is equivalent to approximately one to two per cent of the difference between the B/C and C/D thresholds for the median attribute. However, coupled with high, and increasing trends in pH (see section 3.4.3), the overall toxicity of ammonia may further increase over time at this stream site.

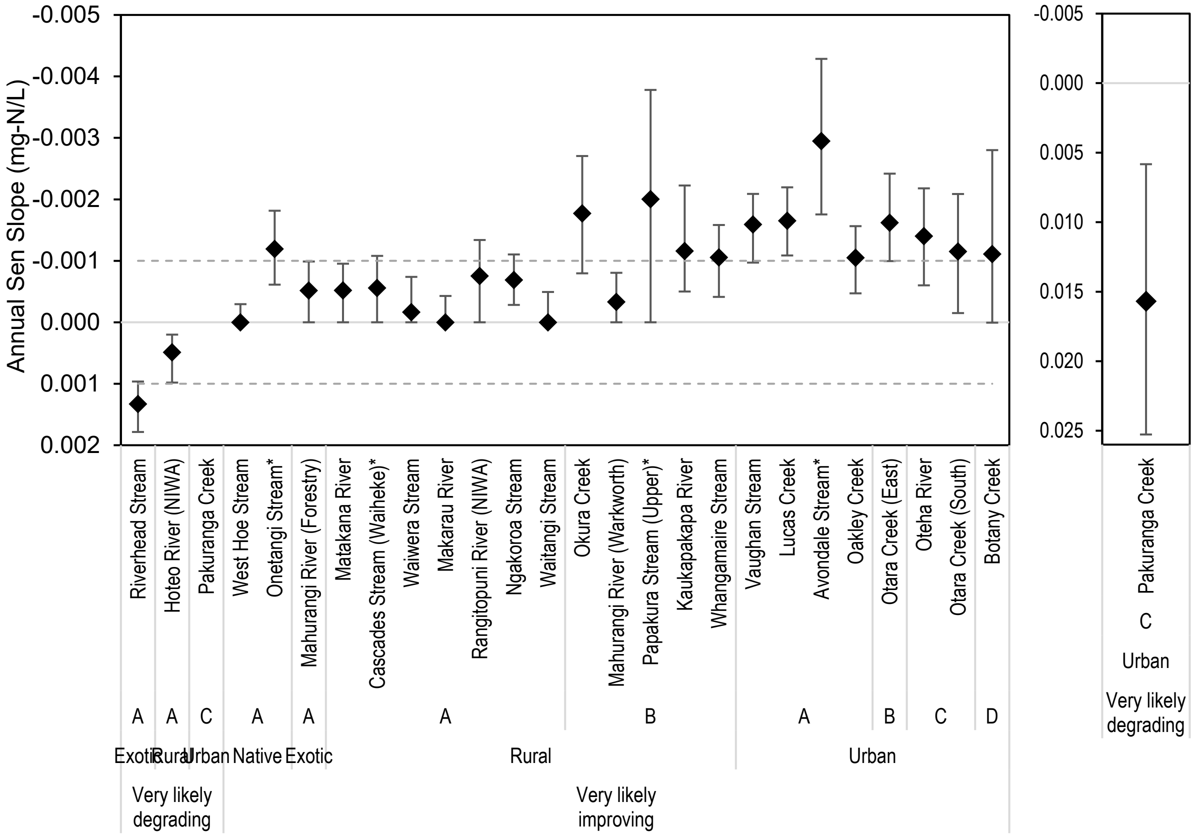


Figure 3-18: Magnitude of 'very likely' trends in ammoniacal N at each site ordered by dominant land cover and overall NPS-FM NOF ammonia toxicity band (2015-2019).

Note different Y axis for Pakuranga Creek.

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
* Shorter time period available for trend analysis.

3.4.5 Phosphorus

Phosphorus is a key nutrient that can stimulate the growth of algae and plants in streams. Excessive plant growth can lead to low dissolved oxygen levels and have adverse effects on communities of aquatic fauna (McDowell et al., 2019). Unlike several forms of nitrogen, phosphorus does not cause toxicity effects in rivers and streams.

Phosphorus is found in water in both dissolved, and particulate forms. Total P is a measure of both of these forms while dissolved reactive P (DRP) reflects the portion that is immediately available for uptake and growth by plants (McDowell et al., 2019). The dominant transport pathways for P losses to surface waters are via overland runoff or shallow sub surface flows (McDowell, et al., 2009). Particulate associated P can also be associated with erosion and trends in Total P may be associated with trends in total suspended solids (McDowell et al., 2019).

The current state of DRP for the four streams with the highest percentage of native forest cover within the upstream catchment ranged from band B (Nukumea Stream and West Hoe Stream) to band D (Wairoa tributary); which suggests that some streams in Auckland may have naturally high dissolved reactive phosphorus levels. This has been found to be the case for some North Island streams with underlying tertiary mudstone and volcanic ash geology (Whitehead, 2018). While these four sites are not associated with these specified parent geology types, further consideration should be given to sources of natural variability in phosphorus concentrations. Conversely, ongoing soil monitoring within Auckland has illustrated that most horticultural and pastoral sites, and some urban parks, have high Olsen P values suggesting that an excess of P fertiliser is being applied, and that there is a risk of this excess P being lost in surface runoff or to groundwater (Curran-Cournane, 2020).

Almost all the monitored sites across Auckland showed very likely improving trends in dissolved reactive phosphorus (Figure 3-19). Within the 10-year trend assessment period presented here, there was a change in methodology between different automated versions of the ascorbic acid method for dissolved reactive phosphorus, to flow injection analysis (which is the preferred method prescribed by the discrete water quality monitoring national standards (NEMS)). Inspection of the data sets either side of this method change suggested an abrupt change in trend direction. Other regional councils have identified similar issues in relation to changes in phosphorus analysis (Vant, 2018).

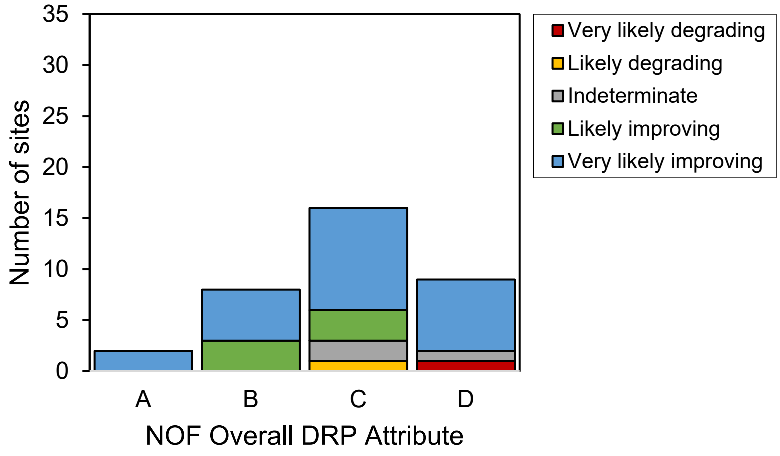
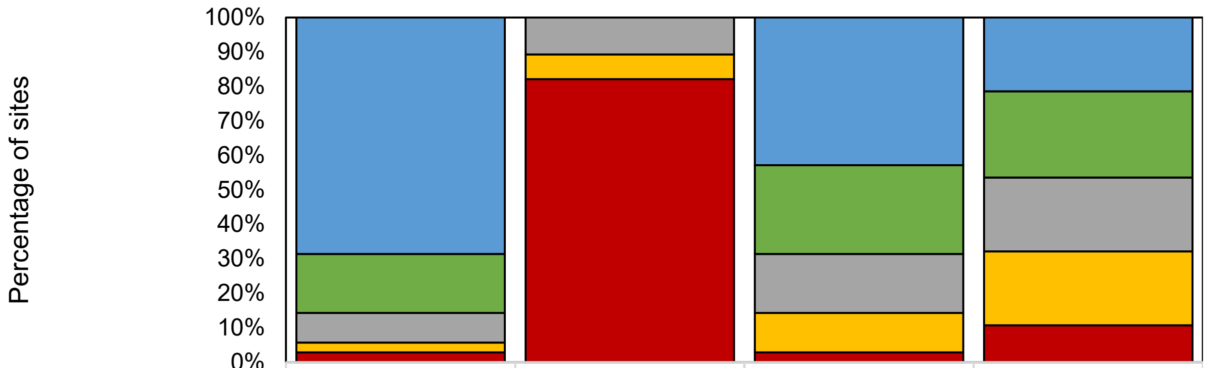


Figure 3-19: Summary of 10-year trends (2010-2019) within each NPS-FM NOF attribute band for dissolved reactive phosphorus (2015-2019).

To further consider the influence of this method change on trend analyses, the data set was partitioned to 2010-2016 and compared to the full time period in Figure 3-20. Only two stream sites showed a consistent pattern in trend direction in DRP across both time periods: Oteha River, and Pakuranga Creek (see Appendix C). Both streams were found to be likely to very likely degrading and were in NOF bands C and D respectively, indicating moderate to high enrichment of DRP. The consistency in trend direction at these two sites suggests DRP was increasing at a rate greater than the analytical variability observed among other monitored streams.

Despite these differences in trend direction between time periods, the full 10-year trend period for dissolved reactive phosphorus is generally consistent with patterns showing a higher proportion of improving trends in total phosphorus (Figure 3-20). National analyses have also demonstrated improving trends in phosphorus across the country (Larned et al., 2018; Gadd et al., 2020; McDowell et al., 2019). The most probable causes of improvement nationally were suggested to be regulatory and management strategies aimed at mitigating the loss of phosphorus from soils although a direct link to Olsen P values was discounted due to regionally and nationally increasing trends in Olsen P values (McDowell et al., 2019). Further analysis of soil quality in the Auckland region was recently undertaken. Within Auckland, differences in mean Olsen P levels over the five-year periods of 2008 to 2012 and 2013 to 2017 suggested that while Olsen P values increased in horticultural areas, they have generally decreased across pastoral and exotic forestry land uses (Curran-Cournane, 2020). Collectively, this suggests that stream dissolved reactive phosphorus concentrations may be improving across the region, or at least being maintained at the current state however, the magnitude or rate of change cannot be estimated due to the change in methodology.



	2010-2019 DRP (n=35)	2010-2016 DRP (n=28)	2010-2019 Total P (n=35)	2010-2016 Total P (n=28)
Very likely improving	69%	0%	43%	21%
Likely improving	17%	0%	26%	25%
Indeterminant	9%	11%	17%	21%
Likely degrading	3%	7%	11%	21%
Very likely degrading	3%	82%	3%	11%

Figure 3-20: Summary of 10-year, and partitioned seven-year trends in DRP and Total P accounting for identified differences in analytical methodology.

3.4.6 Suspended sediment (turbidity)

Turbidity is a measure of how light is scattered by particles suspended in water and provides an estimate of visual clarity. Measured values of turbidity were converted to visual clarity as outlined in section 2.2. A degrading trend means that turbidity is increasing, and water clarity is decreasing. High concentrations of particles in the water reduce water clarity, which can impact visual predation and other behaviours, damage respiratory and feeding structures in fish and macroinvertebrates, and where sediments are deposited this can also affect habitat quality and diversity (Davies-Colley et al., 2015).

Over the 10-year period investigated there was approximately the same proportion of improving to degrading trends across the region and a higher proportion of indeterminate trends (Figure 3-21).

Nearly 30 per cent of monitored stream sites were graded as band C for visual clarity suggesting moderate to high impacts of suspended sediment on aquatic fauna. The majority of these streams in band C were very likely degrading (Figure 3-21). This included both sites on Waiheke Island, Vaughan Stream, Mahurangi River (Forestry), Oteha River, and Papakura Stream (Upper). Whilst Papakura Stream (Lower) is in band A, this site was also very likely degrading, consistent with the upstream site. The only site that was in band C that was very likely improving, was Avondale Stream.

The only site that was below the national bottom line for visual clarity (D band) was Okura Creek and this stream also returned a likely degrading trend for turbidity over time.

All four reference sites were graded as band B for visual clarity, whilst most sites in band A were larger streams (3rd order or larger) in rural or urban catchments. It is possible that turbidity is elevated in steep, shallow headwater streams relative to the higher order larger streams where settlement of sediment may be promoted under the baseflow conditions typically monitored. Two of these reference sites returned indeterminate trends whilst West Hoe Stream was very likely improving, and Wairoa Tributary was very likely degrading.

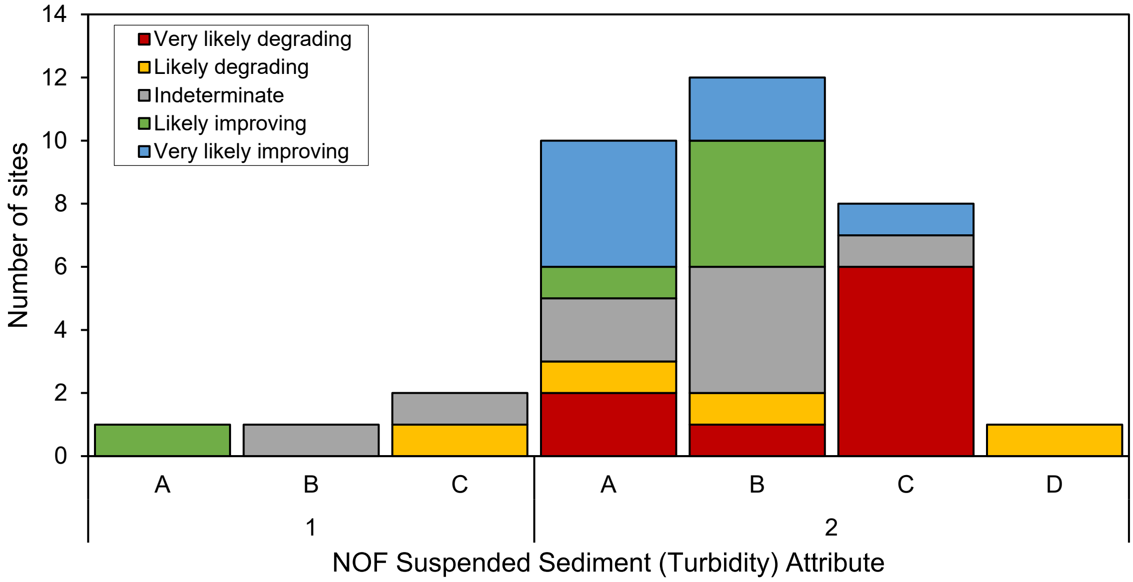


Figure 3-21: Auckland region summary of 10-year trends (2010-2019) within each NOF attribute band by suspended sediment class (1 or 2) (2015-2019).

3.4.6.1 Magnitude of trends in suspended sediment (turbidity/visual clarity)

The estimated rate of change in turbidity was typically greater than the limit of precision for this parameter (>0.1 NTU per annum) (Figure 3-22).

The estimated rate of change in turbidity across all sites in A or B band was less than 0.3 NTU per annum (Figure 3-22). The estimated rate of degradation of 0.2 ±0.1 NTU per annum is equivalent to approximately 10 per cent of the difference between the A/B to B/C band thresholds (for suspended sediment class 2). At Papakura Stream (lower) the current five-year median state is on the threshold between visual clarity bands A and B.

The estimated rate of degradation in turbidity at sites within the C band ranged from 0.2 to 0.6 NTU per annum (Figure 3-22, Appendix C). This is equivalent to approximately seven to twenty per cent of the difference between the B/C to C/D thresholds. The greatest rate of improvement was at Avondale Stream which was very likely improving at an estimated rate of 0.7 ±0.4 NTU per annum (Figure 3-22,

Appendix C). Change over time at this site appears to be primarily associated with high turbidity at the start of the monitoring period in 2012 and 2013 (Appendix C).

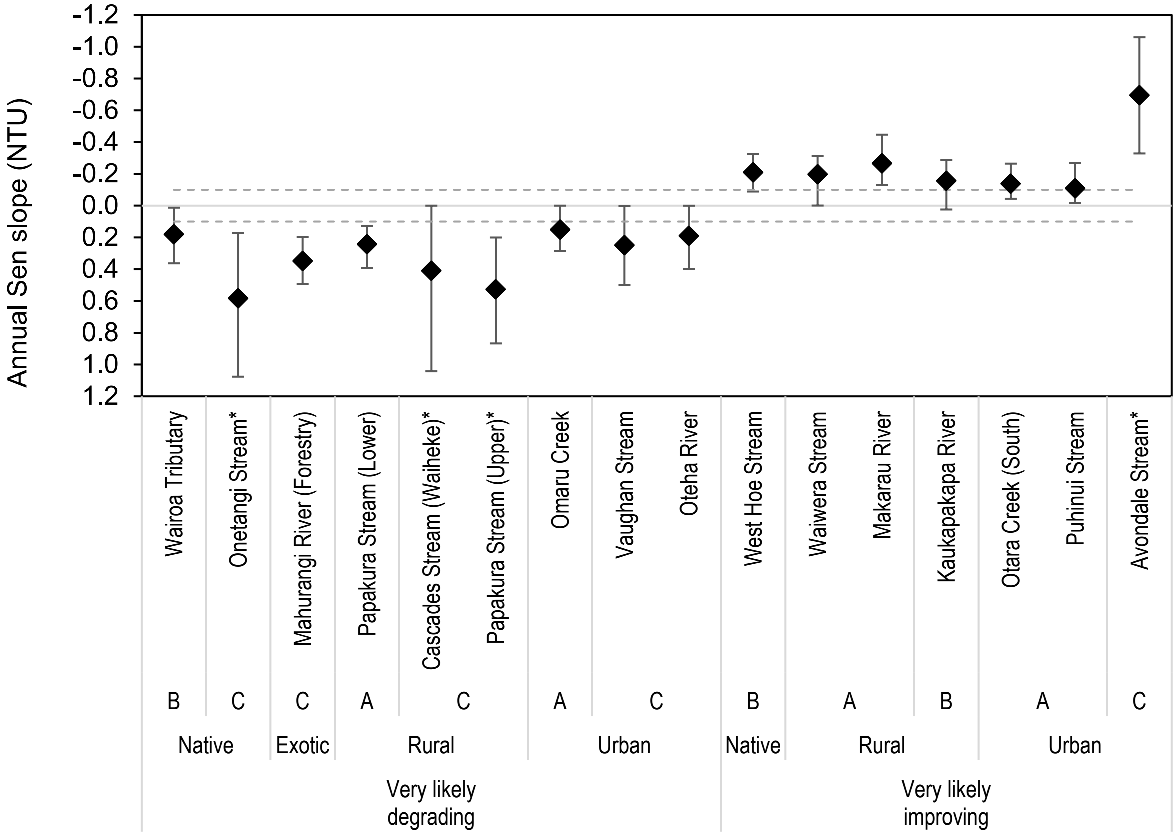


Figure 3-22: Magnitude of 'very likely' trends in turbidity at each site ordered by overall NOF visual clarity band (2015-2019) and dominant land cover.

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
* Shorter time period available for trend analysis.

3.4.7 *E. coli*

E. coli bacteria are indicators of faecal contamination. The assessment undertaken here is **not** in relation to identified primary contact sites or the bathing season. However, the national objectives framework also provides for an assessment of *E. coli* in relation to potential human contact risk for all lakes and rivers.

Nearly 80 per cent of monitored sites across the region were in band E (Figure 3-23), where the predicted average risk of infection is >7 per cent. Over half of these sites were likely to very likely improving but a quarter of the monitored sites within band E were likely to very likely degrading. There was a higher proportion of indeterminate trends amongst rural streams.

One site, with a catchment dominated by native forest is in band C (three per cent predicted average infection risk) and another native forest site was in band E. In both instances, more than 10 per cent of the upstream catchment is influenced by anthropogenic land use pressures. Onetangi Stream (band C) has a number of residential properties within the upstream catchment (>10 per cent urban) and Opanuku Stream (band E), has a relatively high proportion of rural land use (>10 per cent rural). Auckland Council works with property owners and servicing companies to ensure that onsite wastewater systems are appropriately maintained. This includes compliance investigations requesting maintenance records, water quality sampling, and education. This work is supported by local board funding and the water quality targeted rate.

All four reference sites were in bands A and B but showed mixed trend directions. Both sites in the northern, east coast were likely to very likely degrading whilst Wairoa Tributary in the south near the Hunua Ranges, was very likely improving, and Cascades stream in the Waitakere Ranges was likely improving.

Two rural streams, and two urban streams in band E were very likely degrading.

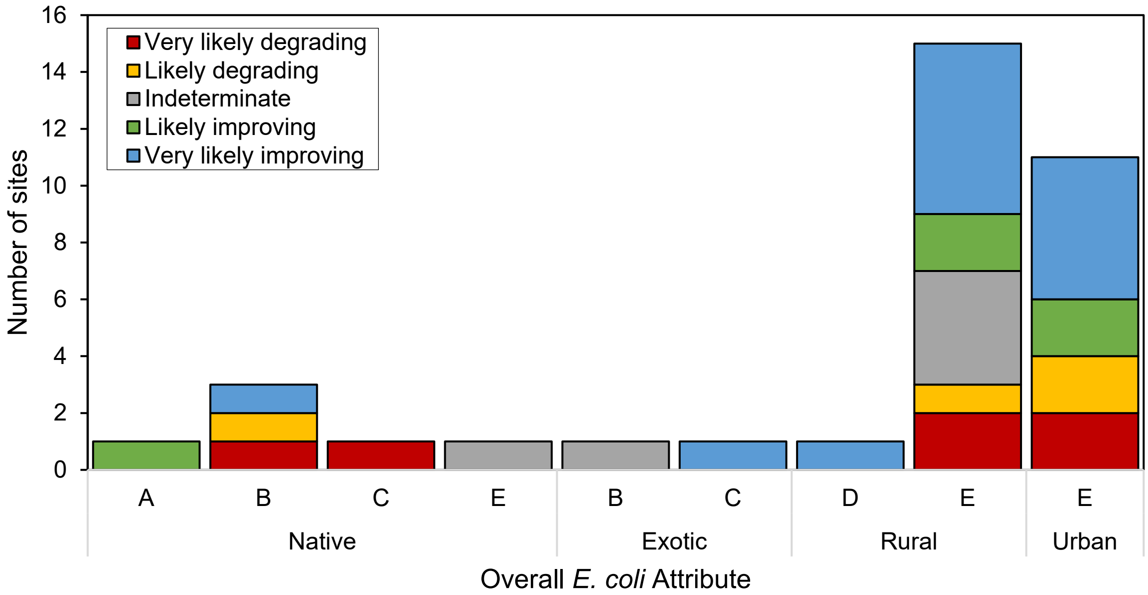


Figure 3-23: Summary of 10-year trends (2010-2019) within each NOF overall attribute band for *E. coli* ordered by dominant land cover (2015-2019).

3.4.7.1 Magnitude of very likely trends in *E. coli*

The estimated rate of change in *E. coli* was greater than the limit of precision for this parameter (>1 CFU/100mL per annum). The estimated rate of change for all sites with catchments dominated by native forest, including Onetangi Stream, was less than 10 CFU/100 mL per annum (Figure 3-24, Appendix C). Potential sources of faecal contamination in most of the native forest areas are limited and may be associated with animals, and localised recreational use, however, as noted above, residential use is another potential source for Onetangi Stream.

It is difficult to estimate changes in the overall attribute band state for *E. coli* as there are a greater number of metrics to consider, including the frequency of high values.

Trends over time are more generally representative of changes in the median state. However, for context, 10 CFU/100 mL equates to less than 10 per cent of the threshold for the median attribute for band D.

The estimated rate of degradation across both rural and urban sites ranged from eight to 55 CFU/100mL per annum with the greatest rate of degradation, at Whangamaire Stream (Figure 3-24, Appendix C). This finding is further supported by an increasing proportion of values >540 CFU from 44 per cent of samples across 2010-2014 to 80 per cent of samples in 2015-2019 which suggests that further investigation may be warranted.

The estimated rate of improvement across rural and exotic forest sites ranged from 15 to 30 CFU/100mL per annum. The largest rate of improvement was across urban sites ranging from 29 to 100 CFU per annum however, the very wide confidence intervals suggest that this rate of improvement was more variable over time (Figure 3-24, Appendix C).

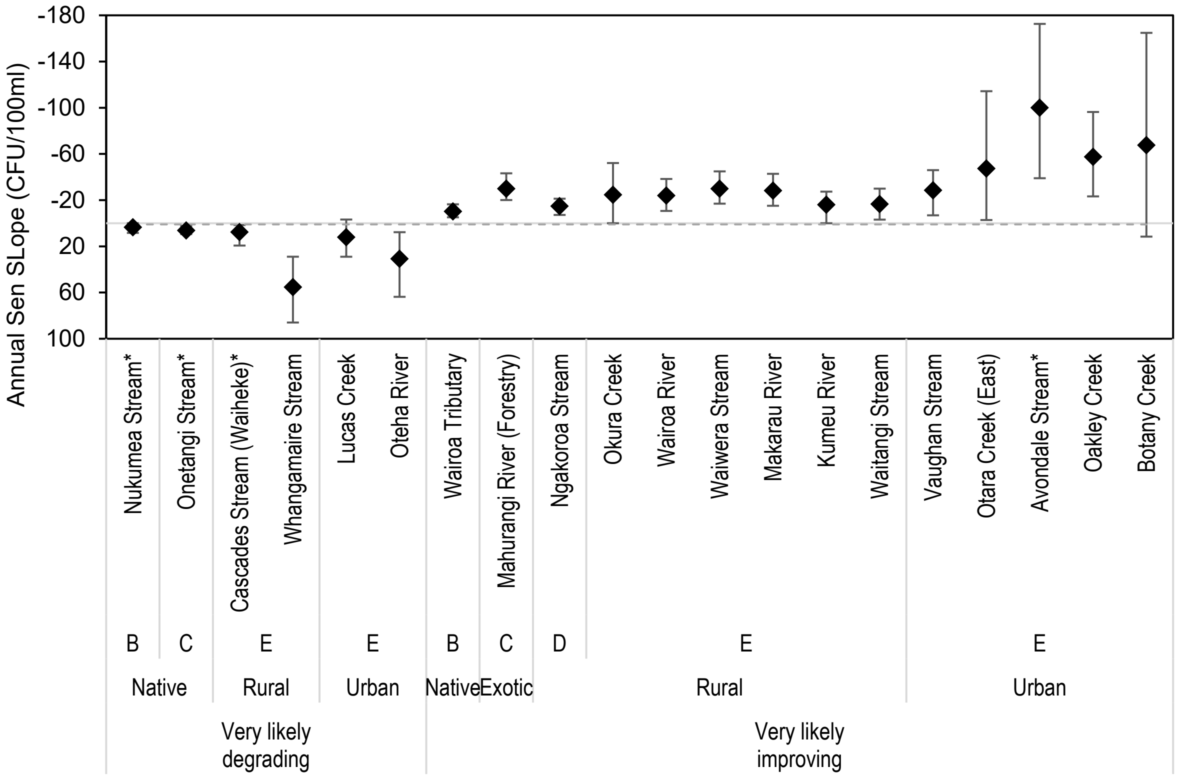


Figure 3-24: Magnitude of 'very likely' trends in *E. coli* at each site ordered by dominant land cover and overall NOF *E. coli* band (2015-2019).

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)

* Shorter time period available for trend analysis.

3.4.8 Metals

Copper and zinc are recognised as key pollutants of urban streams and can be toxic to aquatic animals (Gadd et al., 2019). The NPS-FM national objectives framework does not currently include guidelines for metal toxicity. Provisional grading against the proposed Auckland regional objectives for the soluble metal components are referred to here.

All monitored streams across the region have copper concentrations that are above the proposed regional bottom line (band D). All urban sites are in band C and 30 per cent of these sites were very likely degrading, trends could not be determined for 30 per cent of sites and two sites were likely to very likely improving (Figure 3-25).

Most urban streams have zinc concentrations approaching acute impact levels for sensitive species. However, the majority of these streams were very likely improving over the past 10 years (Figure 3-25). Only three sites were very likely degrading, Riverhead Stream, Kumeu River, and Lucas Creek. One of the most impacted urban streams, Oteha River (band D) was likely degrading.

Higher detection limits[5] were introduced in 2017 which likely induced degrading trends in soluble copper and likely induced improving trends in soluble zinc at sites with low concentrations (A band).

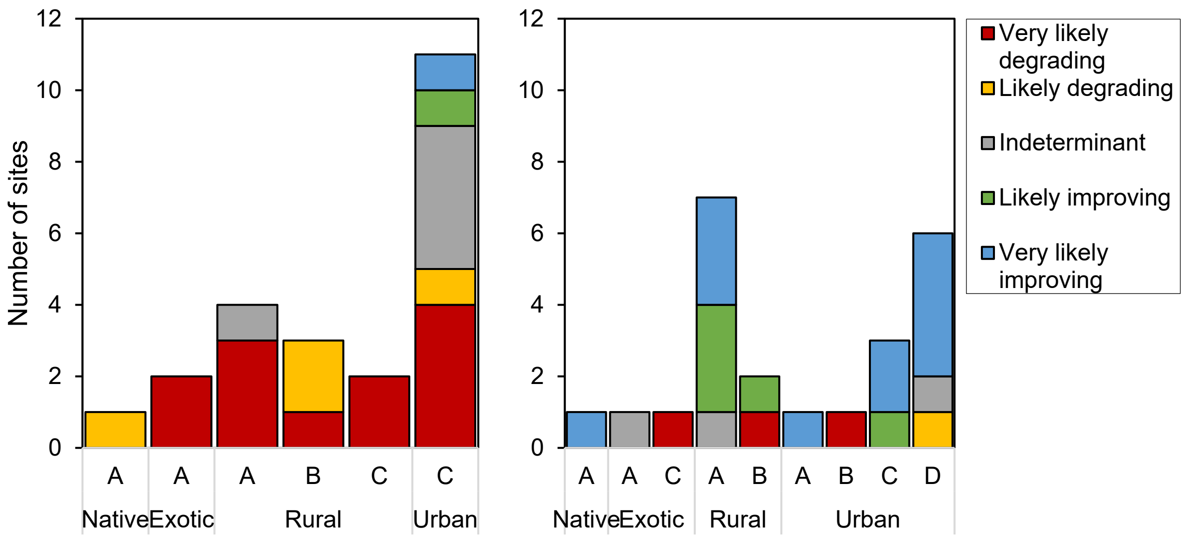


Figure 3-25: Summary of 10-year trends (2010-2019) in each attribute band for copper (left) and zinc (right) toxicity (2015-2019) ordered by dominant land cover.

[5] The higher detection limits are consistent with the National Environmental Monitoring Standards (NEMS) and are adequate to assess current state relative to the proposed regional guideline values.

3.4.8.1 Magnitude of trends in metals

The estimated rate of change in soluble copper and zinc for sites with very likely trends was typically greater than the limit of measurement precision for each parameter (>0.00001 and >0.0001mg/L per annum respectively).

The estimated rate of degradation in soluble copper was less than 0.00002mg/L per annum at the rural sites currently in bands A and B which is less than two per cent of the threshold between bands A and B (Figure 3-26). The estimated rate of degradation across rural and urban sites currently in band C ranged from 0.000017 to 0.000053mg/L per annum with the greatest rate of annual change at Kumeu River (0.00005 ± 0.00002 mg/L, Figure 3-26, Appendix C). This equates to between two and five per cent of the threshold between median state bands C and D where the risk of toxicity would start approaching acute levels. Puhinui Stream was the only monitored stream with very likely improving trends in soluble copper (Figure 3-26, Appendix C).

The estimated rate of change in soluble zinc was less than 0.0003mg/L per annum for sites currently in bands A and B (Figure 3-27), however, this equates to over 10 per cent of the threshold between bands A and B, and five per cent of the threshold between bands B and C for the median metric.

Riverhead Stream, in exotic forestry, had much higher concentrations of zinc than the other monitored forestry site at Mahurangi and was also very likely degrading over the past 10 years at a rate of 0.00033 ± 0.0002 mg/L (Figure 3-27, Appendix C). Kumeu River had higher concentrations of zinc than expected for the surrounding rural catchment and was also very likely degrading.

While no major land cover changes were observed within the Kumeu River catchment between 2009 to 2018, the upstream catchment includes a relatively high proportion of horticultural production (>5 per cent of catchment) including viticulture and kiwi fruit. Horticultural sprays (fungicides/pesticides) are a key source of copper contamination and high concentrations of copper have also been found in soils within horticultural areas in Auckland (Curran-Cournane, 2020). It is also noted that the monitoring site is bridged immediately upstream by State Highway 16 and bordered by an industrial complex. Within the past 10 years, annual average daily traffic volumes on SH16 in the vicinity of the monitoring site have increased by 34 to 48 per cent (NZTA, 2019). The wearing of tyres can be a source of zinc and the wearing of vehicle brake pads is a common source of copper contaminants (Kennedy and Sutherland, 2008) and it is possible that high (>20,000 vehicles per day) and increasing volumes of traffic within the area are contributing to increasing copper and zinc contamination at Kumeu River.

Urban sites in band C and D for zinc toxicity were improving at an estimated rate of 0.00027 to 0.0005 mg/L per annum except at Omaru Creek which was an order of magnitude greater, estimated at 0.0019 mg/L per annum but with wide variability in the rate of change (+0.002, -0.0018) (Figure 3-27, Appendix C). Median concentrations of zinc at Omaru Creek are currently double the regional threshold between bands C and D, and at this estimated rate of change, improvement relative to the attribute band state could take over 10 years. Targeted interventions have been planned, including a new stormwater treatment wetland at Taniwha Reserve.

The area of urban land cover has more than doubled in the Vaughan Stream catchment since 2012. Concentrations of zinc at this site are still currently in band A whilst most streams in older urbanised catchments are in band C or D. Zinc concentrations were very likely improving which suggests that the current state is at least being maintained (Figure 3-27, Appendix C). Conversely, while median copper concentrations are in band A, occasional high concentrations result in the 95th percentile in band C. Copper concentrations were very likely degrading although the estimated rate of change per annum was less than two per cent of the difference between bands A and B for the median attribute (Figure 3-26).

The overall pattern of trends was very similar between soluble and total forms of copper and zinc. Half of the assessable streams had trends in the same direction and likelihood between total and soluble forms of copper, and three quarters of the assessable streams had trends in the same direction and likelihood between total and soluble forms of zinc. The greatest differences in trend assessment were at Avondale Stream, while soluble copper was very likely improving, the rate of change was highly variable (as indicated by wide confidence intervals in Figure 3-26) and no trend was determined in total copper at this site, and at Puhinui Stream where no trend was determined for soluble zinc, but total zinc was very likely improving.

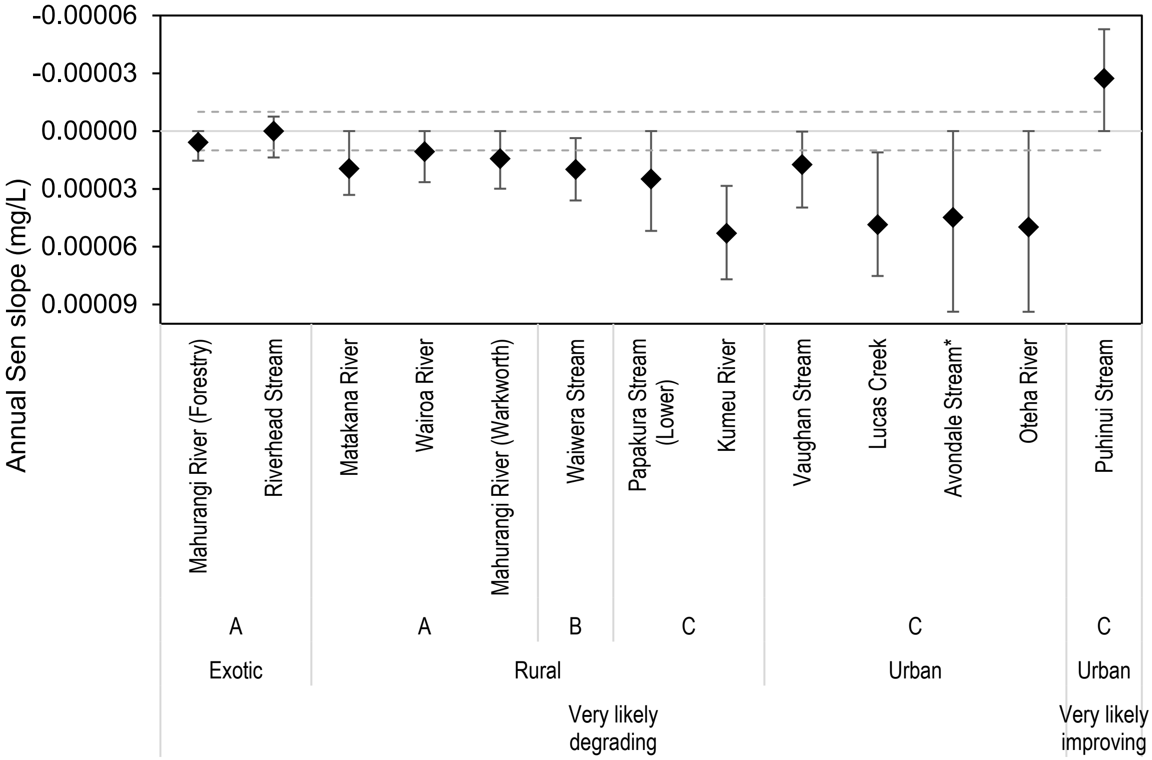


Figure 3-26: Magnitude of 'very likely' trends in soluble copper at each site ordered by proposed overall copper band (2015-2019) and dominant land cover.

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
* Shorter time period available for trend analysis.

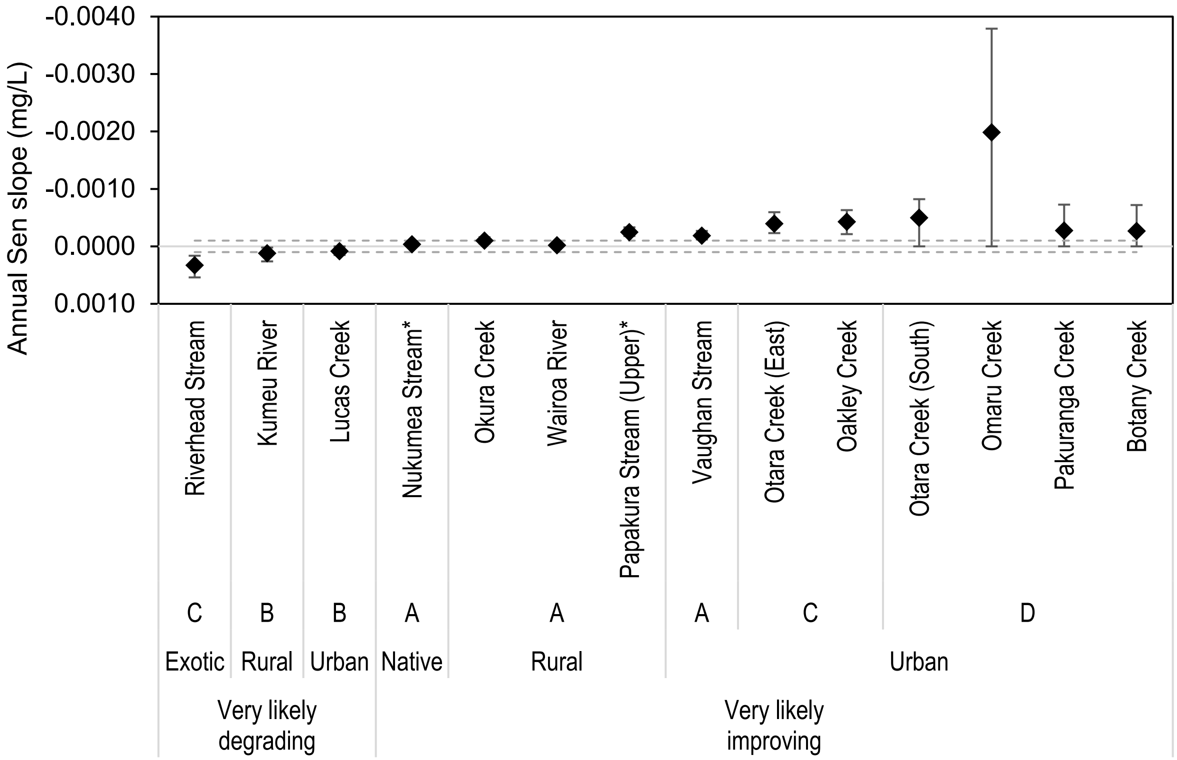


Figure 3-27: Magnitude of 'very likely' trends in soluble zinc at each site ordered by proposed overall zinc band (2015-2019) and dominant land cover.

Bars represent 90% confidence intervals. Dashed lines represent the precision limit (measurement resolution)
* Shorter time period available for trend analysis.

4.0 Summary

This report provides information on the current state of river water quality in relation to national and regional guidelines, and how water quality has changed over the past 10 years in relation to the current state. That is, where water quality is good but declining, poor but improving, or poor and getting worse.

Current state assessment is based on the preceding five-year period from 2015 to 2019 as per the NPS-FM 2020 national objectives framework (NOF) compulsory water quality attributes. Where a '*National Bottom Line'* exists for a specific attribute this refers to the minimum state for each attribute that councils must meet or work towards meeting over time. We expect regional bottom lines to be treated via a similar approach. The 2019 annual data report provides further information on the assessment of water quality state (Ingley and Groom, 2021).

The 10-year period assessed covers environmental management across the Auckland region as governed by the Auckland Council Air, Land and Water Plan 2010, and the Auckland Unitary Plan 2016. The National Policy Statement for Freshwater Management (NPS-FM) came into effect on 1 August 2014 as one of the Government's major initiatives for freshwater management reform. The NPS-FM 2020 replaced previous versions of this policy on 3 of September 2020 (MfE, 2020). Where water quality is currently below national bottom lines, management efforts must seek to improve river water quality over time unless this state is due to established natural causes. River water quality that is above the national bottom lines may still be considered to require improvement following further regional analysis of values, community consultation, and in partnership with mana whenua.

Key regional issues were highlighted including instream nutrient enrichment and potential effects of eutrophication, increasing turbidity (suspended sediment), and generally high levels of *E. coli*.

The nitrate and ammonia NOF attributes assess chronic (long-term exposure) toxicity risk for sensitive instream animals such as shrimp, and other macroinvertebrates, and fish. Regionally, there is a very low risk of toxicity effects even for the most sensitive species, however, there are risks (below the national bottom line) of nitrate toxicity in rural streams in the Franklin area, and risks of ammonia toxicity in almost half of our monitored urban streams. For many of these streams already experiencing risk of toxic effects, concentrations are continuing to increase (degrading trends). At least one monitored stream in the Franklin area has improving levels of nitrate, supported by similar trends in the underlying groundwater quality.

Adverse effects of nutrient enrichment (nitrogen and phosphorus) can occur at concentrations far lower than levels that cause toxicity effects on instream biota (nitrogen). The limiting nutrient in rivers and streams is most commonly phosphorus (McDowell et al., 2019) and regionally, concentrations of dissolved reactive phosphorus were at levels indicating moderate to high enrichment, which may drive excessive plant growth and affect instream communities. Potential eutrophication effects are further supported by indications that over 50 per cent of monitored streams may experience hypoxic conditions, at least in summer. While there were indications that phosphorus levels instream were generally improving across the region, the rate of change was not able to be estimated with confidence due to analytical variability over time. Further investigation is also necessary to ascertain potential natural sources phosphorus in Auckland rivers and streams.

A new regional monitoring programme was started in 2019 to monitor periphyton, or slime/algae naturally found on the beds of streams. Monitoring the response of this algae, in conjunction with fluctuations in nutrients (phosphorus and nitrogen) oxygen saturation and changing seasonal conditions, will support development of more stringent nutrient objectives targeting eutrophication, initially for hard bottom streams.

Suspended sediment was assessed in accordance with the latest NOF framework which provides for monitored turbidity to be converted to visual clarity. Over a third of our monitored streams, including streams in all dominant land cover categories, were found to have low water clarity (bands C and D) where moderate to high impacts may be expected for instream fauna, particularly sensitive fish species. It was these impacted sites, that had a higher proportion of degrading trends. Less impacted sites (bands A and B) were typically improving, or trends were indeterminate. The historic accumulation of sediment within streams, particularly those that are, or would have been, naturally hard bottomed, is also an important consideration and additional monitoring will be required to assess this under the NPS-FM 2020.

Two key metal contaminants were assessed in relation to chronic (long-term exposure) toxicity risk for river fauna. Almost all urban streams monitored have a moderate to high risk of toxicity effects from both copper and zinc (bands C and D) and some rural streams are also at moderate risk of copper toxicity (band C). Over half of these impacted rural and urban streams had copper levels that were degrading, and zinc levels were largely improving.

Several site-specific water quality issues were also highlighted where water quality was poor, and/or the rate of degradation was notable relative to other monitored streams. including:

Urban

- ammonia toxicity and phosphorus enrichment at Pakuranga Creek
- high and degrading *E. coli* levels, and turbidity, phosphorus enrichment, and metal toxicity at Oteha River.

Rural/Native

- copper and zinc contamination at Kumeu River
- high turbidity at Okura Creek
- high and degrading *E. coli* levels at Whangamaire Stream
- high and degrading *E. coli* levels, and turbidity, and nitrate enrichment (not toxicity) at both monitored streams on Waiheke Island.

Exotic forestry

- low and decreasing dissolved oxygen, zinc contamination, and increasing ammonia at Riverhead Stream (forestry)
- nitrate enrichment and poor and degrading turbidity at Mahurangi River (Forestry).

Some site-specific positive changes in water quality were also noted at two urban streams where water quality was notably improving relative to other monitored streams:

- poor but improving turbidity, dissolved oxygen, and *E. coli* levels at Avondale Stream
- Puhinui Stream was the only monitored stream with very likely improving trends in soluble copper, this was also the only site that had cooler surface water temperatures over the 10-year period.

These regional, and site-specific issues raised in this report present avenues to prioritise investigations to identify additional information on current pressures, consider current and planned management interventions, and/or prioritise additional management efforts as required. It is anticipated that a follow-on discussion paper will be produced over the next year to help elucidate these components.

A key direction for Auckland is to manage the effects of growth and development on our natural environment. The greatest changes in land cover (and inferred land use) over the past 10 years (summer 2008/09 to 2018/19) within the catchments upstream of our monitoring sites, are associated with urban growth in the upstream catchments of Otara Creek East (Flat Bush) and Vaughan Stream (Long Bay). Both Flat Bush and Long Bay were master planned urban areas developed with water sensitive design principles (van Roon, 2011). The current state of NOF attributes at Otara Creek East was typically one band better than the adjacent Otara Creek South catchment, and Vaughan Stream typically had better water quality than other monitored urban streams and it was the only 'urban' stream that still has low zinc concentrations (band A).

Turbidity was found to be poor, and degrading over the last 10 years at Vaughan Stream. Event based sediment monitoring is also undertaken within this catchment and no significant trends were observed in sediment loads in this catchment over 2012 to 2019 (Hicks et al. *in press*). There were no degrading trends observed across attributes at Otara Creek East, however development commenced prior to the 10-year period assessed here and further assessment of longer-term data may be necessary to provide a better estimate of the pre-development baseline.

4.1 Response to previous recommendations

The last regional water quality state and trends report made five key recommendations for future analyses (Buckthought and Neale 2016).

Firstly, it was noted that differences in the time of day that monitoring is undertaken could affect physical water quality measurements such as dissolved oxygen and installation of continuous monitoring could be considered further to investigate diurnal variability. While continuous water quality monitoring is not reported here, the effect of diurnal variability on discrete monitoring was taken into consideration in the interpretation of trends in physical parameters presented here. Continuous water quality monitoring is required to assess dissolved oxygen concentration under the national objectives framework, in areas associated with point source discharges in the first instance. Continuous monitoring of dissolved oxygen is undertaken as part of the ecosystem metabolism network programme and further analysis of this is forthcoming.

Secondly, it was recommended that monitoring for lead could be discontinued due to low instream concentrations typically below detectable levels. This was enacted, with surveillance monitoring continuing on a five-yearly basis to ensure concentrations remain low.

It was recommended that variation in laboratory detection limits was assessed and compiled to provide further context for assessment of long-term trends. These changes have been compiled for the 10-year period assessed and further consideration of how left censored values, or values below detection limits are treated in trend analysis has been similar to that undertaken nationally (e.g. Larned et al., 2018).

In the previous state and trend report, the value of aggregating data to undertake regional assessment of trends was questioned. Within this report, the level of confidence in trends at individual sites were aggregated based on the proportion of all sites in each category to provide a regional overview of water quality change. This avoids the issues raised previously with large trends at one or two sites overwhelming the entire data set.

Finally, the results of trend analysis were recommended to be considered in conjunction with separate reporting on the current state of water quality. This report proactively combines these two sources of information to enable more effective decision making for improved management of the region’s river water quality.

4.2 Knowledge gaps and future directions

There can be considerable time lags between the adoption of management practices and the detection of improvement in water quality, associated with the time it takes for a practice to be adopted, the time for that practice to produce an effect, and the time for rivers to respond to that effect (Meals et al., 2010). Differences in these processes for different water quality variables can range from years to decades. The mosaic of physical variability and range of land uses within each dominant land cover class, legacy impacts, interactions with groundwater and underlying geology, and long-term climatic variability make this assessment complex, and connections between cause and effect can be tenuous without additional supporting information on changing pressures and catchment scale mitigations.

Several regional, and site-specific issues were identified above, and it is anticipated that a discussion paper will be prepared over the next year to elucidate this further.

New monitoring programmes are currently in the pioneer stages as part of Auckland Council’s response to the requirements set out in the National Policy Statement for Freshwater Management (2020). Monitoring of periphyton (algal) communities in hard bottomed streams will provide further information on ecological responses to nutrient enrichment to support refinement of water quality objectives for dissolved reactive phosphorus and dissolved inorganic nitrogen.

The toxicity of metals is affected by other chemical properties of water such as water hardness. Once we have a minimum of five years of additional monitoring of these properties the assessment of metal toxicity for copper and zinc can be revised (by 2022). The proposed objectives for these parameters also require further revision.

This report provides part of the knowledge base supporting the future work necessary to develop the long-term vision for Auckland rivers and streams and to set effective freshwater objectives, limits and/or targets to meet that vision.

5.0 Acknowledgements

The Auckland Council river water quality monitoring programme has benefitted from the efforts of numerous people since its inception in 1985.

We acknowledge the efforts of several Environmental Specialist staff and students from RIMU who undertook sample collection and quality control processes over the past 10 years. Thanks to Vanitha Pradeep and Jade Khin for data management and quality assurance processes.

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Appendix A Methodology – additional details

Data Collection and management

All field practices were conducted according to RIMU's own quality assurance procedures and from 2019, aligned with National Environmental Monitoring Standards (NEMS) where possible. This covers procedures for the collection, transport and storage of samples, and methods for data verification and quality assurance to ensure consistency and accuracy across monitoring programmes.

Six parameters are determined in the field using the EXO Sonde, a portable water quality meter by YSI Inc., and the remainder are determined by laboratory analysis.

River water samples were analysed by Watercare Services Ltd prior to June 2017 and by RJ Hills Laboratories Ltd (Hills), from July 2017 onwards. Both laboratories are IANZ accredited. A full list of the parameters measured is outlined below.

The NIWA Hoteo River, and Rangitopuni River sites are monitored for the same parameters listed in Table 6-1 except for salinity, suspended solids, and copper and zinc. Temperature and dissolved oxygen are determined in the field and the remainder are determined by laboratory analysis at NIWA's water quality laboratory in Hamilton. Further information can be obtained from https://www.niwa.co.nz/freshwater/water-quality-monitoring-and-advice/national-river-water-quality-network-nrwqn.

The river water quality data were processed in a series of steps to ensure the data were accurate and treated consistently. All field and laboratory data were checked and assigned a quality assurance code in accordance with Auckland Council's internal Stream Water Quality Sampling Protocol. Draft updated National Environmental Monitoring Standards (NEMS) were released in April 2019. Therefore, data associated with quality coding prior to this date are not directly comparable with these standards.

Prior to analysis, any data points that were assigned a quality assurance code of poor quality were removed from the dataset.

All water quality data is stored in Auckland Council's water quality archiving database (KiWQM). The data for the Hoteo River were extracted from NIWA's web-based Water Quality Information System.

Table 6-1: Analytical methods for water quality parameters assessed.

Parameter	Units	Lab/ Field	Equipment/ 2010-2014	Equipment 2014-2019	Detection Limit	Detection Limit
Dissolved oxygen	% sat	Field	YSI 556	EXO sonde, optical method	0	0
Dissolved oxygen	mg/L	Field	YSI 556	EXO sonde, optical method	0	0
Temperature	°C	Field	YSI 556	EXO sonde, thermistor	-5	-5
Conductivity	mS/cm	Field	YSI 556	EXO sonde, 4-electrode nickel cell	0	0
Salinity	ppt	Field	YSI 556	EXO sonde, 4-electrode nickel cell	0	0
pH		Field	YSI 556	EXO sonde, glass combination electrode	0	0
Parameter	**Units**	**Lab/ Field**	**WCS Lab Methods 2010-June 2017**	**Hills Lab Methods July 2017-2019**	**WCS Detection Limit**	**Hills Detection Limit**
Total suspended solids	mg/L	Lab	APHA (2005/2012) 2540 D	APHA (2017) 2540 D	0.2	3
Turbidity	NTU	Lab	APHA (2005-2012) 2130 B (modified)	APHA (2017) 2130 B (modified)	0.05	0.05
Ammoniacal nitrogen	mg N/L	Lab	APHA (2005-2012) 4500-NH3 G (Modified) APHA (online edition) 4500-NH3 H (Modified) (from July 2016)	APHA (201) 4500-NH3 H (Modified)	0.005	0.005
Total oxidised nitrogen	mg N/L	Lab	APHA (2005-2012) 4500-NO3 F (Modified) APHA (online edition) 4500-NO3 I (from July 2016)	APHA (2012) 4500-NO3 I Flow injection	0.002	0.001
Total nitrogen	mg N/L	Lab	APHA (2005-2012) 4500-P J, 4500-NO3 F (Mod) APHA (online edition) 4500-P J (modified), 4500-NO3 (from July 2016)	APHA (2017) 4500-N C, 4500-NO3 I (Mod)	0.01	0.01
Dissolved reactive phosphorus	mg P/L	Lab	APHA (2005-2012) 4500-P B, F (Modified) APHA (online edition) 4500-P F	APHA (2017) 4500-P G (Modified) Flow injection	0.005 0.002 (from August 2014)	0.004 0.001 (from June 2019)
Total phosphorus	mg P/L	Lab	APHA (2005-2012) 4500-P B, J (Modified)	APHA (2017) 4500-P B, E (Modified)	0.004	0.004
Soluble copper	µg/L	Lab	USEPA 200.8 (Modified)	APHA (2017) 3125 B	0.00001	0.0005
Total copper	µg/L	Lab	USEPA 200.8 (Modified)	APHA (2017) 3125 B / USEPA 200.8 (Modified)	0.00001	0.00053
Soluble zinc	µg/L	Lab	USEPA 200.8 (Modified)	APHA (2017) 3125 B	0.0003	0.001
Total zinc	µg/L	Lab	USEPA 200.8 (Modified)	APHA (2017) 3125 B / USEPA 200.8 (Modified)	0.0003	0.0011
Escherichia coli	cfu/100mL	Lab	USEPA 200.8 (Modified)	APHA (2017) 9222 G	2	1

Appendix B Land cover aggregation

Table 6-2: Summary of LCDB Land Cover Classes and Broad Aggregations.

LCDB Land Cover Classes within catchments upstream of river water quality monitoring sites	Aggregated Land Cover Classes	Broad Level Dominant Land Cover
Broadleaved Indigenous Hardwoods	Native forest	Native
Indigenous Forest	Native forest	Native
Manuka and/or Kanuka	Native forest	Native
Deciduous Hardwoods	Exotic forest	Exotic
Exotic Forest	Exotic forest	Exotic
Forest – Harvested	Exotic forest	Exotic
Orchard, Vineyard or Other Perennial Crop	Horticulture	Rural
Short-rotation Cropland	Horticulture	Rural
Gorse and/or Broom	Rural	Rural
High Producing Exotic Grassland	Rural	Rural
Low Producing Grassland	Rural	Rural
Built-up Area (settlement)	Urban	Urban
Transport Infrastructure	Urban – Transport Infrastructure	Urban
Urban Parkland/Open Space	Urban Parkland	Urban
Sand or Gravel	Other	NA
Surface Mine or Dump	Other	NA
Lake or Pond	Water	NA
Mangrove	Water	NA
Flaxland	Wetland	NA
Herbaceous Freshwater Vegetation	Wetland	NA

Appendix C Selected time series plots

Note Y axes vary between plots to best fit the data for the specific site and parameter

Dissolved oxygen

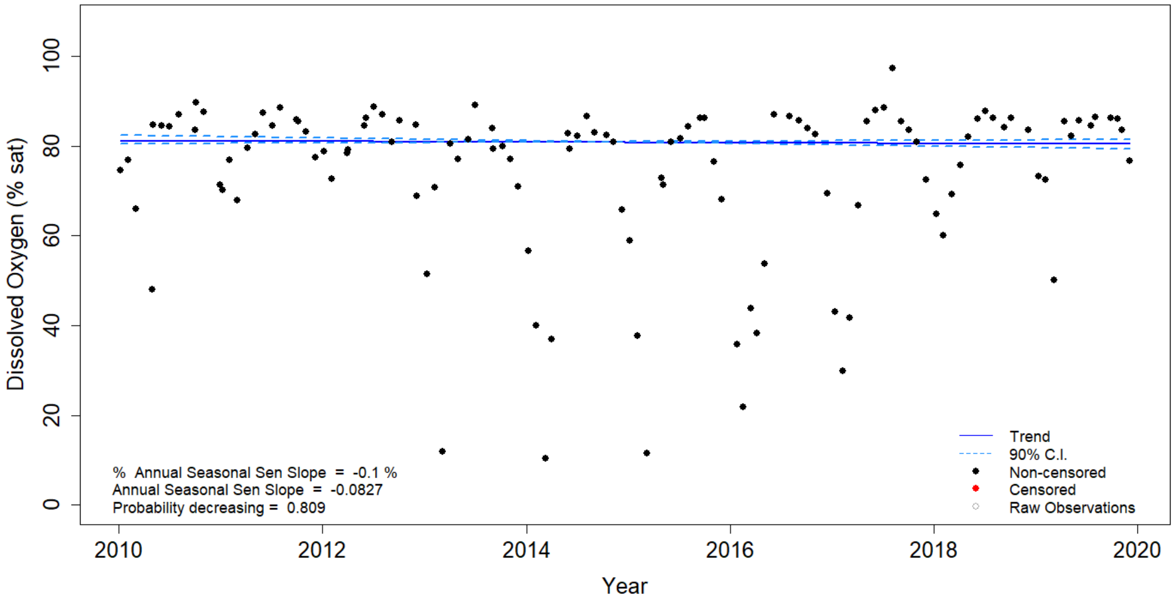


Figure 6-1: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Riverhead Stream.

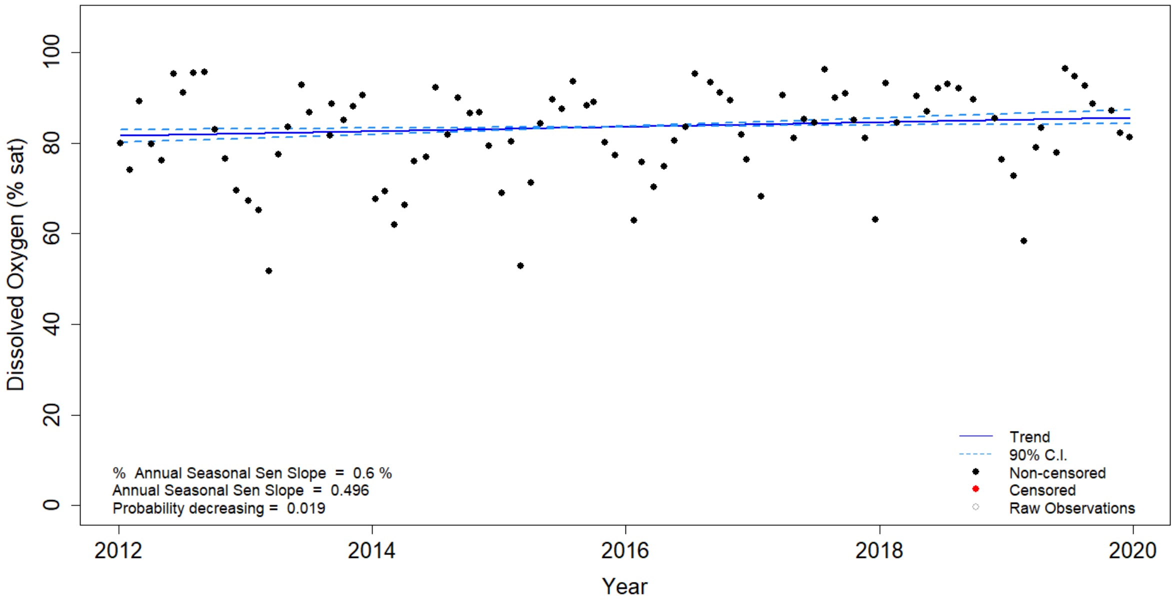


Figure 6-2: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Avondale Stream.

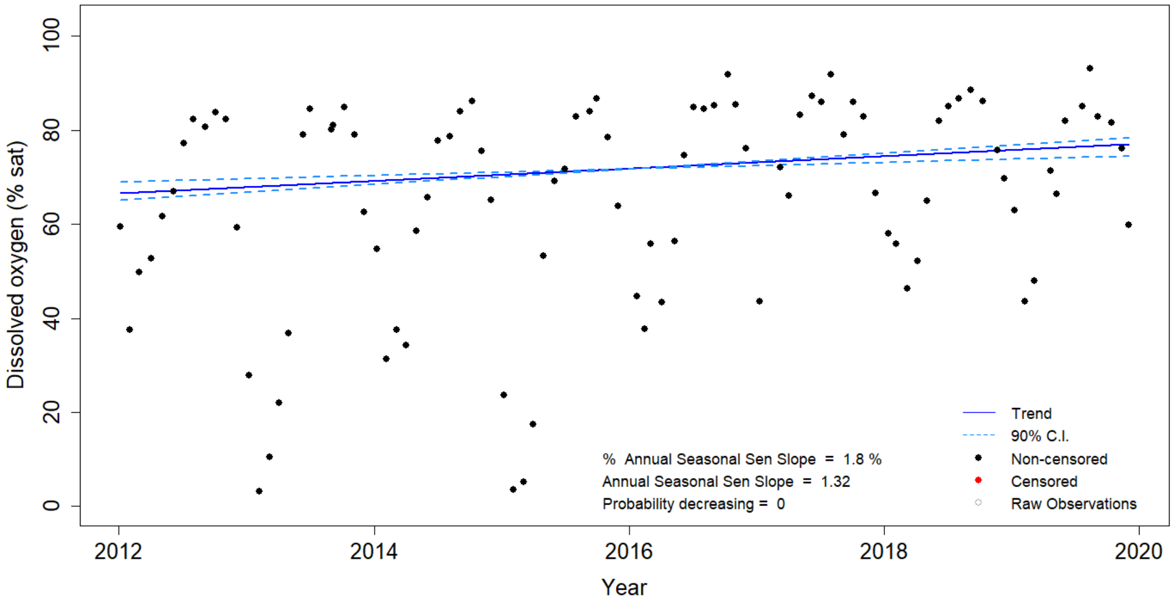


Figure 6-3: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Papakura Stream (upper).

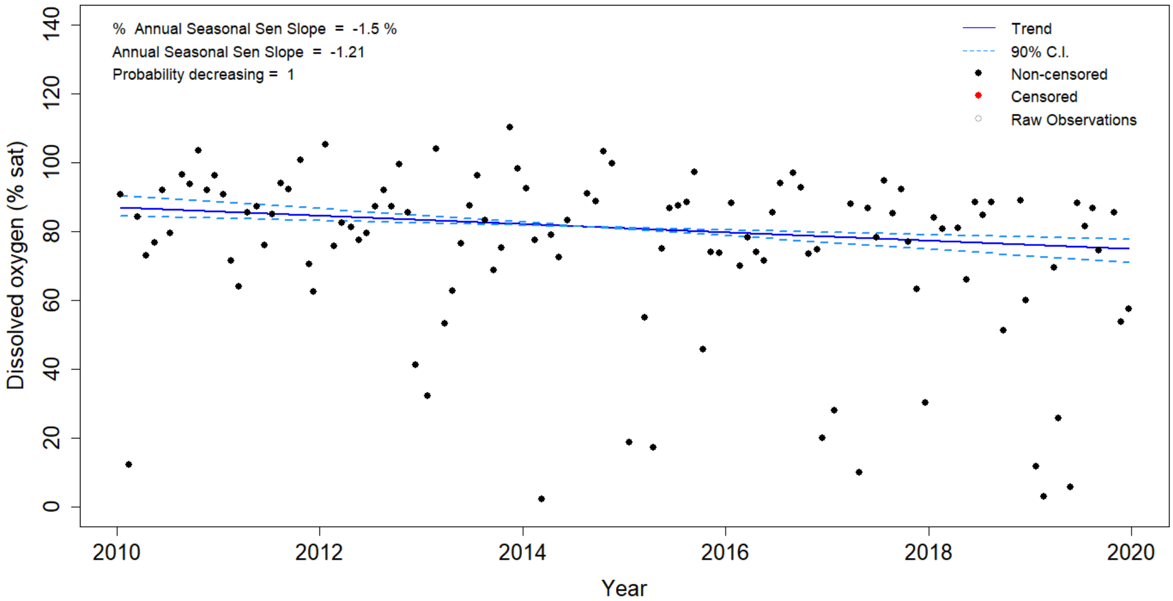


Figure 6-4: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Omaru Creek.

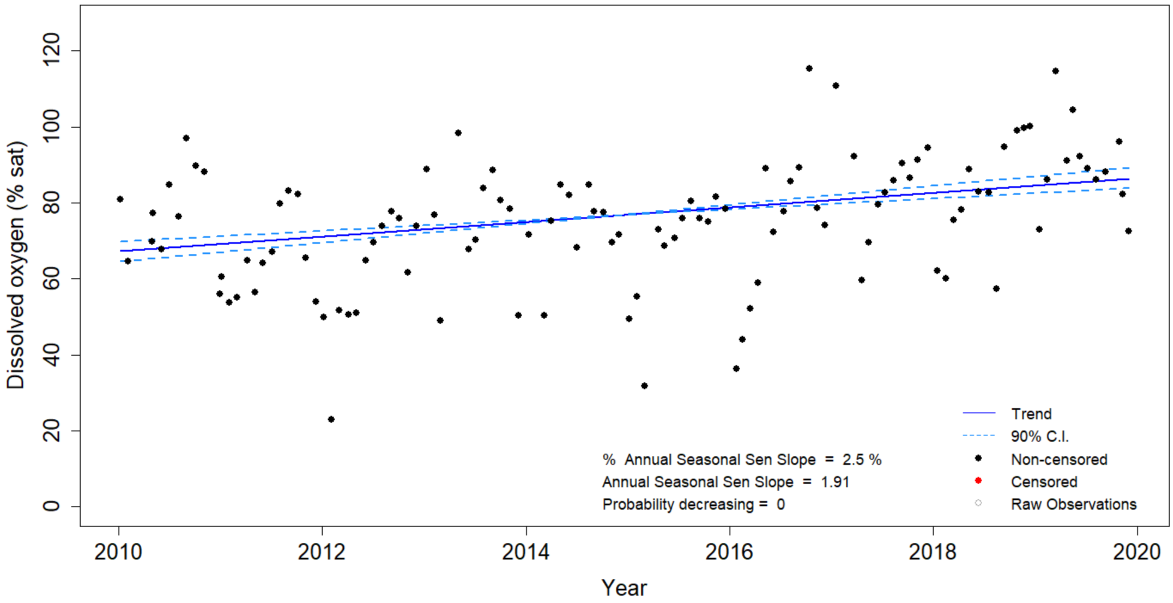


Figure 6-5: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Vaughan Stream.

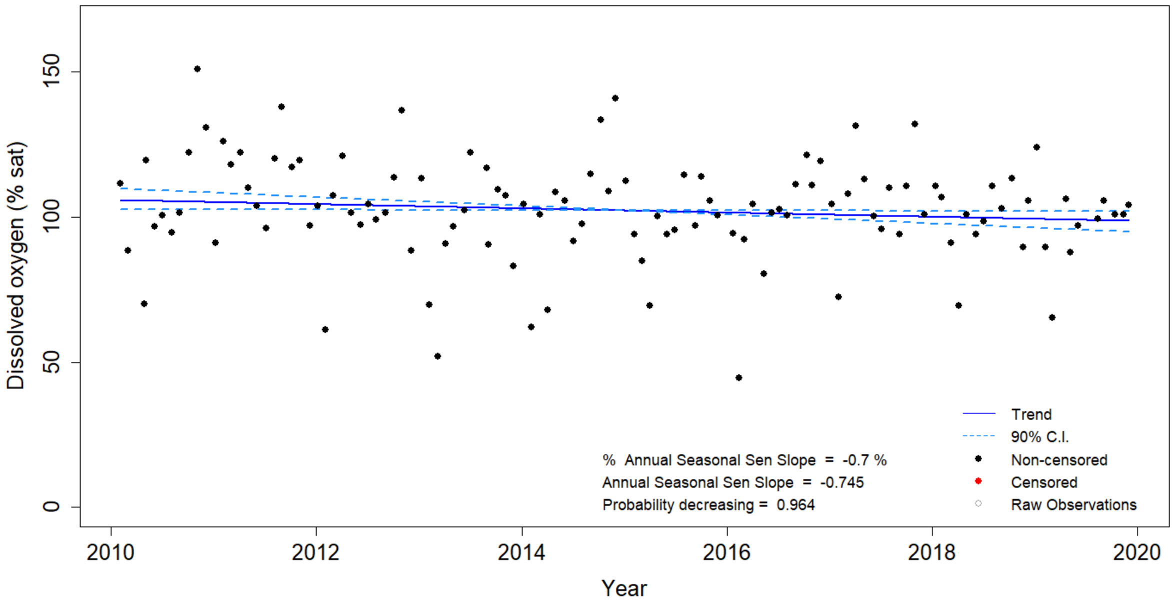


Figure 6-6: Field observations of dissolved oxygen saturation over time fitted with annual Sen Slope and 90% confidence intervals for Puhinui Stream.

pH

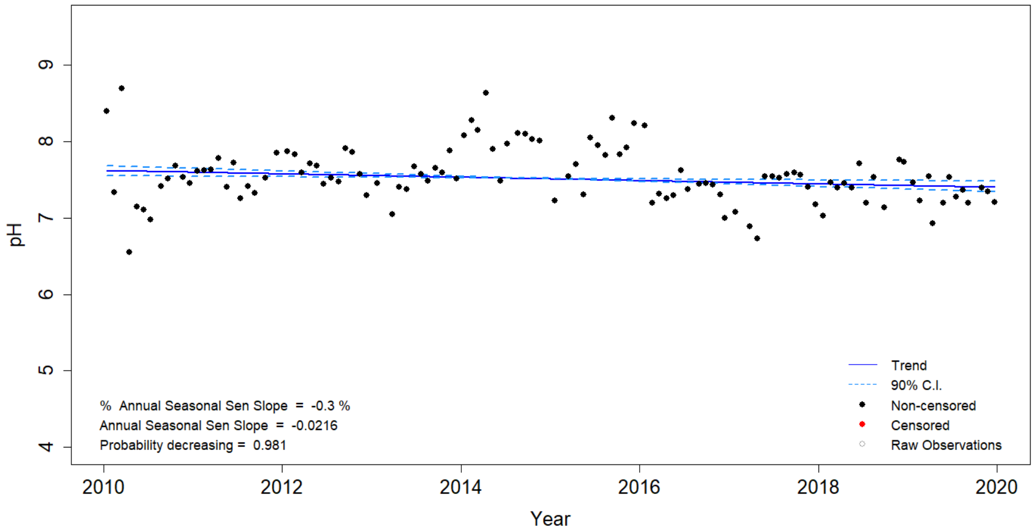


Figure 6-7: Field observations of pH over time fitted with annual Sen Slope and 90% confidence intervals for Omaru Creek.

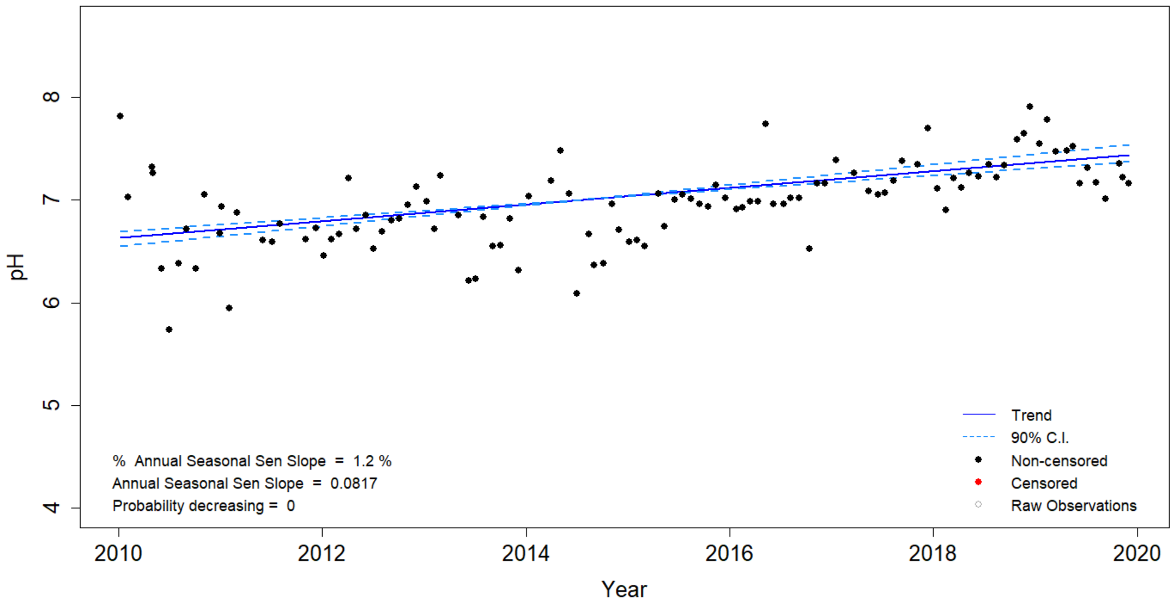
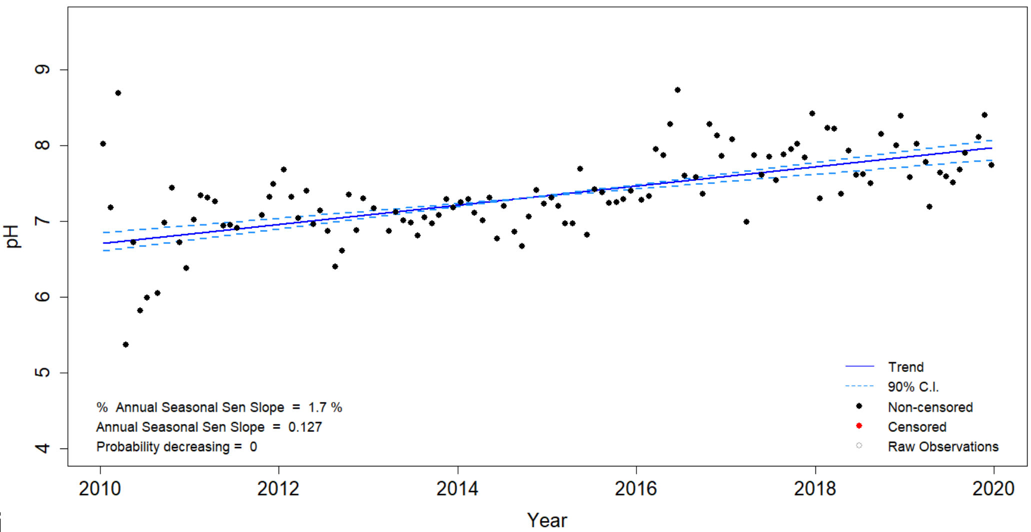


Figure 6-8: Field observations of pH over time fitted with annual Sen Slope and 90% confidence intervals for Vaughan Stream.



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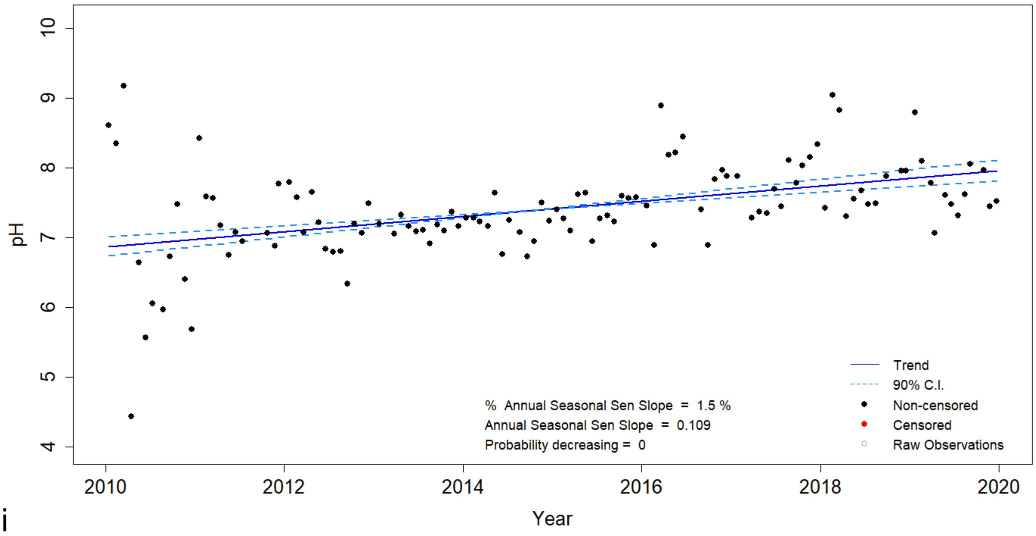
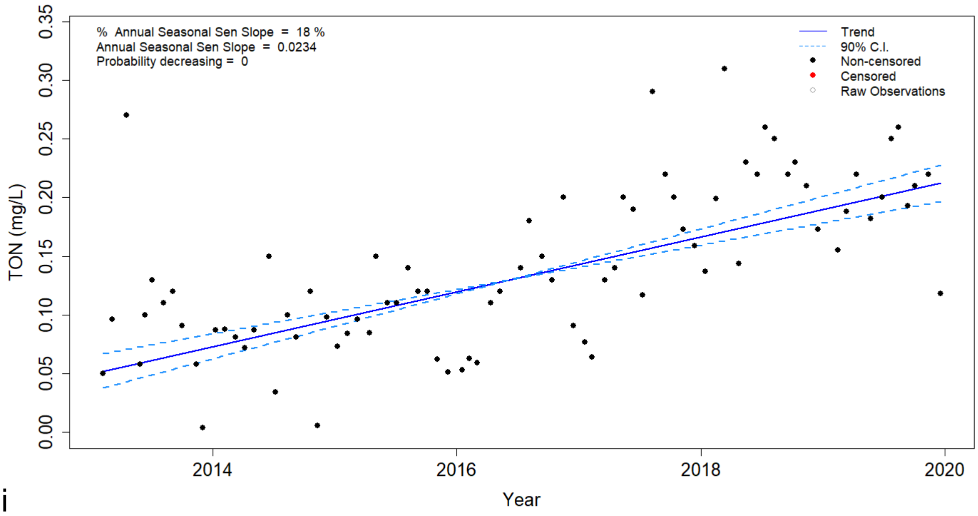


ii

Figure 6-9: Observations of TON over time fitted with annual Sen Slope and 90% confidence intervals for – Otara Creek (i) East, (ii) South.

Total oxidised nitrogen (Nitrate)



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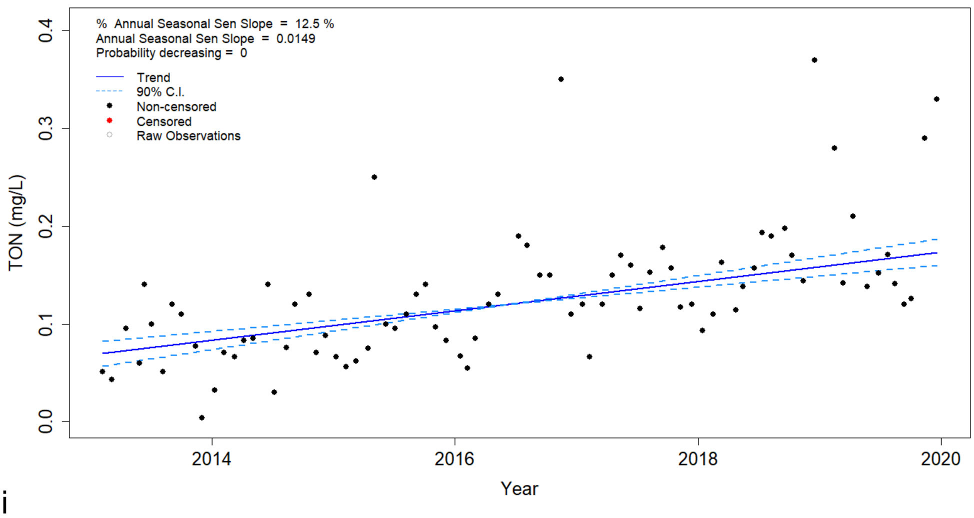


ii

Figure 6-10: Observations of TON over time fitted with annual Sen Slope and 90% confidence intervals for – Waitangi Island streams (i) Onetangi Stream, (ii) Cascades Stream.

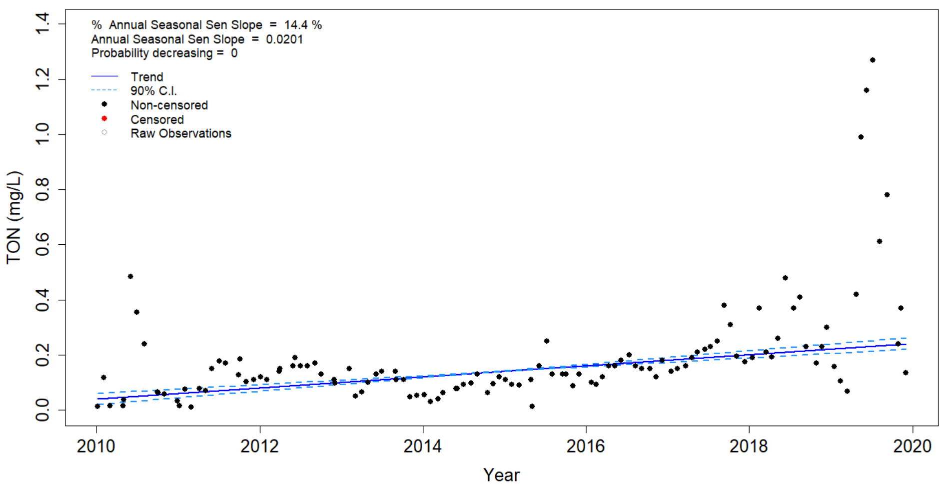
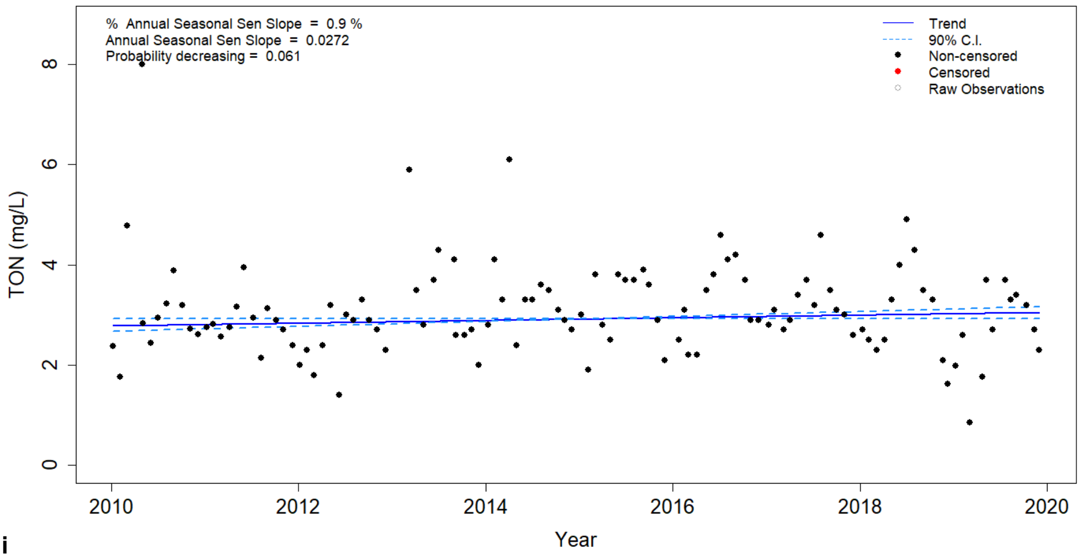


Figure 6-11: Observations of TON over time fitted with annual Sen Slope and 90% confidence intervals for Mahurangi River (Forestry).



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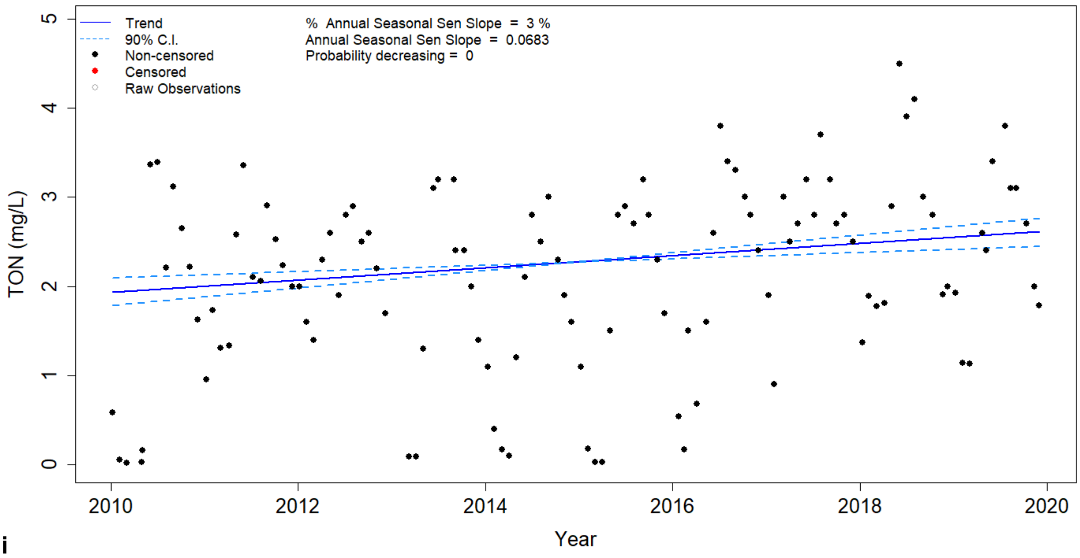

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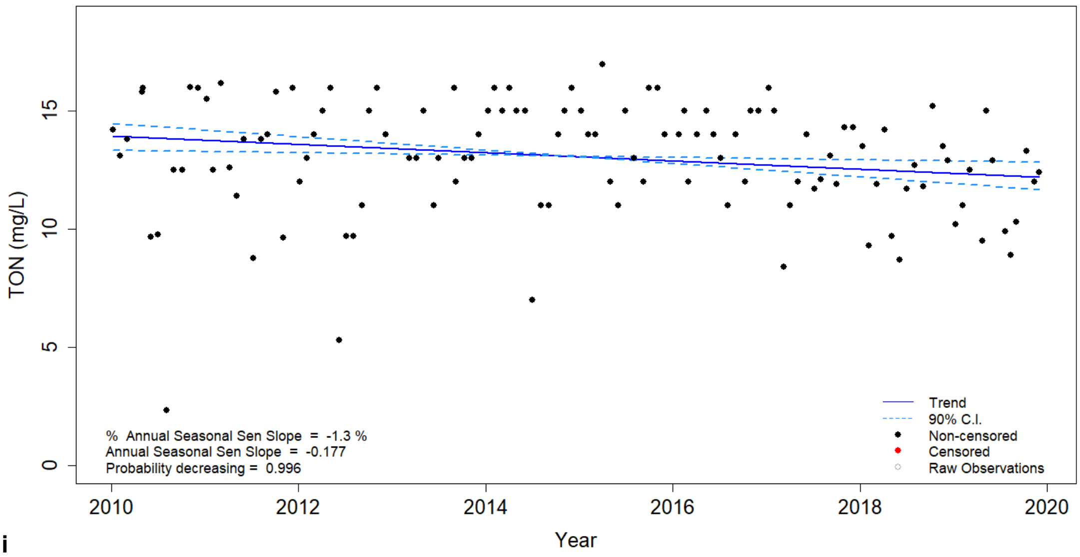


iii

Figure 6-12: Observations of TON over time fitted with annual Sen Slope and 90% confidence intervals for – Franklin nitrate area streams (i) Ngakoroa Stream, (ii) Waitangi Stream, (iii) Whangamaire Stream.

Ammoniacal nitrogen

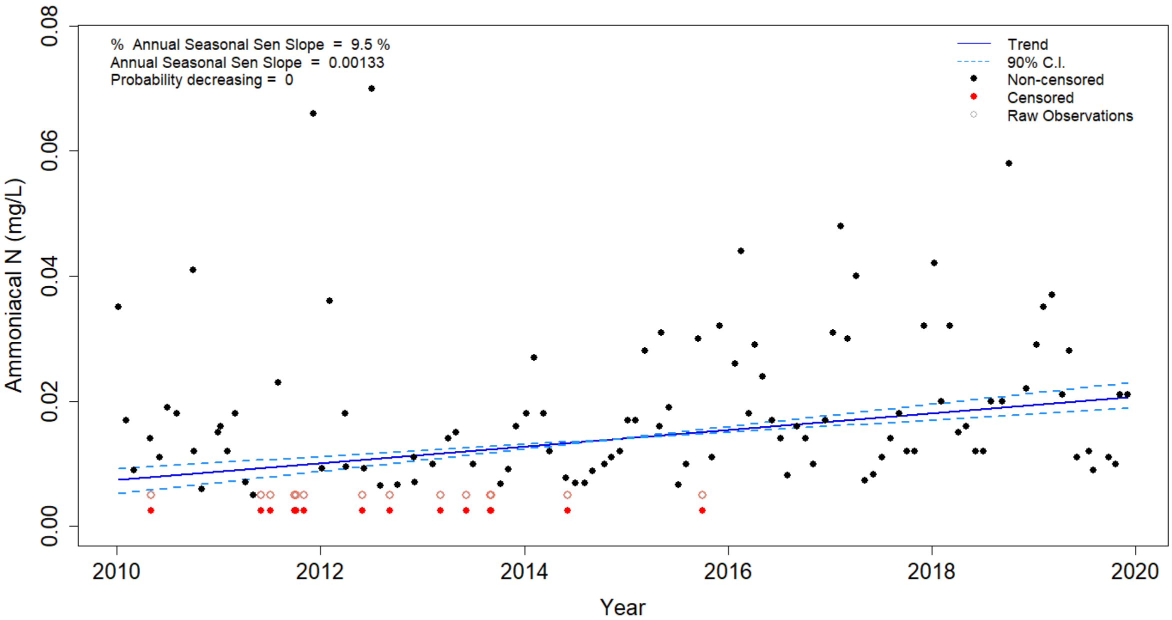


Figure 6-13: Observations of ammoniacal N over time fitted with annual Sen Slope and 90% confidence intervals for Riverhead Stream.

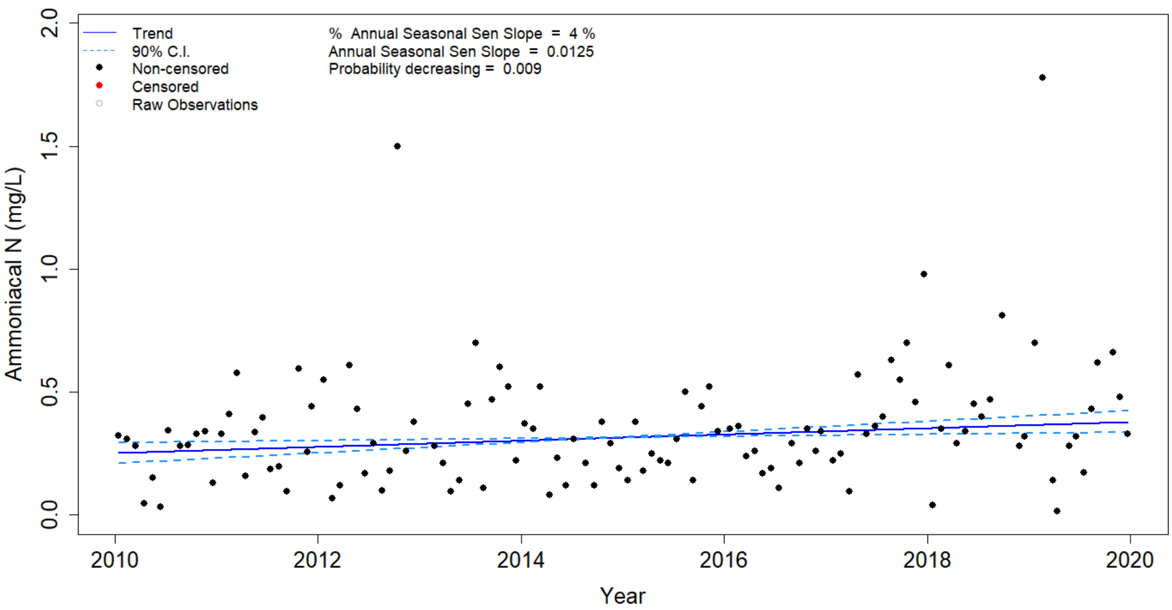


Figure 6-14: Observations of ammoniacal N over time fitted with annual Sen Slope and 90% confidence intervals for Pakuranga Stream.

Dissolved reactive phosphorus

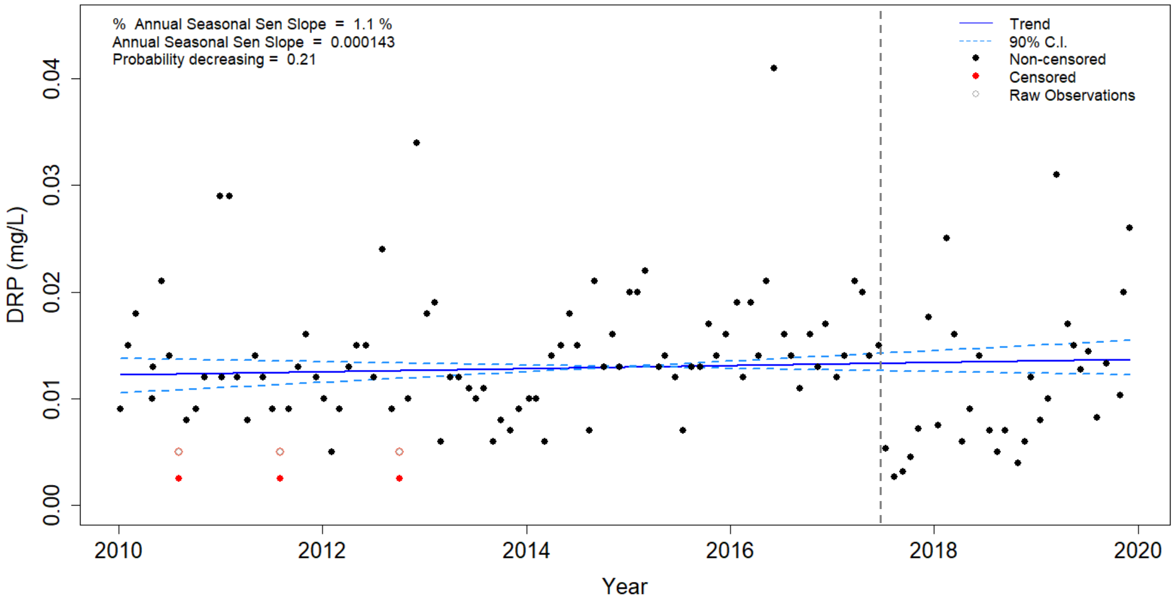


Figure 6-15: Observations of DRP over time fitted with annual Sen Slope and 90% confidence intervals for Oteha Stream. Method change from July 2017 shown by black dashed line.

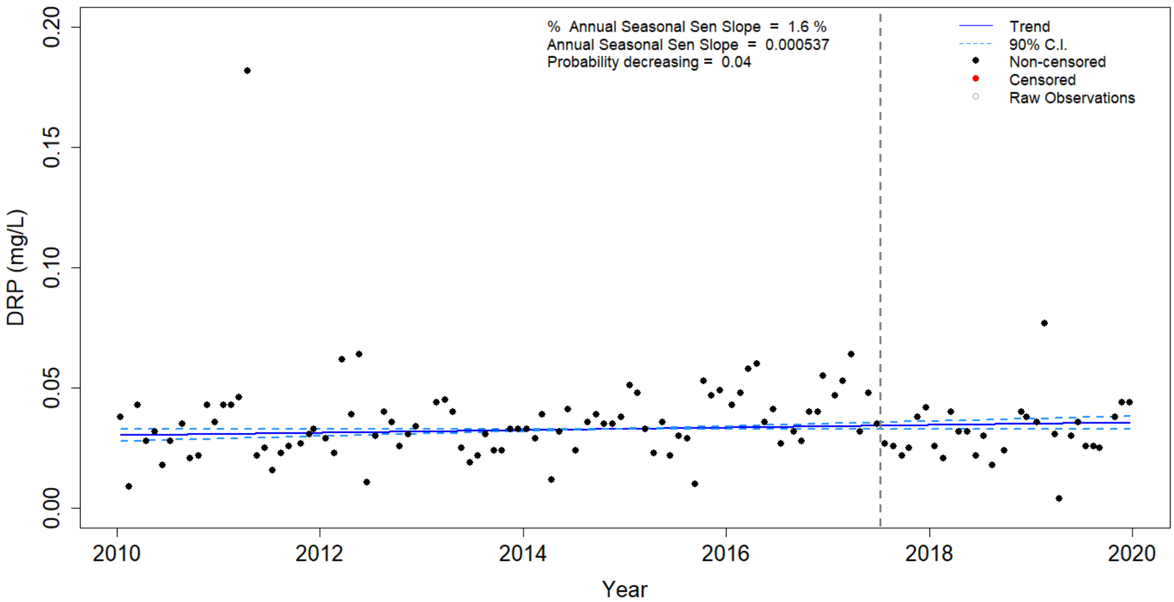
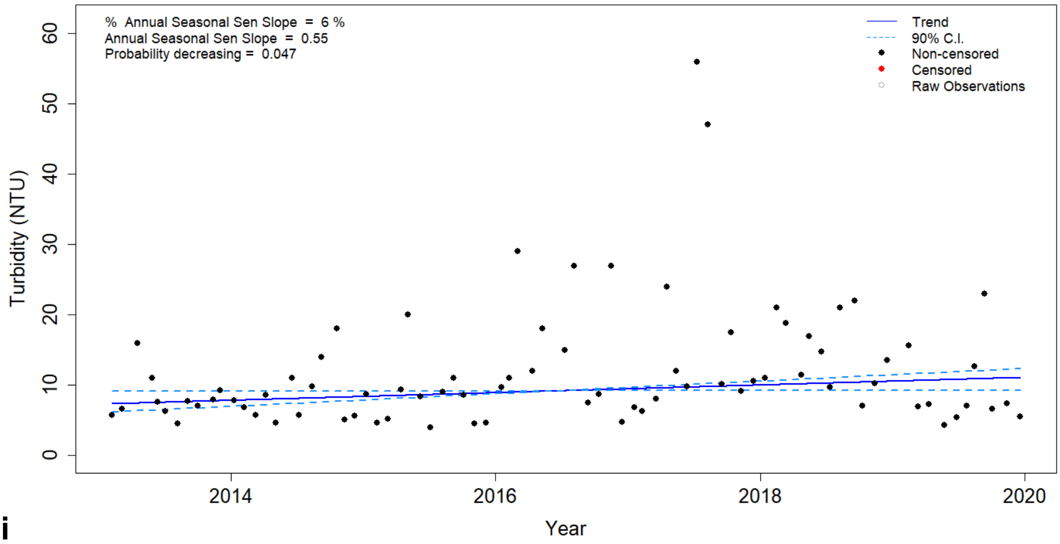


Figure 6-16: Observations of DRP over time fitted with annual Sen Slope and 90% confidence intervals for Pakuranga Stream. Method change from July 2017 shown by black dashed line.

Turbidity



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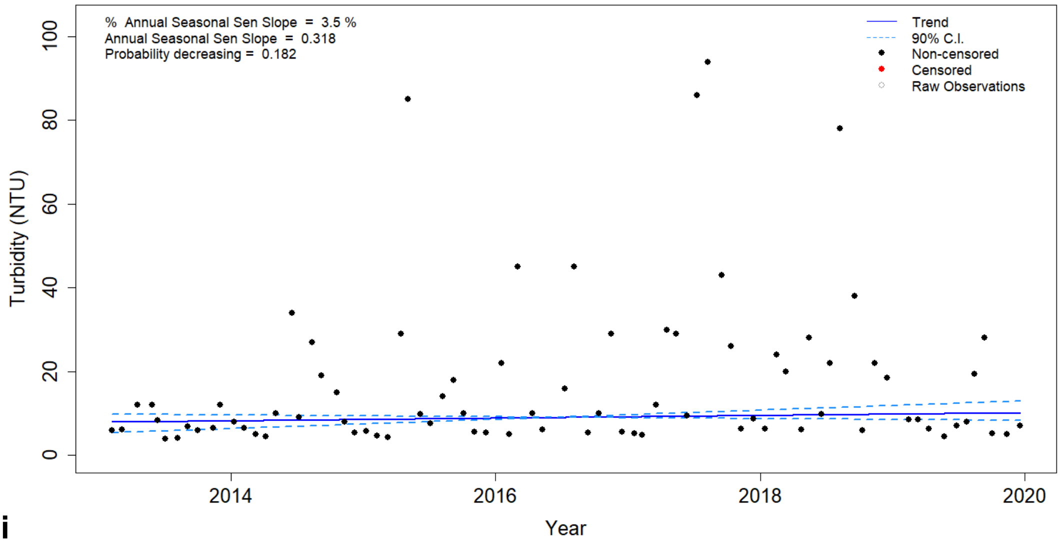

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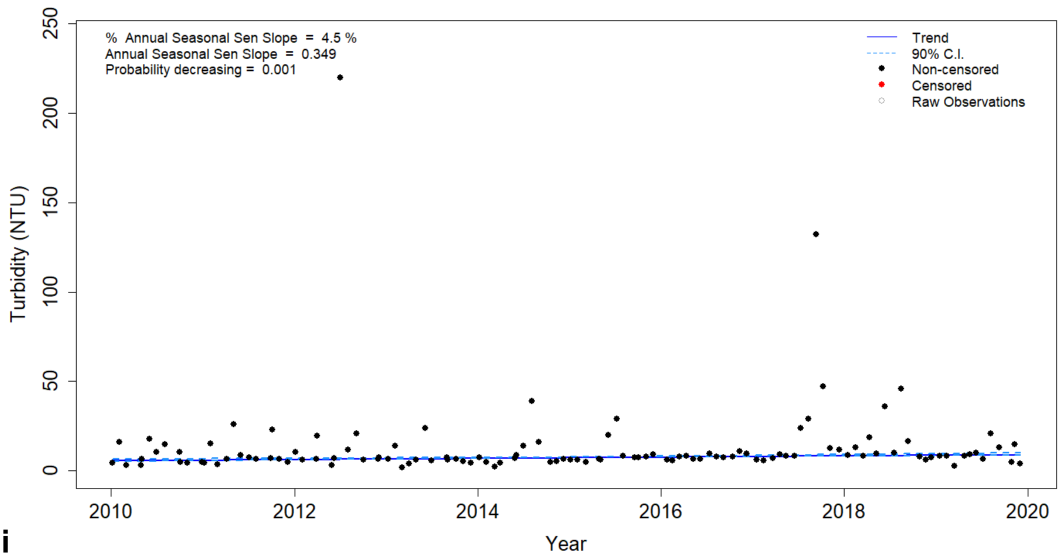


iii

Figure 6-17: Observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for – Waitangi Island streams (i) Onetangi Stream, (ii) Cascades Stream and (iii) Mahurangi River (Forestry).

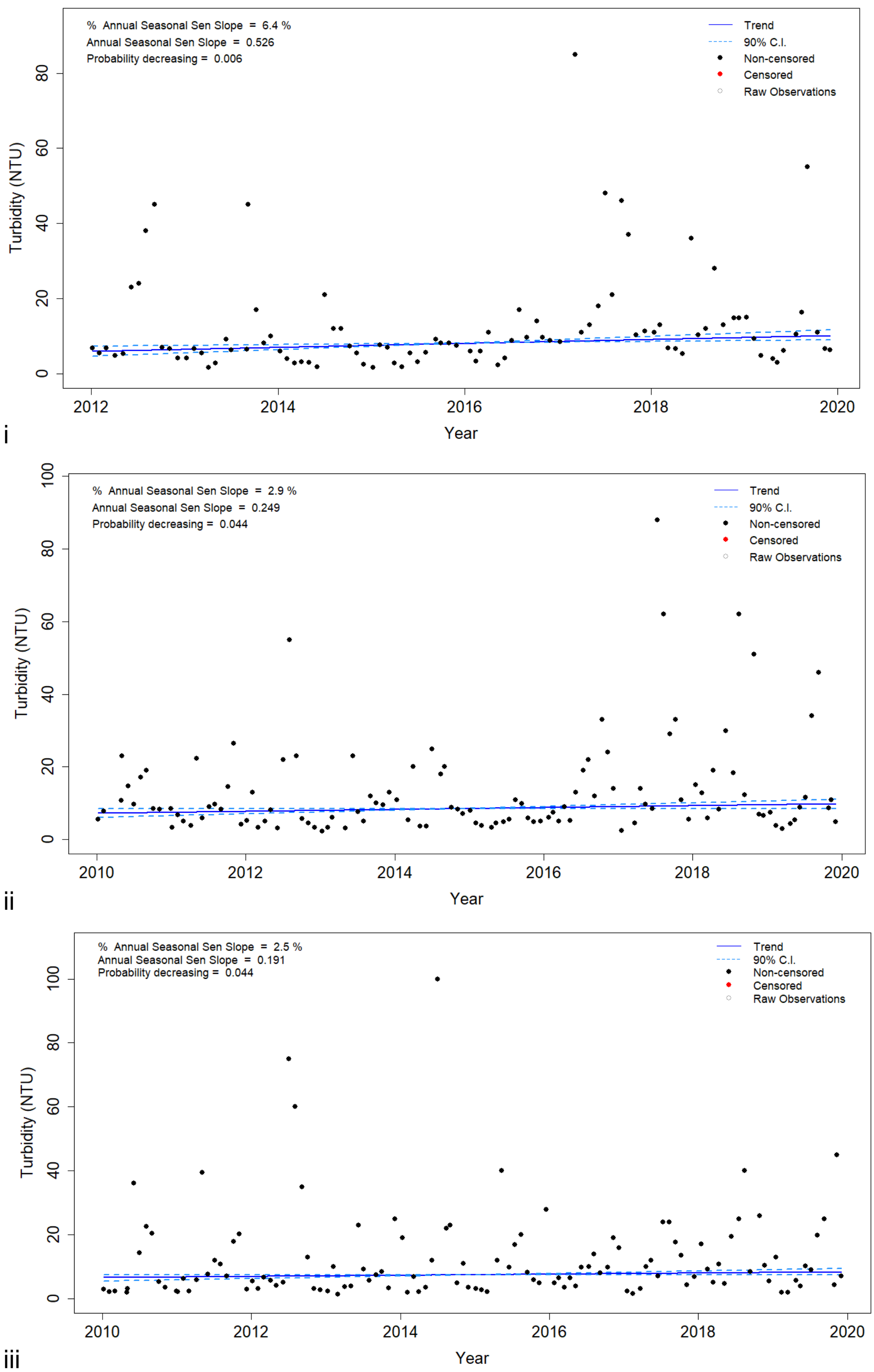


Figure 6-18: Observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for (i) Papakura Stream (upper)), (ii) Vaughan Stream, (iii) Oteha River.

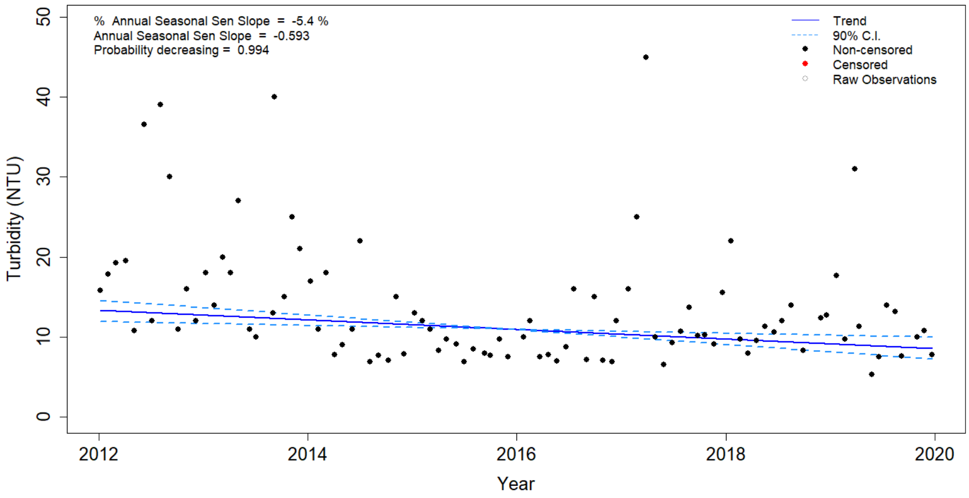


Figure 6-19: Observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for Avondale Stream.

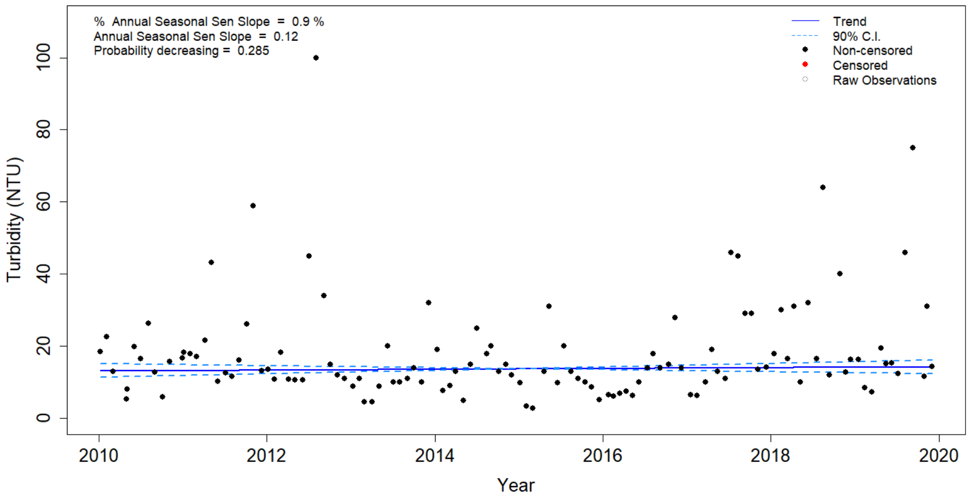


Figure 6-20: Observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for Okura Creek.

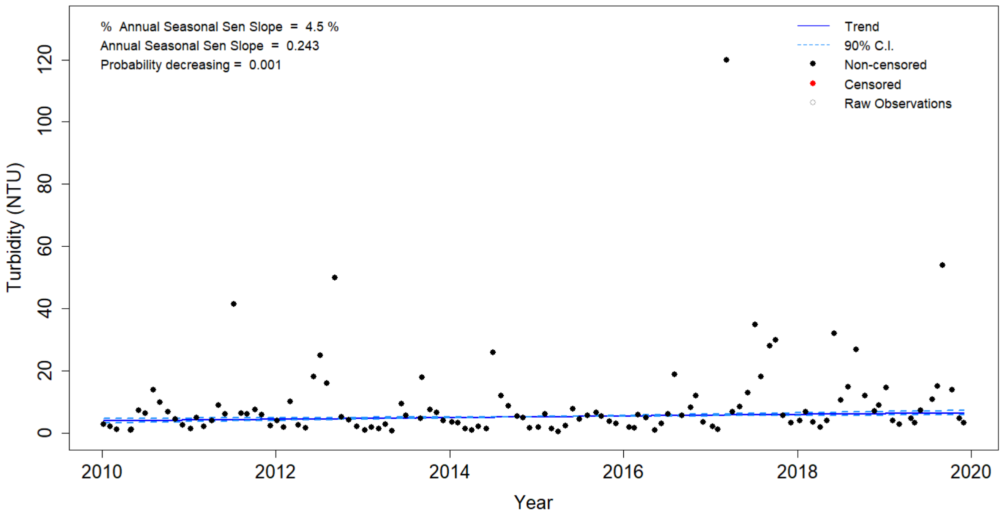
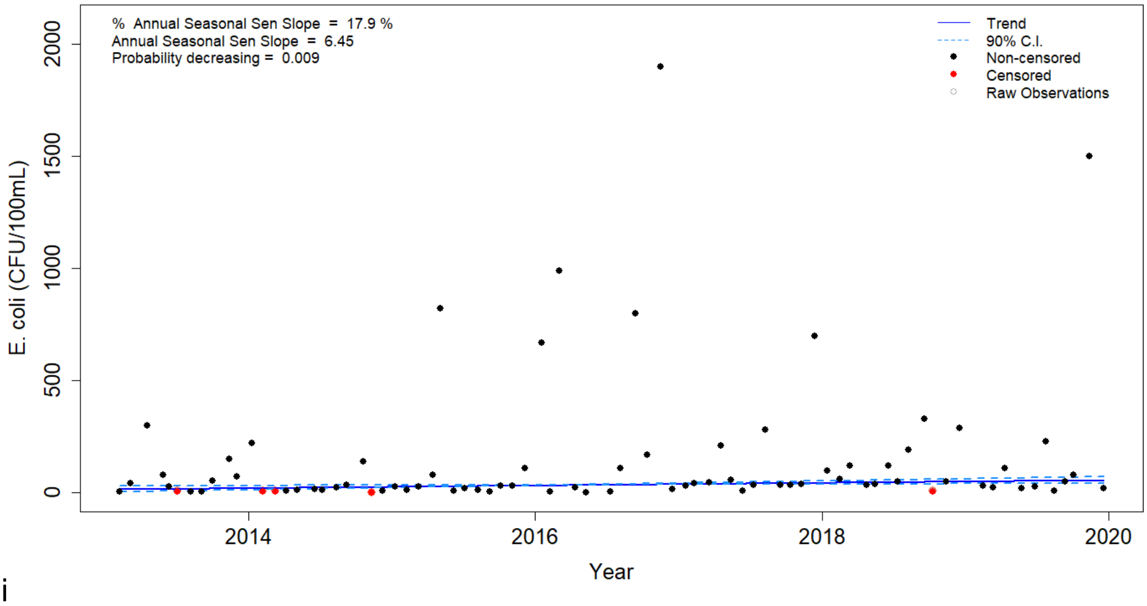


Figure 6-21: Observations of turbidity over time fitted with annual Sen Slope and 90% confidence intervals for Papakura Stream (Lower).

E. coli



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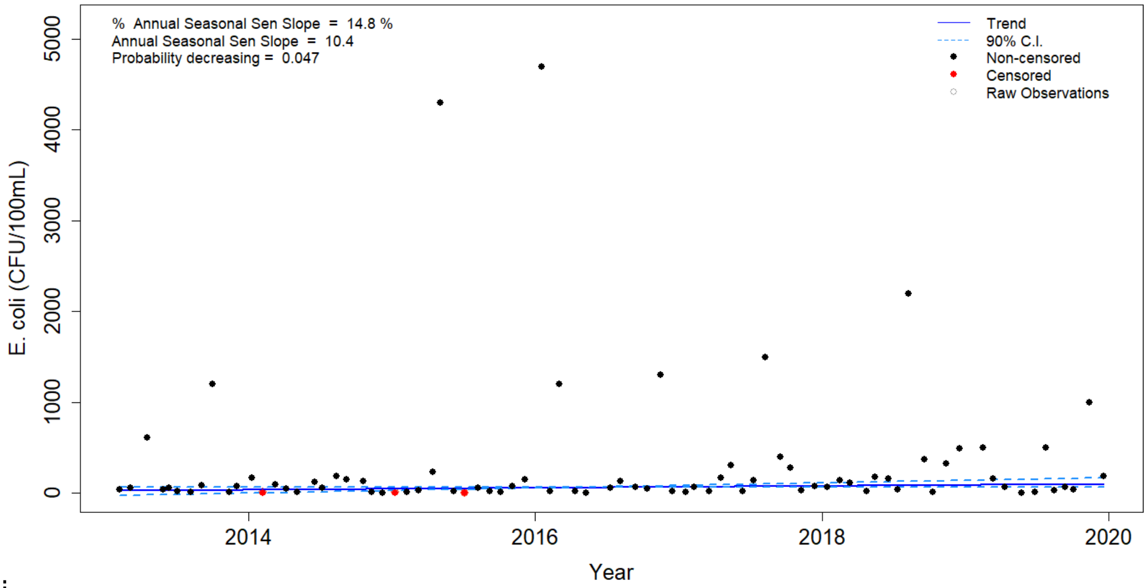

ii

Figure 6-22: Observations of *E. coli* over time fitted with annual Sen Slope and 90% confidence intervals for – Waitangi Island streams (i) Onetangi Stream, (ii) Cascades Stream.

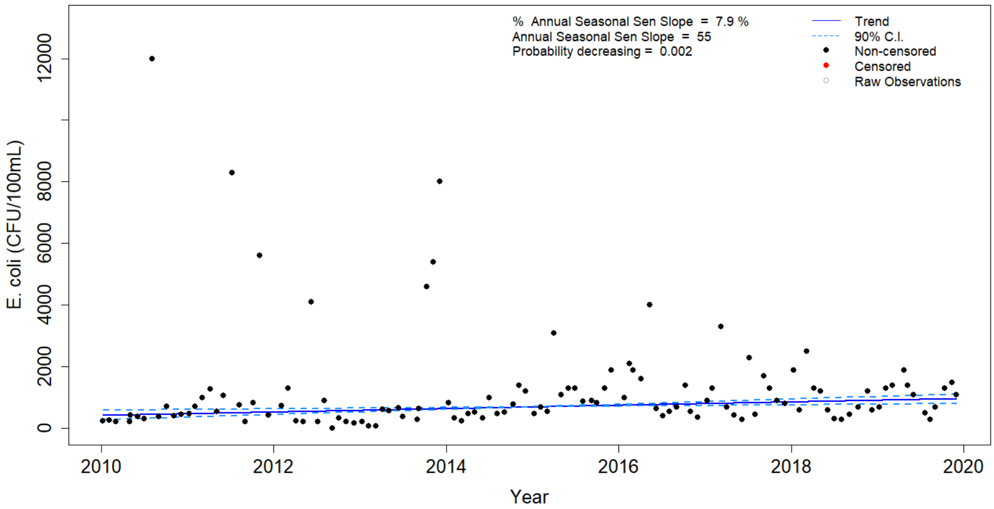

Figure 6-23: Observations of *E. coli* over time fitted with annual Sen Slope and 90% confidence intervals for Whangamaire Stream.

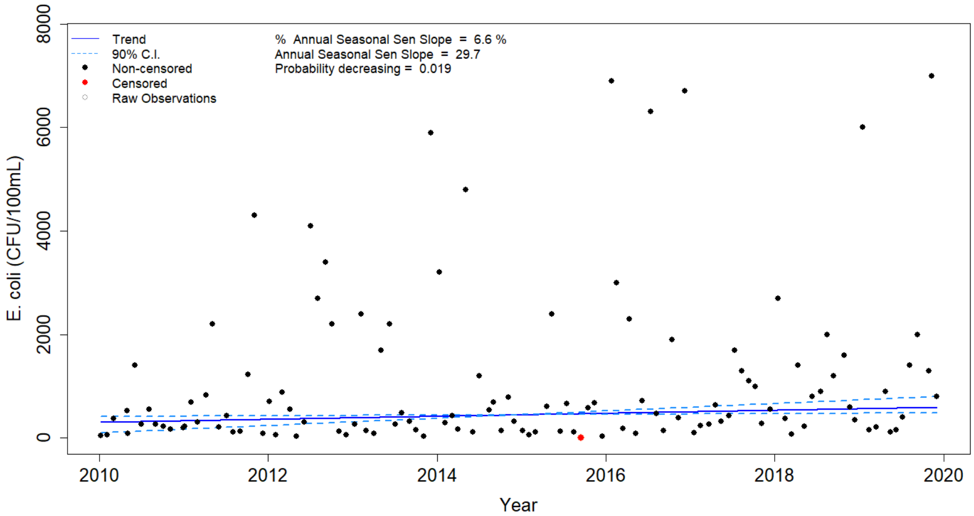

Figure 6-24: Observations of *E. coli* over time fitted with annual Sen Slope and 90% confidence intervals for Oteha River.

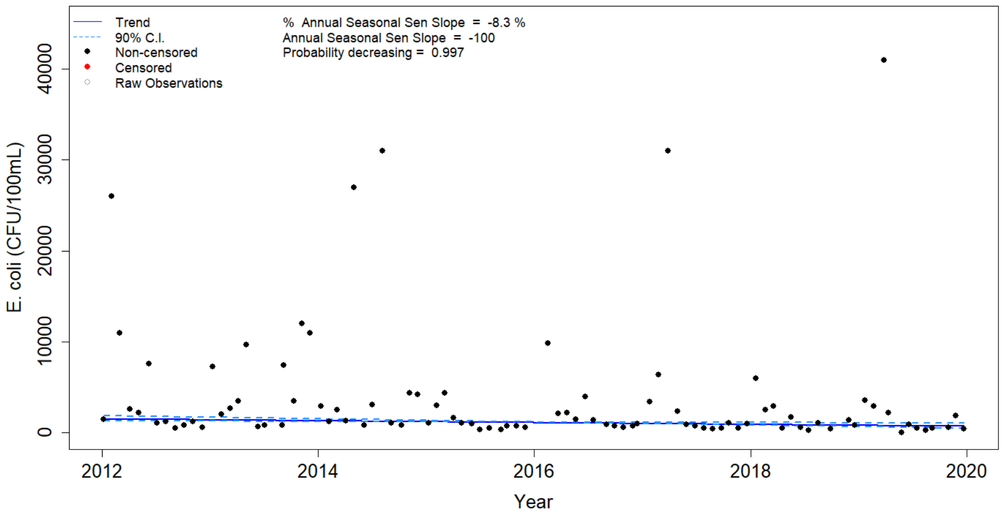

Figure 6-25: Observations of *E. coli* over time fitted with annual Sen Slope and 90% confidence intervals for Avondale Stream.

Soluble copper

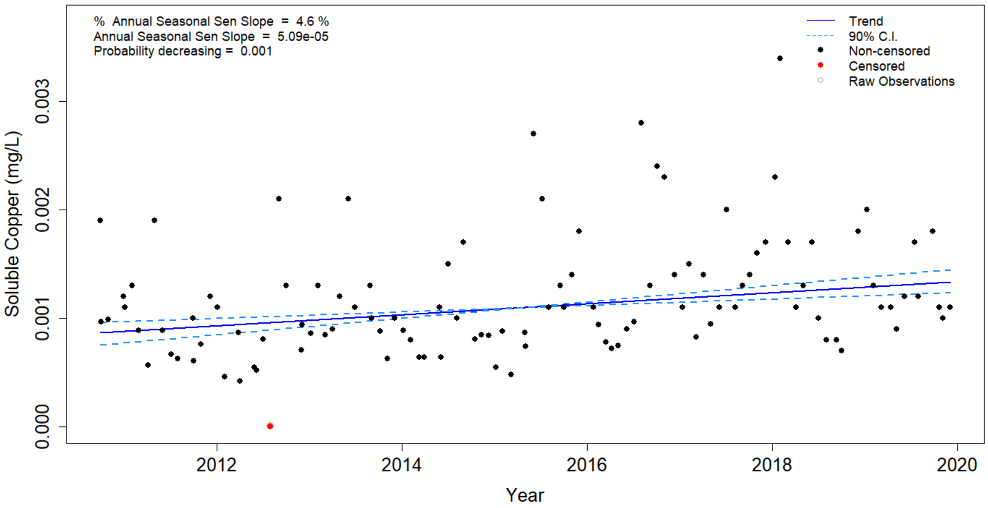

Figure 6-26: Observations of soluble copper over time fitted with annual Sen Slope and 90% confidence intervals for Kumeu River.

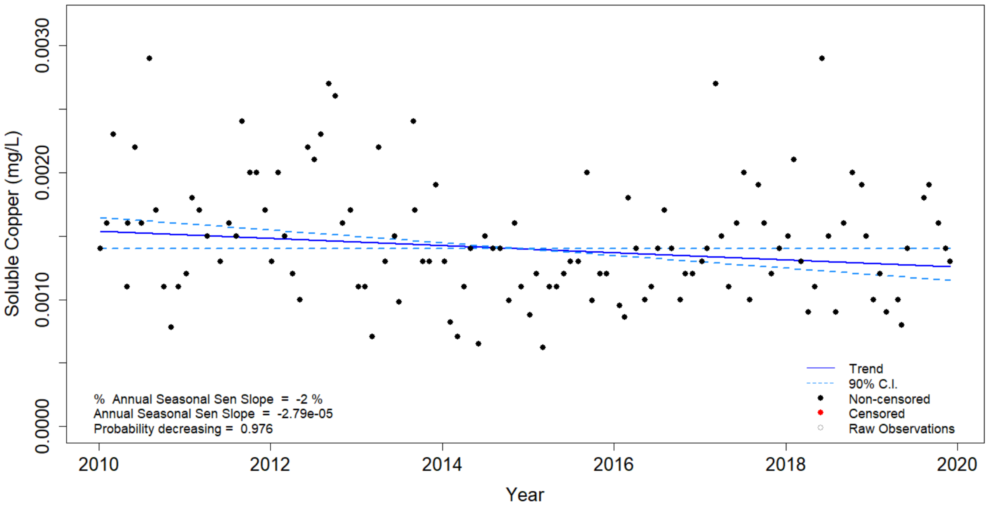

Figure 6-27: Observations of soluble copper over time fitted with annual Sen Slope and 90% confidence intervals for Puhinui Stream.

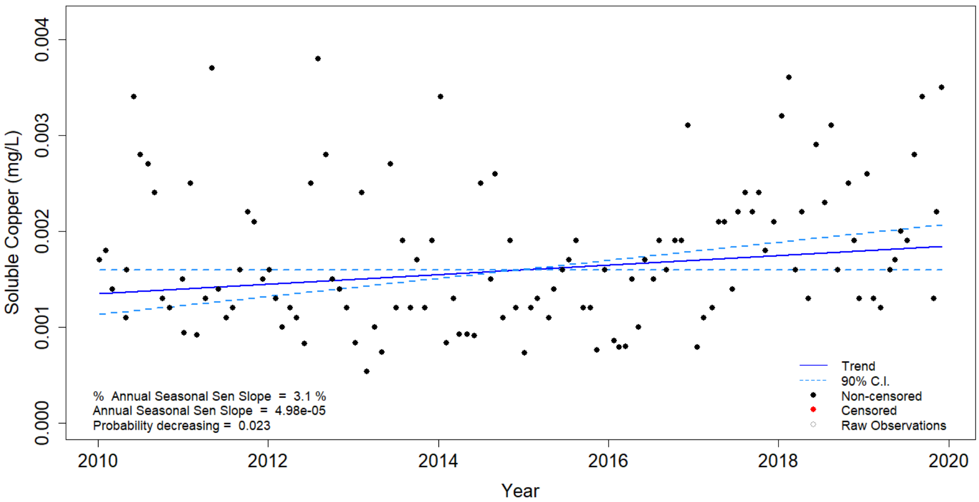

Figure 6-28: Observations of soluble copper over time fitted with annual Sen Slope and 90% confidence intervals for Oteha River.

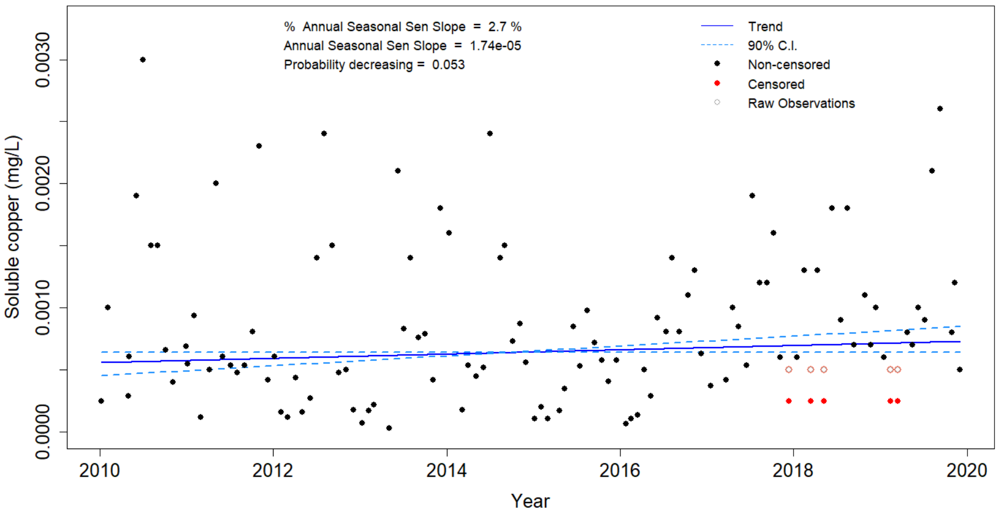

Figure 6-29: Observations of soluble copper over time fitted with annual Sen Slope and 90% confidence intervals for Vaughan Stream.

Soluble zinc

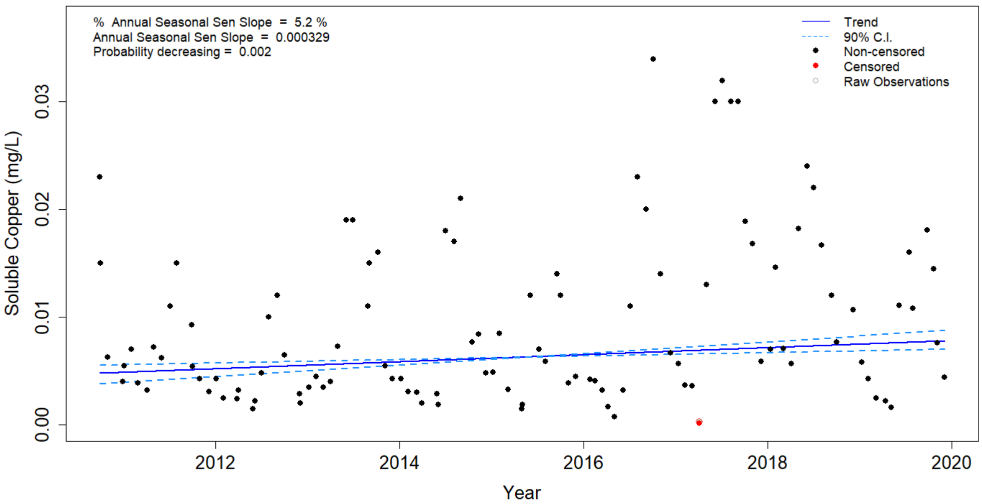

Figure 6-30: Observations of soluble zinc over time fitted with annual Sen Slope and 90% confidence intervals for Riverhead Stream.

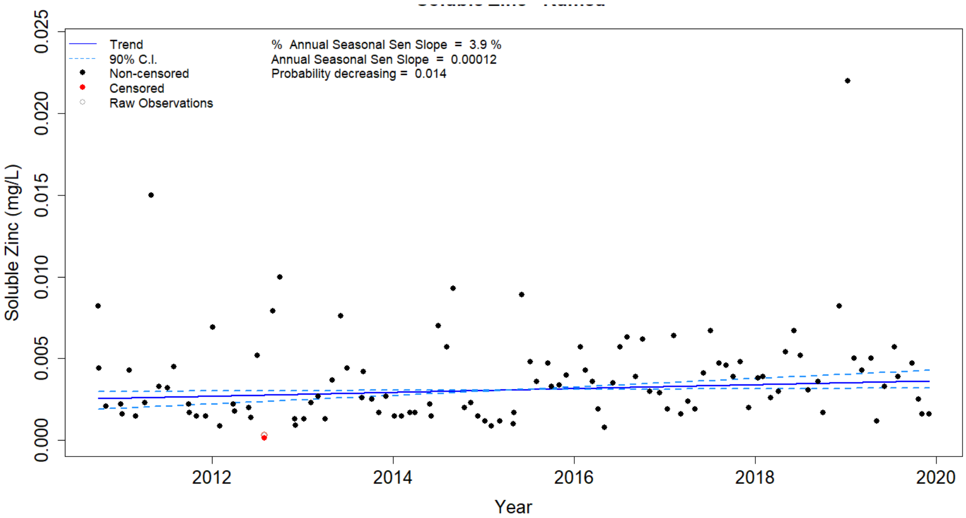

Figure 6-31: Observations of soluble zinc over time fitted with annual Sen Slope and 90% confidence intervals for Kumeu River.

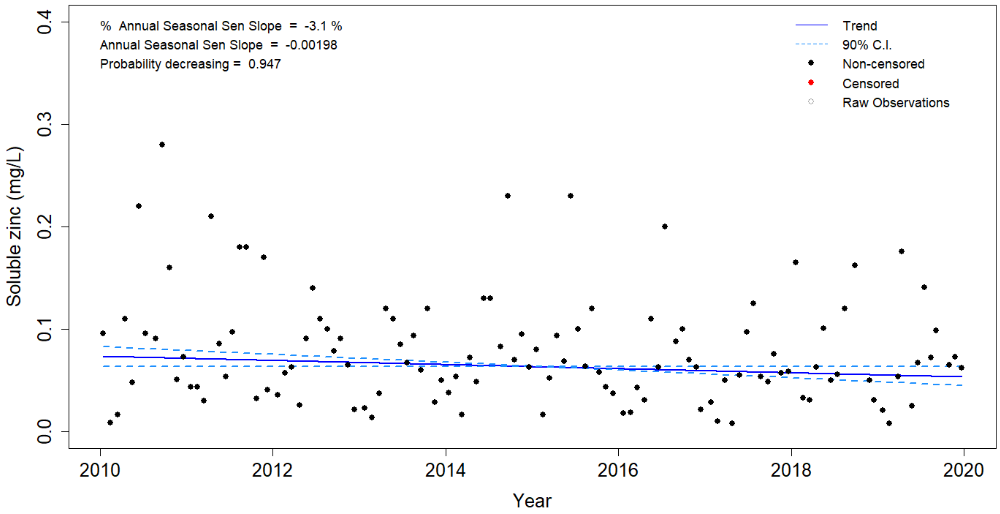

Figure 6-32: Observations of soluble zinc over time fitted with annual Sen Slope and 90% confidence intervals for Omaru Creek.

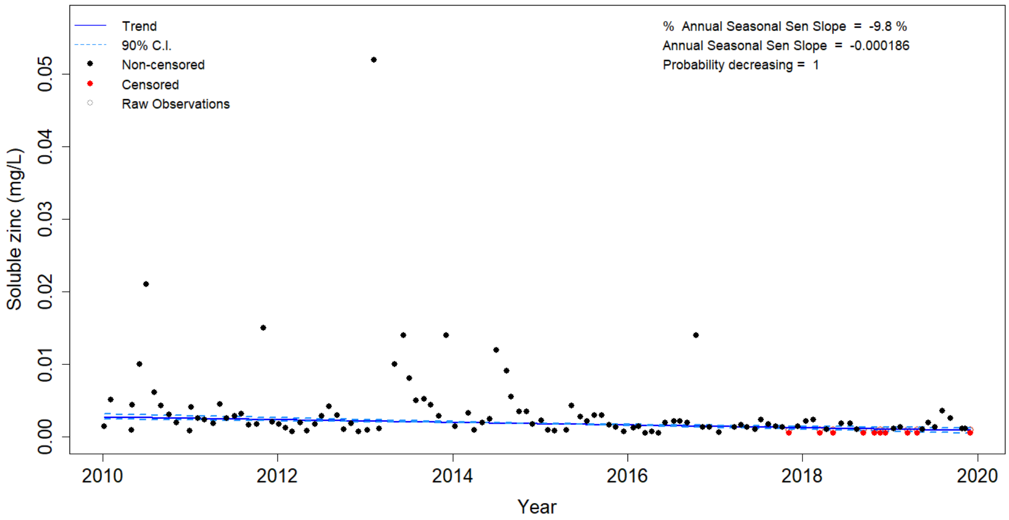

Figure 6-33: Observations of soluble zinc over time fitted with annual Sen Slope and 90% confidence intervals for Vaughan Stream.

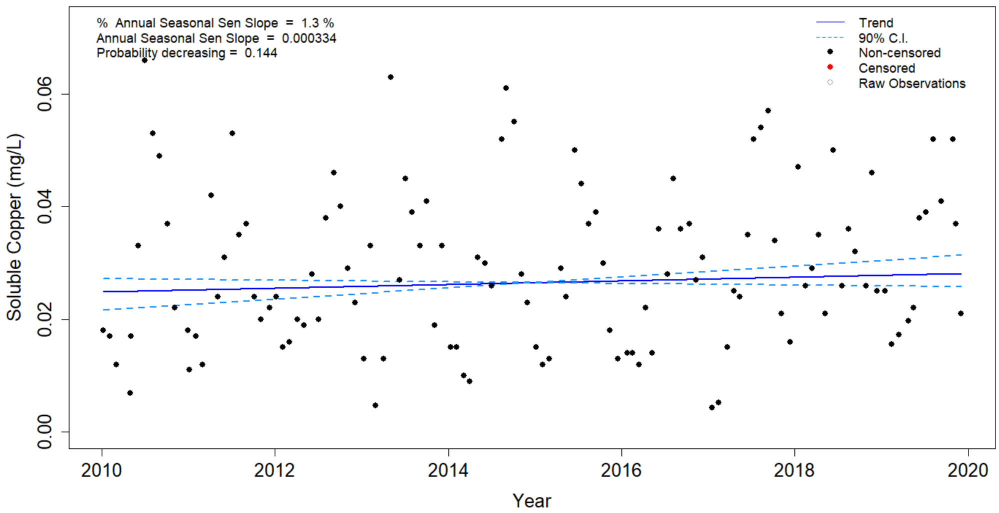

Figure 6-34: Observations of soluble zinc over time fitted with annual Sen Slope and 90% confidence intervals for Oteha River.

Find out more: phone 09 301 0101, email
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aucklandcouncil.govt.nz and knowledgeauckland.org.nz