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Regional river water quality monitoring programme: Data report 2023

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Executive Summary

Waikato Regional Council (WRC) has monitored river water quality for over 30 years

The Waikato Regional Council (WRC) monitors river water quality through the Waikato River Monitoring Programme (WaRiMP) and the Regional Rivers Monitoring Programme (ReRiMP), established in 1989 and 1993, respectively. The data from these programmes underpin the assessment of the state, trends, and drivers of riverine water quality.

This report provides an overview of the regional monitoring programme and data

This report provides an overview of the ReRiMP, including sampling and measurement protocols, laboratory analyses, quality assurance procedures, a timeline of changes, and a summary of water quality data and state.

We monitor 110 rivers for 18 water quality parameters

Eighteen physical, chemical, and microbiological parameters are monitored monthly at 110 regional river sites under ReRiMP. We summarise these parameters for five hydrological years from 2018 to 2023. This approach contrasts with previous ReRiMP data reports that summarised data by calendar year.

We assess the state of river water quality using relevant guidelines

This study applies the National Policy Statement for Freshwater Management (NPS-FM) water quality attribute states for ecosystem health and human contact values. In contrast, previous reports used the WRC water quality criteria. The NPS-FM classifies freshwater states with bands ranging from A (good) to D (poor) and an additional band, E, for *Escherichia coli* (*E. coli*). A key feature of the NPS-FM is the national bottom line, which represents the minimum acceptable state for specific freshwater attributes. We classify attribute states at or below the national bottom line as failing to meet this minimum standard for water quality.

This report also summarises key physio-chemical parameters, including water temperature, conductivity, and pH. Although these parameters are fundamental to understanding riverine water quality, the NPS-FM does not include them as attributes. Therefore, we use alternative assessment criteria to evaluate.

More than half of our rivers show sediment impacts

Over 51% of sites failed to meet the national bottom line for sediment. Indicating that the potential impacts of sediment on instream fauna are widespread across the region. In contrast, only 26% of sites fell below the national bottom line in the 2017 NPS-FM baseline assessment. A decline that could reflect degradation, but could also be driven by climate-driven state shifts. Highlighting the need to consider climate-driven variability when setting target states. Gap-filling processes may also contribute to the differences between assessment periods, particularly since we gap-filled 15% of the visual clarity data and identified limitations with generic gap-filling regressions. We are developing an in situ transmissometer system to reduce the proportion of data gaps and provide recommendations to improve gap-filling regressions.

Some of our rivers are enriched in organic matter, influencing water clarity

The levels of organic matter absorbance varied substantially across the region. Notably, several rivers that fell below the national bottom line for sediment, as measured by visual clarity, also show high levels of organic matter absorbance. The visual clarity metric is affected by light attenuation, which results from both particulate scattering and organic matter absorption. Therefore, quantifying the influence of organic matter absorbance on water clarity is essential to define the state appropriately and to set relevant targets for sediment reductions. Interestingly, we identified a positive association between organic matter absorbance and phosphorus, suggesting that strategies to reduce phosphorus levels could also reduce organic matter absorbance, with improved optical clarity.

The analytical detection limit (i.e., censored data) affected a high proportion of absorbance data. A simple method change will address this limitation. Additionally, gap-filling regressions for visual clarity should include the optical influence of organic matter absorbance.

Over half of river monitoring sites show elevated faecal contamination

Although the *E. coli* attribute does not specify a national bottom line, 52% of sites were classified in the E band, indicating high faecal contamination and elevated pathogenic risk for human health. Our regional data shows positive associations between *E. coli*, organic forms of nitrogen, and turbidity. Indicating that sediment-associated transport mechanisms are associated with faecal enrichment across monitoring sites and that catchment initiatives targeting sediment inputs could result in concurrent improvements to faecal inputs.

Our rivers show nitrogen enrichment, but toxicity effects are limited

Nitrogen toxicity was relatively low across the region. For ammonia and nitrate, 3.6% and 6.4% of sites failed to meet the national bottom line (i.e., classified as C and D band). However, nitrogen-associated eutrophication impacts can occur at concentrations much lower than those considered toxic, which the NPS-FM does not directly address. Although dissolved inorganic nitrogen is more readily bioavailable, several rivers across the Waikato are characterised by high organic nitrogen concentrations. Therefore, total nitrogen is the most appropriate measure for assessing potential nitrogen-driven eutrophication. Compared to an applied criteria of 1 g/m^3, 40% of sites showed potential for nitrogen-driven ecosystem impacts.

More than half of our rivers show substantial phosphorus enrichment

For phosphorus, which does not have a national bottom line, 59% of sites exhibited moderate to substantial phosphorus enrichment (combined C and D bands), indicating the potential for phosphorus-driven eutrophication pressures across the region. The fraction of total to dissolved phosphorus was highly variable, with several sites graded as A or B band (i.e., no adverse to slight impacts) having very high total phosphorus concentrations. This finding suggests that the NPS-FM dissolved phosphorus attribute may not fully capture phosphorus impacts in the Waikato region, meaning that total phosphorus is an important measure for assessing phosphorus-related state.

Warmer, low-gradient rivers in wetland and peatland catchments are at risk of low dissolved oxygen

Our dissolved oxygen data is discrete rather than continuous, so it is not directly comparable to the NPS-FM dissolved oxygen attribute. Instead, we compared the 5^{th} percentile of discrete measurements to the criterion of 6.5 mg/L to identify sites with potential hypoxic (low dissolved oxygen) risks. This approach identified 16% of sites at risk of riverine hypoxia. These rivers, primarily in the lower Waikato and Hauraki, are characterised by warmer temperatures, lower gradients, and catchments with upstream wetland and peatland areas. Regional analysis further revealed that higher water temperatures correspond with lower dissolved oxygen levels, underscoring both the immediate role of temperature and the compounding pressure of climate-driven change. We recommend deploying continuous dissolved oxygen loggers at sites identified as at risk of riverine hypoxia to allow for NPS-FM state assessments and better understand hypoxia drivers.

Insights from water temperature, conductivity, and pH data

This study shows that over 50% of rivers across Waikato have occasional to significant thermal stress effects. Collecting continuous temperature data at sites identified as higher risk will improve our understanding of thermal stress to aquatic biota and identify sites to prioritise improvement initiatives.

Across the region higher conductivity was associated with higher nitrate concentrations. In comparison to an aquatic life benchmark, we identified 13 sites (11.8%) in exceedance. At these sites it is recommended that supplementary monitoring of major ions and metal(loid)s is completed to quantify the constituents contributing to conductivity and to examine changes with time.

The pH of rivers across the region was generally within applied criteria. This study identified a regional association between pH and ammonia, with higher pH associated with lower ammonia concentration. However, as water pH rises, the toxicity of ammonia increases. As pH varies daily, improving our understanding of pH daily fluctuations at key sites and completing further analyses will improve our understanding of the relationship between pH and ammonia concentrations and toxicity risk.

Concluding insights and programme improvements

This report provides an overview of how we monitor and assess riverine water quality in the Waikato region. It identifies areas for programme improvements for data quality and assessment of state, trends, drivers, and targets. While this report examines each attribute independently, many rivers show poor state for multiple attributes. Consequently, our rivers often have multiple stressors with complex interactions, and climate-driven change could exacerbate these stressors.

1 Introduction

1.1 Background

Waikato Regional Council (WRC) river water quality monitoring is comprised of two programmes: the Waikato River Monitoring Programme (WaRiMP) and the Regional Rivers Monitoring Programme (ReRiMP) (Figure 1; Appendix A). These programmes measure physio-chemical and microbial properties to track water quality state and trends across the rivers of the Waikato region.

WaRiMP began in 1989 and includes 12 sites, while ReRiMP began in 1993 and includes 110 sites. For a detailed timeline of ReRiMP, see Appendix B. The lake and coastal programmes also measure water quality. Collectively, these programmes provide a comprehensive water quality dataset across the region (Figure 2).

The river programmes are supplemented with periodic and campaign-based projects to improve methods and characterisation of water quality. For example, major ions and metal(loid)s[1] are monitored on a periodic five-year cycle. From November to March (summer recreational season), additional microbial risk monitoring is completed at 30 ReRiMP and six WaRiMP sites. This document does not include the recreational, periodic, and campaign-based data. See Section 1.3 for links to access this data.

This report presents State of the Environment (SOE) data from 110 ReRiMP sites across five hydrological years, from the 1st of July 2018 to the 30th of June 2023. It focuses solely on river water quality monitoring and does not include data on aquatic life (e.g., periphyton, fish, macroinvertebrates) or physical habitat (i.e., deposited sediment) values reported in the Regional Ecological Monitoring of Streams (REMS) programme.

1.2 Purpose

This report provides an overview of ReRiMP sites, parameters, and methods. It highlights programme changes, recommends improvements, summarises monitoring data, and assesses the state of water quality against relevant guidelines.

1.3 Supplementary Links and Data Request Process

For further information on WRC water quality publications, please visit our website at http://www.waikatoregion.govt.nz/Publications/.

To request water quality monitoring data or information, use the request for service form at www.waikatoregion.govt.nz/request.

Additionally, Land, Air, Water Aotearoa (LAWA) is a comprehensive online resource that provides environmental[2] and recreational (can I swim here?)[3] water quality monitoring data at a national level. LAWA presents a subset of the parameters reported here and includes raw data, state and trend analyses, and educational resources. Waikato regional data on the LAWA website can be accessed at https://www.lawa.org.nz/explore-data/waikato-region.

[1] Metal(loid)s refers to metals and metalloids.
[2] https://www.lawa.org.nz/explore-data/waikato-region/river-quality
[3] https://www.lawa.org.nz/explore-data/swimming

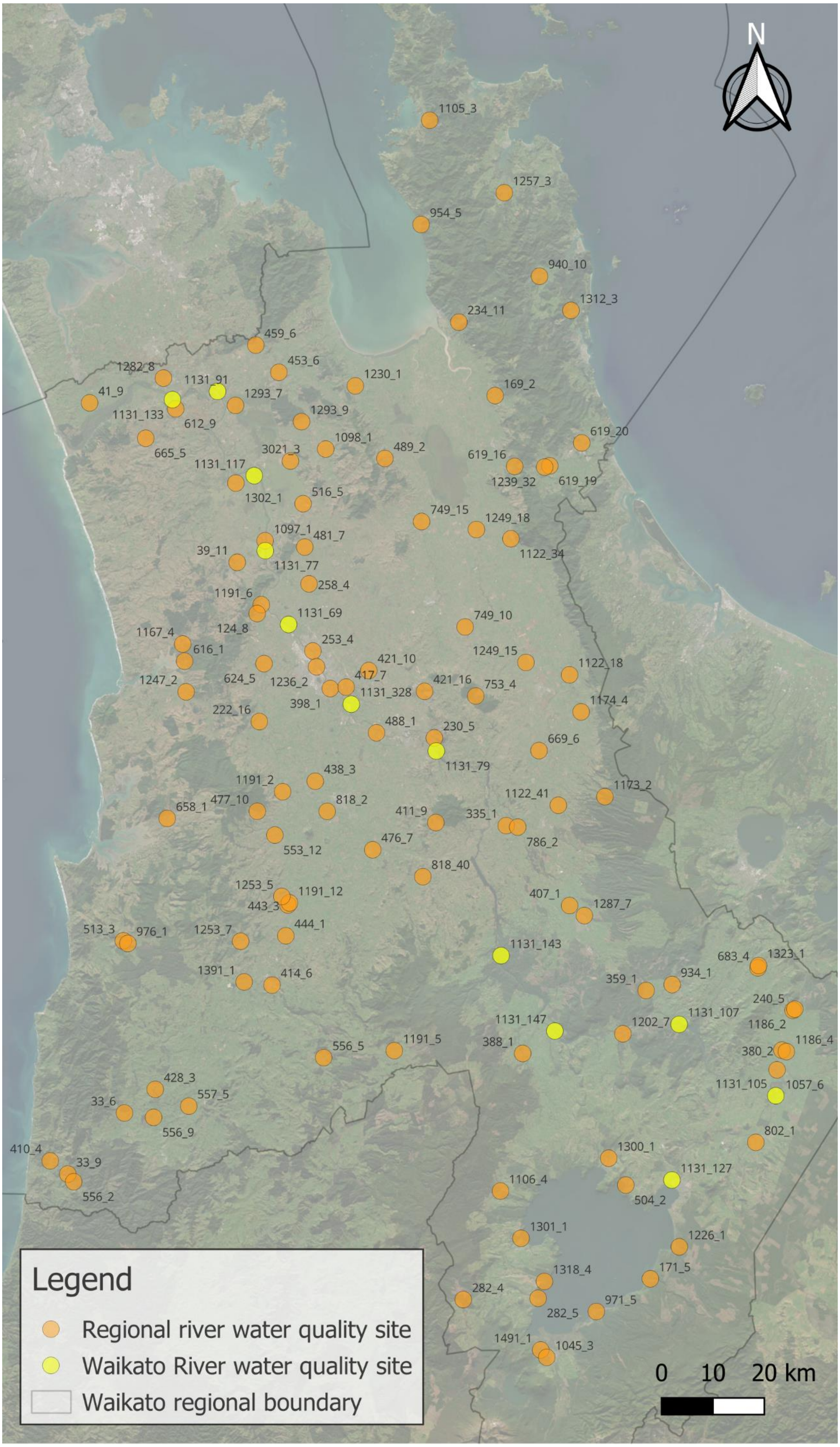

Figure 1 Location of Regional Rivers Monitoring Programme (ReRiMP) and Waikato River Monitoring Programme (WaRiMP) sites. Numeric labels represent Site_Station identifier.

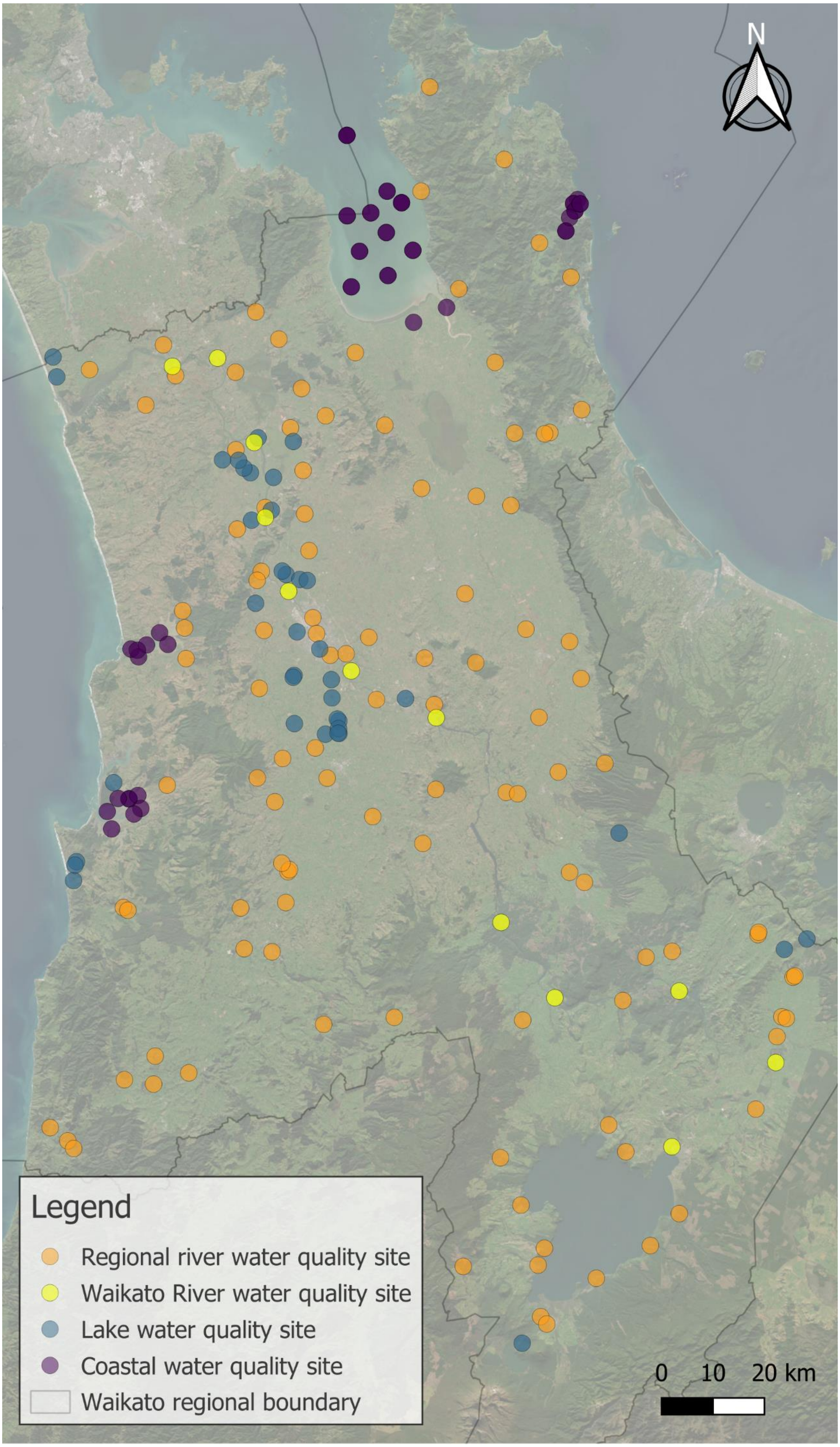

Figure 2 Waikato regional river, lake, and coastal water quality monitoring sites.

2 Methods

2.1 Water Quality Sampling, Analyses, and Quality Control

WRC Environmental Monitoring Scientists conduct monthly SOE water sampling and measurements. Typically, these datasets are complete with 12 samples each year. However, logistical or health and safety constraints sometimes prevent sampling. The sampling process involves visiting sites in a predetermined sequence each month, ensuring that sampling occurs at approximately the same time of day for each site. This punctual sampling approach minimises variation from diurnal changes in water quality measurements. It also ensures that the sampled flow distribution corresponds to the actual flow distribution.

Monitoring physical, chemical, and microbiological water quality parameters is used to assess ecosystem water quality and human health values. A total of 18 parameters (Table 1), comprised of four field measurements and 14 laboratory analyses, are monitored at all sites (except for black disc [BDISC]; see Section 2.2.5.4 for details). Appendix C details the parameter analytical method and detection limit.

Table 1 Water quality parameters with reporting short name, units, and type (laboratory or field measurement).

Parameter	Short name	Units	Measurement type
Absorbance at 340 nm	A340	AU cm^{-1}	Laboratory
Absorbance at 440 nm	A440	AU cm^{-1}	Laboratory
Absorbance at 780 nm	A780	AU cm^{-1}	Laboratory
pH	pH	$-\log_{10}[H^{+}]$	Laboratory
Specific Conductivity at 25°C	COND	µS/cm	Laboratory
Water Temperature	TEMP	°C	Field
Black disc	BDISC	m	Field
Turbidity	TURB	NTU	Laboratory
Dissolved oxygen (mg/L)	DO	mg/L	Field
Dissolved oxygen (%)	DO%	%	Field
Dissolved Reactive Phosphorus	DRP	g/m^3	Laboratory
Total Phosphorus	TP	g/m^3	Laboratory
Escherichia coli	*E. coli*	cfu/100mL	Laboratory
Enterococci	ENT	cfu/100mL	Laboratory
Faecal Coliforms	F.coli	cfu/100mL	Laboratory
Total Kjeldahl Nitrogen	TKN	g/m^3	Laboratory
Ammoniacal Nitrogen	TAN	g/m^3	Laboratory
Nitrate + Nitrite-Nitrogen	TON	g/m^3	Laboratory

2.1.1 Supplementary Monitoring

Since its inception, the programme has included major ions[4] testing every five years at all sites, for one year. Similarly, from 2009, metal(loid)s were monitored at a subset of ReRiMP sites

[4] Major ions are the positively and negatively charged ions such as calcium, sodium, potassium, magnesium, bicarbonate, chloride, sulphate, and fluoride present in water. These are the constituents that contribute to the amount of total and dissolved solids and specific conductance in waters.

(n=11). In 2018-2019, pesticide screening[5] occurred at four of the 11 metal/metalloid monitoring sites. Aligning future major ion and metal/metalloid monitoring is important for understanding environmental dynamics and toxicity (e.g., water hardness[6], alkalinity, pH, temperature, and organic matter influence metal/metalloid toxicity). The next round of major ions (n=110) and metal(loid)s (n=10) [7] testing is the 2025 hydrological year (1st July 2025 to 30th June 2026). This document does not report these supplementary datasets. See Section 1.3 for links to reporting and data requests.

2.1.2 Field Measurements, Sample Collection, and Transport

Field measurements and sample collection follow WRC standard operating procedures and National Environmental Monitoring Standards (NEMS). Field-based measurements include visual clarity (BDISC), dissolved oxygen (DO), and water temperature (TEMP)[8]. Water samples are collected 20 cm below the water surface using clean laboratory-supplied sample containers. The reporting of measurement and sample collection time uses the New Zealand Standard Time (NZST) format. Samples are stored in the dark, on ice, and transported directly to Hill Labs (IANZ)[9] for analysis following daily site visits. Water samples are held at Hill Labs for two weeks until results have been verified by WRC quality assurance and quality control procedures (see Section 2.1.3).

2.1.3 Data Quality Assurance, Database, and Processing

The WRC-developed tool Sampler automatically processes quality assurance and control checks of analytical results from Hill Labs. This tool prepares water quality data for importing into the WRC KiWQM and Wiski databases by running a series of automated quality checks. For example, database percentile statistics for each site/station/measurement combination are cross-checked with new data values to highlight outliers or erroneous values. Any result flagged by this process undergoes further investigation. For example, this could include reviewing sample metadata to explain the result or re-running sample testing at the laboratory.

2.1.4 Inter-laboratory and Field-based Quality Assurance Testing

An inter-laboratory quality assurance project has been running since 2019. This programme involves duplicate sampling of 13 parameters[10] at five ReRiMP[11] sites, with analytical testing completed at both Hill Labs and the NIWA[12] (Hamilton) Water Quality Laboratory. This data is not presented here but is available on request (see Section 1.3). A quality assurance project has not been completed testing field-based measurements (e.g., DO, TEMP, BDISC) and sample collection. To manage the quality of field-based measurements, in-house and inter-agency training is used.

[5] 2018 – 2019 pesticide screening completed at four sites (749_15 Piako River @Paeroa-Tahuna Rd Br, 619_16 Ohinemuri River @ Karangahake, 1191_2 Waipa River @ Pukehoua Bridge on Baffin Road, 1122_18 Waihou River @ Okauia).

[6] Toxicity values for metals (i.e., cadmium, chromium, copper, lead, nickel, zinc) have been derived for a low (or soft) water hardness of 30 g/m^3 $CaCO_3$ which corresponds to higher toxicity. Therefore, if water hardness is known then trigger values can be adjusted for site-specific hardness as per formula presented in ANZECC (2000). For example, the average hardness for the Waikato River is 40 g/m^3 $CaCO_3$, which would result in guideline increasing by 1.27 to 1.44 times default guideline.

[7] 619_16 Ohinemuri River at Karangahake, 749_15 Piako River at Paeroa-Tahuna Rd Br, 1122_18 Waihou River at Okauia, 41_9 Awaroa River, 1293_7 Whangamarino River at Island Block Road, 258_4 Komakorau Stm at Henry Road, 253_4 Kirikiriroa Stm at Tauhara Dr, 1236_2 Waitawhiriwhiri Stm at Edgecumbe Street, 1191_2 Waipa River at Pukehoua Bridge on Baffin Road, 1249_18 Waitoa River at Mellon Rd Recorder.

[8] Dissolved oxygen and temperature are measured using a Hach HQ30D portable meter paired with an LDO101 rugged field luminescent dissolved oxygen sensor calibrated daily using 100% saturation and reference thermistor cross-validation per standard operating procedures.

[9] International Accreditation New Zealand.

[10] Laboratory testing includes Total Coliforms, *Escherichia coli*, Absorbance at 340 nm, Absorbance at 440 nm, Absorbance at 780 nm, Turbidity, pH, Electrical Conductivity, Ammoniacal Nitrogen, Nitrate-Nitrogen + Nitrite-Nitrogen, Dissolved Reactive Phosphorus, Total Phosphorus.

[11] 1122_34 Waihou River at Te Aroha, 1191_6 Waipa River at Ngaruawahia Bridge, 234_11 Kauaeranga River at Smiths Cableway recorder, 556_9 Mokau River at Totoro Rd Recorder, 971_5 Tauranga-Taupō River Upstream of SH1 Bridge.

[12] National Institute of Water and Atmospheric Research

2.2 Data Analysis

2.2.1 Summary Statistics and Data Visualisation

Water quality data summaries for five hydrological years (1^{st} July 2018 to 30^{th} June 2023) use Hazen percentiles (5^{th}, 50^{th}, 95^{th}). Boxplots for all sites, for each water quality parameter, are provided in Appendix D. Geospatial figures present 5^{th}, 50^{th} (median), and 95^{th} percentile data (see Section 3). The combination of plotted percentiles represents data with the most applicability to ecosystem or human health. For example, DO uses 5^{th} and 95^{th} percentile data to highlight low DO (hypoxic) and high DO (supersaturation) risk. Whereas *E. coli* is presented with median and 95^{th} percentile as elevated counts correspond to human health contact recreation risk.

Each point on the figure represents a monitoring location, with colour and point size indicating the value. The colour gradient (Figure 3) ranges from blue to yellow, where blue reflects better environmental or human health conditions, and yellow reflects poorer conditions. For example, both low and high extremes of dissolved oxygen (DO) are mapped towards the yellow end to reflect potential environmental stress. Point size is proportionally scaled based on normalised values to enhance visual contrast.

Figure 3 Colour gradient used for water quality data visualisation.

2.2.2 Analytical Detection Limits

Analytical results reported at laboratory Limits of Detection (LOD) are known as non-detect or censored values. LOD results mean the value is not quantified but is known to be either less than or exceeding a threshold value (i.e., left-censored and right-censored, respectively). For example, the analytical detection limit for Total Ammoniacal Nitrogen (TAN) is 0.010 g/m^3. If a value is at or below LOD (left-censored), then the concentration is recorded as < 0.010 g/m^3.

There are several processes to handle censored observations, such as substitution, Maximum Likelihood Estimation (MLE), and Regression on Order Statistics (ROS) (Rangeti et al. 2015). The standard approach used at WRC is substitution, where left-censored values are 0.5 times the LOD (i.e., < LOD = LOD/2) and right-censored values (e.g., microbial) equal to LOD (i.e., > LOD = LOD). As a result, the TAN example of < 0.010 g/m^3 is then reported as 0.005 g/m^3.

It is important to acknowledge the potential limitation of the substitution method in comparison to MLE and ROS methods. Substitution of a constant fraction multiplied by the reporting limits can lead to erroneous estimates of summary statistics, particularly if a large proportion of the values are at the detection limit. In contrast, methods like MLE and ROS can more accurately handle censored data and are less likely to skew summary statistics or impact trend analysis.

2.2.3 Statistical Correlations and Principal Component Analysis

This report uses Spearman rank correlation coefficients (r_s) to assess monotonic relationships between water quality parameters across the Waikato region ($\alpha < 0.01$). Principal Component Analysis (PCA) was used to examine associations between variables and identify variables explaining variation in the water quality dataset across the Waikato region. All parameters, apart from absorbance at 780 nm, were included from the five-year reporting period. Although PCA performs well when several parameters correlate, highly correlated (Pearson correlations [r_p]) variables were removed from the PCA to improve the interpretation of results. Missing values in the data matrix were substituted using a moving average with a window size of five months. Standardisation of all variables using z-score normalisation accounted for different measurement scales between parameters. Data was not transformed for normality as this is not a strict requirement for PCA testing. The analysis included calculating eigenvalues, eigenvectors, and explained variances. Principal components (PCs) with eigenvalues less than one are often excluded. To enhance the interpretability of the PCA results, a varimax rotation was applied to the PC loadings to generate rotated components (RCs). This orthogonal rotation method maximises the variance of squared loadings of each factor, making it easier to identify which variables are associated with which principal components. The PCA included censored data.

2.2.4 Water Quality Guidelines

Previous reports compared water quality data to the WRC water quality guidelines (Aroha 2023). These guidelines were developed based on a range of datasets and guidelines (Davies-Colley 1991; ANZECC 1992; MfE 1994; Maasdam and Smith 1994; Smith and Maasdam 1994; Stephan et al. 1998; MfE 2003a). For example, values derived for nitrogen and phosphorus used percentile banding from the NIWA National River Water Quality Network (NRWQN) (Maasdam and Smith 1994; Smith and Maasdam 1994). However, since the inception of the WRC water quality guidelines, a number of guidelines have been revised (ANZECC and ARMCANZ 2000; ANZG 2018) and The National Policy Statement for Freshwater Management 2020 (NPS-FM 2020) introduced. Therefore, for reporting to be current and nationally consistent, this report prioritises comparison to NPS-FM (2020) attributes, followed by ANZG (2018), ANZECC and ARMCANZ (2000), and relevant literature.

2.2.5 National Policy Statement for Freshwater Management (NPS-FM 2020) Attribute State

The NPS-FM (2020) provides a National Objectives Framework (NOF) that defines several attributes or indicators (e.g., ammonia toxicity) with associated banding to classify ecosystem and human health state for freshwaters. Ecosystem health attribute bands range from A – D (good to poor), and human health from A – E. For further information on NPS-FM attribute bands, see LAWA[13] and Ministry for the Environment (MfE)[14] publications.

2.2.5.1 Minimum Data, Percentile Method, and Grading

2.2.5.2 Attribute Grading: Data Requirements and Percentile Method

The general approach to attribute band grading adopted by LAWA and outlined in MfE (2018) guidance is to use Hazen percentiles from monthly SOE sampling collected over a five hydrological year period. LAWA grading requires a minimum of 90% or 54 of 60 monthly samples. As a result, there are instances where LAWA does not present an attribute state.

This report uses Hazen percentiles from five hydrological years but does not apply the LAWA minimum data requirements. This approach provides an overview of the best available dataset across the region. Attributes with multiple numeric state bands (i.e., median and 95th percentile categories) are assigned an overall attribute state equivalent to the worst band, as McBride (2016) recommended. For example, if the median (50th percentile) result is an A band and the 95th result is a B band, then the overall state for a site is graded as B. This approach is consistent with the LAWA method. The following sections outline the additional data requirements and processing methods to apply NPS-FM (2020) attribute gradings.

2.2.5.3 Nitrogen Parameters, Nitrate Proxy, and Ammonia Toxicity Standardisation

The analytical forms of nitrogen reported in freshwater monitoring are varied. The various forms of nitrogen reported are Total Nitrogen (TN), Total Ammoniacal-Nitrogen (NH_4-N or TAN), Nitrate-Nitrogen (NO_3-N), Nitrite-Nitrogen (NO_2-N), Total Kjeldahl Nitrogen (TKN), Organic Nitrogen (OrgN), Total Oxidised Nitrogen (TON or NNN), and Dissolved Inorganic Nitrogen (DIN). Equations Equation 1 to Equation 5 outline commonly reported forms of nitrogen and their components.

Equation 1 $TON = NO_3N + NO_2N$
Equation 2 $TN = TON + TKN$
Equation 3 $TKN = TAN + OrgN$
Equation 4 $DIN = TON + TAN$
Equation 5 $DIN = NO_3N + NO_2N + TAN$

[13] https://www.lawa.org.nz/learn/factsheets/calculating-water-quality-state-for-rivers
[14] https://environment.govt.nz/acts-and-regulations/national-policy-statements/

WRC measures combined nitrate- and nitrite-nitrogen, hereafter referred to as TON. Nitrate and nitrite are not directly measured. Nitrite is generally a small component of TON as nitrite oxidation is generally faster than its formation. Therefore, the nitrate toxicity attribute state is derived using TON as a proxy for nitrate.

Assessment of the TAN, or ammonia, attribute as per the NPS-FM (2020), is reported to a standardised pH of 8[15], using Equation 6, as per (ANZECC and ARMCANZ 2000) and USEPA (1999). Development of TAN toxicity standardisation used pH values ranging from 6.5 to 8 (Stephan et al. 1998; USEPA 1999), with guidance tables for conversion ranging from 6 to 9 (MfE 2018). A few WRC sites have pH ranges outside of the validated pH range. In these cases, where the sample pH was < 6 (n=62) or > 9 (n=9), the pH was adjusted to 6 or 9, respectively. The geothermally influenced site 1186_2 - Waiotapu Stm Campbell Rd Br is characterised by low pH, with 5th to 95th percentiles ranging from 4.4 to 5.9 and a median of 5.5. Interpreting values with low pH values must be done cautiously as these are outside the toxicity model development.

The MfE (2018) guide to attributes states that "*a method for converting to standard temperature is not currently available*." In contrast, ANZG (2023) guidelines use joint-toxicity models to convert toxicity values to standard pH and temperature. Using the ANZG (2023) approach, a pH and temperature standardisation equation was derived for TAN (Equation 7). Equation 6 and Equation 7 use chronic (rather than acute) toxicity models from USEPA (1999).

Equation 6 $$\boldsymbol{TAN_{(pH8)}} = \left(\frac{\boldsymbol{TAN_{pH}}}{\frac{0.0676}{1+10^{7.688-pH}}+\frac{2.91}{1+10^{pH-7.688}}}\right)$$

Equation 7 $$\boldsymbol{TAN_{(pH8,\ T20)}} = \boldsymbol{10}\hat{}\left(\boldsymbol{log_{10}}\left(\frac{\boldsymbol{TAN_{pH}}}{\frac{0.0676}{1+10^{7.688-pH}}+\frac{2.91}{1+10^{pH-7.688}}}\right) - (\boldsymbol{-0.028(T-20)})\right)$$

Where,
TAN_{pH8} = TAN standardised to pH of 8 (no temperature standardisation)
$TAN_{pH8,\ T20}$ = TAN standardised to pH of 8 and temperature of 20°C
TAN_{pH} = uncorrected TAN
pH = representative pH valid between 6 and 9
T = representative temperature (°C).

2.2.5.4 Sediment Parameters – Visual Clarity (BDISC) and Turbidity (TURB)

The NPS-FM (2020) includes two metrics to protect river ecosystems from sediment impacts. First, suspended fine sediment measured by BDISC visibility, and second, deposited fine sediment measured by the proportion of bed cover. In addition to BDSIC, suspended sediment can be measured using turbidity (TURB) and suspended sediment concentration (SSC or TSS)[16]. Routine monitoring includes TURB and BDISC. However, measurements of BDISC are partially or completely missing at some locations due to water level and accessibility-related factors[17]. Measurement of suspended sediment concentrations is not part of routine SOE monitoring but is included in sediment load monitoring at 11 sites[18] across the Waikato region.

[15] In an aquatic environment, ammonia exists in two main forms: unionised ammonia (NH_3) and ionised ammonium (NH_4^+). Total ammonia is the sum of NH_3 and NH_4^+. The two forms are in equilibrium, primarily determined by pH and temperature. The ratio of NH_3 to NH_4^+ increases 10-fold per pH unit rise and approximately 2-fold for each 10°C rise in temperature. NH_3 is the more toxic of the two forms. Therefore, at higher pH there is more NH_3 and higher toxicity.

[16] SSC = suspended sediment concentration and TSS = total suspended solids concentration. SSC and TSS represent the mass of suspended particulates in unit volume of water. However, the laboratory methods used are different. Specifically, SSC determination uses the complete volume of the original sample, whereas TSS generally uses a subsample of the original sample.

[17] For example, clarity is not captured in situations where water levels that are too low for an appropriately sized disc, locations where sampling is completed from a bridge, grabber samples, or instances where persons are unable to safely enter water or unable to avoid user disruption to water clarity.

[18] Waihou River (1122_18, 1122_34), Waingaro River [Pukemiro] (1167_4), Waitoa River (1249_18), Whakapipi Stream (1282_8), Kaniwhaniwha Stream (222_16), Mangatutu Stream (476_7), Matahuru Stream (516_5), Ohinemuri Stream (619_16), Piako River (749_15), Tapu Stream (954_15).

The NPS-FM (2020) visual clarity attribute includes bands based on four suspended sediment classes. These classes represent River Environmental Classification (REC) groupings and thresholds based on the ecological effects of increased fine sediment levels as they depart from the reference state.

The visual clarity attribute allows for TURB measurements to be converted to visual clarity for assessment, as these parameters are correlated. A national correlation between site-median visual clarity and site-median TURB can be used for estimating visual clarity from TURB data, as outlined in Equation 8 (Franklin et al. 2020). To improve robustness of gap-filling, Waikato regional and water quality zone (Aroha 2023), regressions were derived (Figure 4) as an alternative to using the national regression (Franklin et al. 2019). For all sites, the water quality zone regression was applied except for Inflows to Lake Taupo where the Waikato regional regression was used as the fit for this zone was poor (Figure 4).

Equation 8 $$\ln(clarity) = 1.21 - 0.72\ \ln(turbidity)$$

Where,
clarity = site-median visual clarity (m)
turbidity = site-median turbidity (NTU).

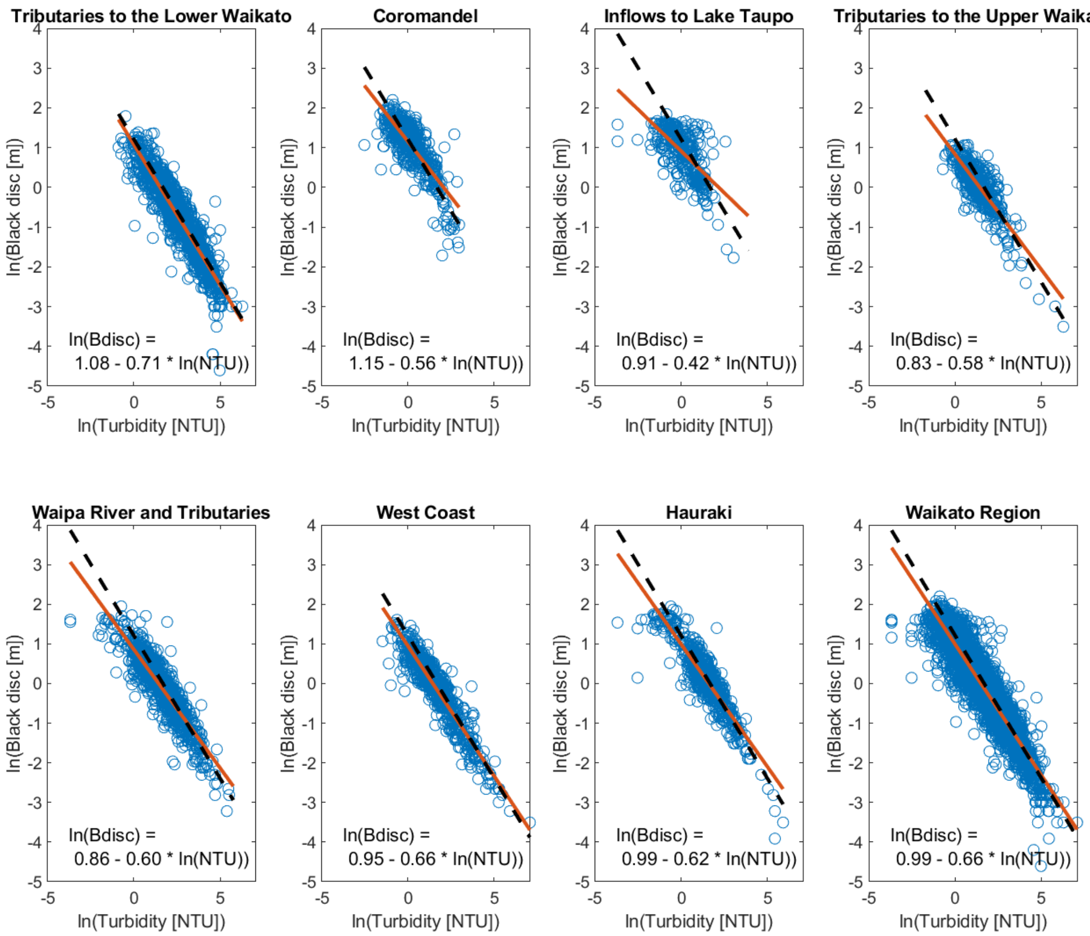

Figure 4 Natural log (ln) black disc (m) versus natural log turbidity (NTU) from ReRiMP sites (n=110) over the last five hydrological years, grouped by water quality zone. Red line and equation represent water quality zone regressions and black dashed line represents the national regression.

3 Results and Discussion

3.1 Data Collection Overview

The ReRiMP monitors 18 physical, chemical, and microbiological parameters. Over the last five hydrological years, the number of samples collected per parameter, per site, ranged from 49 (82% complete) to 58 (97% complete), with a median of 55 (92% complete). These are adequate sample sizes and periods to reflect the state of water quality (McBride 2016).

An important aspect to highlight with discrete data is that several variables exhibit diel variation (e.g., pH, TEMP, DO). ReRiMP sites are visited in a predetermined sequence to minimise the effects of diurnal variation on water quality measurements. Over the last five hydrological years, site measurements and sample collection generally occurred within a $\pm$ 2.7 hr (95th percentile) window. The median time at a site ranged from 0706 to 1412 hr, with a maximum time difference of 6.1 hr (Appendix E). Therefore, analyses of trends and drivers for discrete data with diel variation should consider variation explained by time of day.

Gap-filling BDISC using TURB data was completed at 72 sites (n=1006). In total, 12 sites had no BDISC data for the entire five-year period:

- 1045_3 - Tokaanu Stm Off SH41 Turangi
- 1057_6 - Torepatutahi Stm Vaile Rd Br
- 1173_2 - Waiohotu Stm Waiohotu Rd (Off SH5)
- 1186_4 - Waiotapu Stm Homestead Rd Br
- 1300_1 - Whangamata Stm (Kinloch) Whangamata Rd
- 1301_1 - Whanganui Stm Lakeside Lake Taupo T8
- 1318_4 - Whareroa Stm (Taupo) Lakeside Lake Taupo T9
- 1323_1 - Whirinaki Stm Corbett Rd
- 1491_1 - Tokaanu Power Station Tailrace Canal SH41 Bridge Over Canal
- 282_5 - Kuratau River Te Rae Street T10
- 516_5 - Matahuru Stm Waiterimu Road Below Confluence
- 940_10 - Tairua River Morrisons Br Hikuai

Gap-filling BDISC data used the water quality zones outlined in Aroha (2023) to develop zone-specific regressions. The exception was sites in the Inflows to Lake Taupo zone, where the Waikato regional regression was used as the zone-specific regression was poor (Figure 4). Although BDISC and TURB are interrelated, these generic correlations exhibit considerable data scatter. TURB as a surrogate for suspended sediment is confounded by the composition of riverine suspended material (mineral sediment, organic composition and coloured dissolved organic matter), particle size factors (proportion of clay, silt and sand) and shape of sediments resulting in noisy relationships between concentration and TURB (Bright et al. 2020). In comparison, for individual rivers, TURB and visual clarity are more closely related and better suited for use as surrogates (i.e., site-specific correlation) (Ballantine et al. 2015). Therefore, deriving site-specific regressions will improve the robustness of gap-filling.

However, this is not achievable at the 12 sites with no BDISC measurements. Furthermore, at sites with BDISC data, the data gaps are typically related to safe site access associated with high flow, which limits the robustness of site-specific regression relationships. To address these limitations, it is recommended to develop a water clarity monitoring plan that includes the collection of discrete in situ transmissometer measurements concurrently with existing monthly monitoring. Light beam attenuation measured by a transmissometer (or beam-c) is related to visual clarity (Zaneveld and Pegau 2003; Davies-Colley et al. 2021; Davies-Colley et al. 2024).

3.2 Regional Water Quality Overview

Across monitored sites, water quality values ranged widely over the last five hydrological years (Table 2). Appendix D presents summary boxplots for each parameter and site. A high proportion of censored data is observed for absorbance measures, TAN and DRP. Therefore, methods to handle censored data should be considered for these parameters, as high proportions of censored data can influence state and trend assessments. For each parameter, regional summary figures and comparison to guidelines are presented in Sections 3.3 and 3.4.

To examine linear and monotonic relationships between water quality parameters across the Waikato region, parametric Pearson (r_p) and non-parametric Spearman rank correlations (r_s) were completed (Figure 5, Figure 6). Spearman rank correlations highlighted strong correlations between absorbance measures A330 and A440 ($r_s = 0.99$; $p < 0.001$), *Escherichia coli* (*E. coli*) and faecal coliforms (F.coli) ($r_s = 0.99$; $p < 0.001$), and TKN and Turb ($r_s = 0.80$; $p < 0.001$). Although BDISC and TURB show a significant correlation ($r_s = -0.94$; $p < 0.001$), this is not valid as values are not independent because of the gap-filling of BDISC using TURB.

Table 2 Statistical summary of water quality variables for the 110 ReRiMP sites over the last five hydrological years, using the Waikato Regional Council (WRC) substitution method for censored values.

Parameter	Units	Minimum	Hazen Percentile			Maximum	SD
			5th	50th	95th		
A340	AU cm^{-1}	0.001	0.006	0.026	0.119	0.880	0.054
A440	AU cm^{-1}	0.001	0.001	0.005	0.021	0.149	0.009
A780	AU cm^{-1}	0.001	0.001	0.001	0.001	0.004	0.000
pH	$-log_{10}[H^+]$	4.1	6.7	7.3	7.9	9.8	0.4
COND	µS/cm	8	54	120	379	1418	120
TEMP	°C	5.1	9.5	14.3	21.6	32.0	3.8
BDISC[19]	m	0.01	0.16	1.08	4.61	30.76	1.78
TURB	NTU	0.025	0.49	4.	55	1180	31.47
DO	mg/L	0.1	6.7	9.6	11.2	14.2	1.5
DO%	%	1.5	70.5	95	105.7	162.9	12.2
DRP	g/m^3	0.002	0.002	0.013	0.11	2	0.065
TP	g/m^3	0.001	0.006	0.045	0.21	2.3	0.111
E. coli	cfu/100mL	0.5	12	260	3600	220000	5774.051
ENT	cfu/100mL	0.5	5	150	2800	56000	2073.151
F. coli	cfu/100mL	0.5	18	340	4800	250000	6793.859
TKN	g/m^3	0.025	0.025	0.2	1.28	8.4	0.6436
TAN (raw)[20]	g/m^3	0.005	0.005	0.005	0.27	2.6	0.1479
TAN (pH8)[21]	g/m^3	0.0018	0.0021	0.0045	0.1134	1.2473	0.0601
TON	g/m^3	0.001	0.004	0.56	2.3	11.2	0.7903
TN[22]	g/m^3	0.026	0.089	0.845	3.22	13.19	1.081

PCA explored how parameters explained variation in water quality data across the Waikato region. Highly correlated variables were removed prior to analysis to reduce redundancy. High correlations existed ($r_p > 0.85$; $p < 0.001$) between A340 and A440, DO (mg/L) and DO% (%), and *E. coli* and F.coli, with one of the two correlated variables removed from the PCA. The retained parameters were A340, DO, and *E. coli*. This was based on measurement precision (A340 versus A440, see Section 3.3.4), relative environmental importance and availability of guidelines, rather than evaluating purely based on relative loading[23] on the principal component (PC). ENT was subjectively removed, even though the correlation between ENT and *E. coli* was not strong ($r_p = 0.59$; $p < 0.001$), to avoid redundancy of microbial parameters. Additionally, BDISC was removed from PCA to examine the influence of TURB and absorbance parameters (organic matter) on water quality variability and associations. A780 was also removed as values were predominately

[19] BDISC data set including gap-filling from regression with TURB.
[20] TAN raw laboratory result.
[21] TAN corrected to pH 8.
[22] TN calculated from TKN + TON.
[23] Loading in Principle Component Analysis (PCA) represents the correlation between a component with a variable.

at analytical detection limit (Table 2). This screening criteria refined the total of 18 parameters to 12 for inclusion in PCA.

The PCA identified five PCs with eigenvalues from 3.7 to 0.9. Collectively, the five PCs explained 71.5% of the water quality variability across the Waikato region. The variance explained by each PC was 28.6% (PC1), 14.8% (PC2), 10.8% (PC3), 9.6% (PC4) and 7.7% (PC5). To further improve interpretation, a Varimax rotation was applied to the first five PCs. The loadings for each parameter on the first five rotated components (RC) are presented in Table 3. Absolute loadings greater than or equal to 0.7 are strongly correlated, from 0.5 to 0.7 are moderately correlated, and from 0.4 to 0.5 are weakly correlated to the component, with values less than 0.4 considered non-significant to the RC. All 12 parameters were identified as significant variables in RCs, highlighting the relevance of these parameters in the ReRiMP network.

PCA revealed that RC1 is primarily driven by TP and DRP, indicating a moderate relationship between these parameters and their combined influence on water quality variability across monitoring sites. In addition, RC1 has significant absorbance (A340) loading, highlighting a linkage between organic matter (CDOM) and phosphorus, which has implications for optical clarity and microbial oxygen demand with increasing phosphorus. RC2 shows a moderate positive contribution from TEMP and a significant negative contribution from DO, highlighting the influence of TEMP on DO levels (see Section 3.3.2). The microbial faecal indicator *E. coli*, TURB, and TKN were positively correlated with RC3. This highlights a linkage between the drivers of these parameters. As *E. coli* loading is related to overland flow (Ballantine and Davies-Colley 2013), reductions in sediment delivery could translate to concurrent reductions in *E. coli,* and organic and ammoniacal nitrogen. RC4 is characterised by a negative contribution from TAN (not corrected for pH) and a positive contribution from pH. This could be related to the effect of pH on TAN nitrification (Le et al. 2019). Lastly, RC5 is influenced by a positive loading from TON and COND, indicating an association between inputs of TON to rivers with increased COND.

Visual clarity measured using BDISC is a product of both TURB and absorbance, and the PCA suggests that the processes driving these parameters are related to different components with potential implications for approaches for targeted improvements in visual clarity. Future analyses using the PCA approach, including major ions, season, and catchment data, could provide further insights into water quality variables and factors driving water quality across the Waikato region. Expanded PCA testing would provide valuable insights for simplifying the communication of water quality targets to achieve water quality improvements and monitoring programme optimisation.

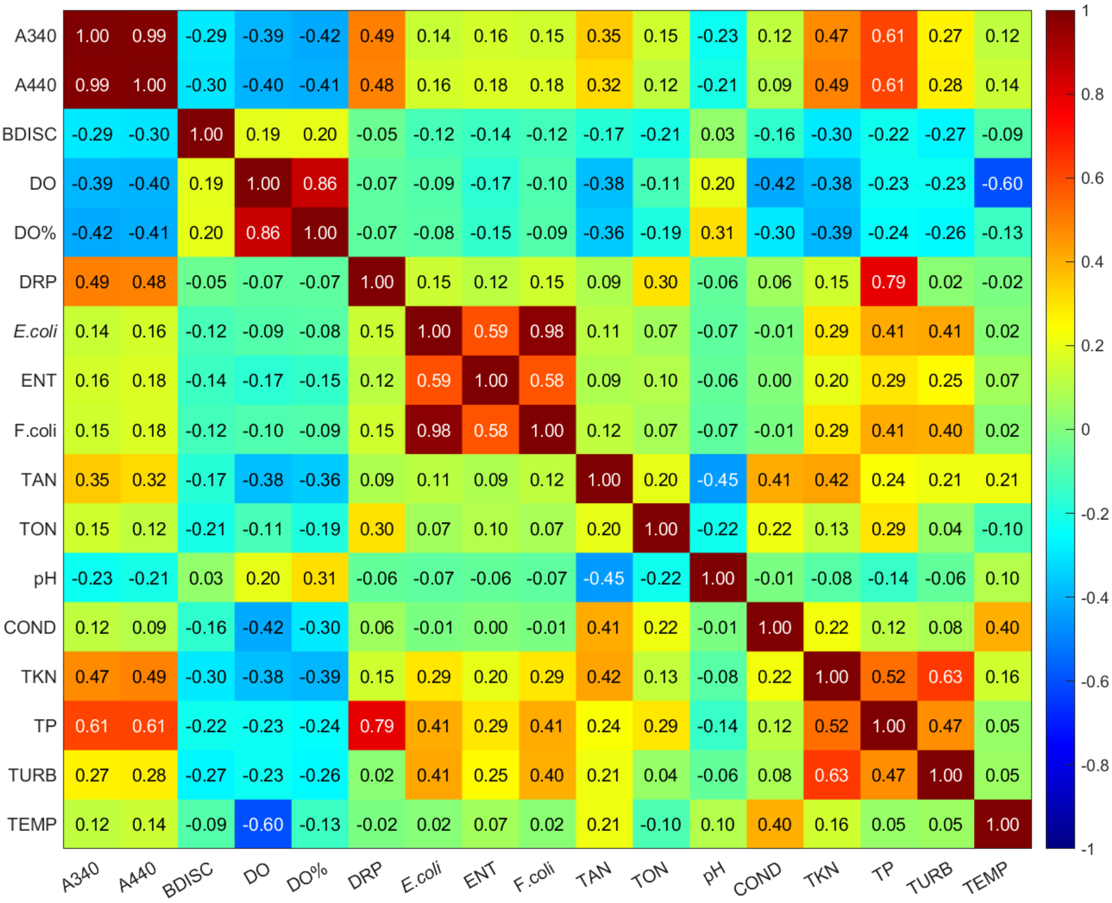

Figure 5 Pearson correlations (r_p) of water quality parameters from ReRiMP sites (n=110) over the last five hydrological years. Each cell in the matrix represents the correlation (r_p) between variables. The colour and value of r_p indicate the strength and direction of the correlation.

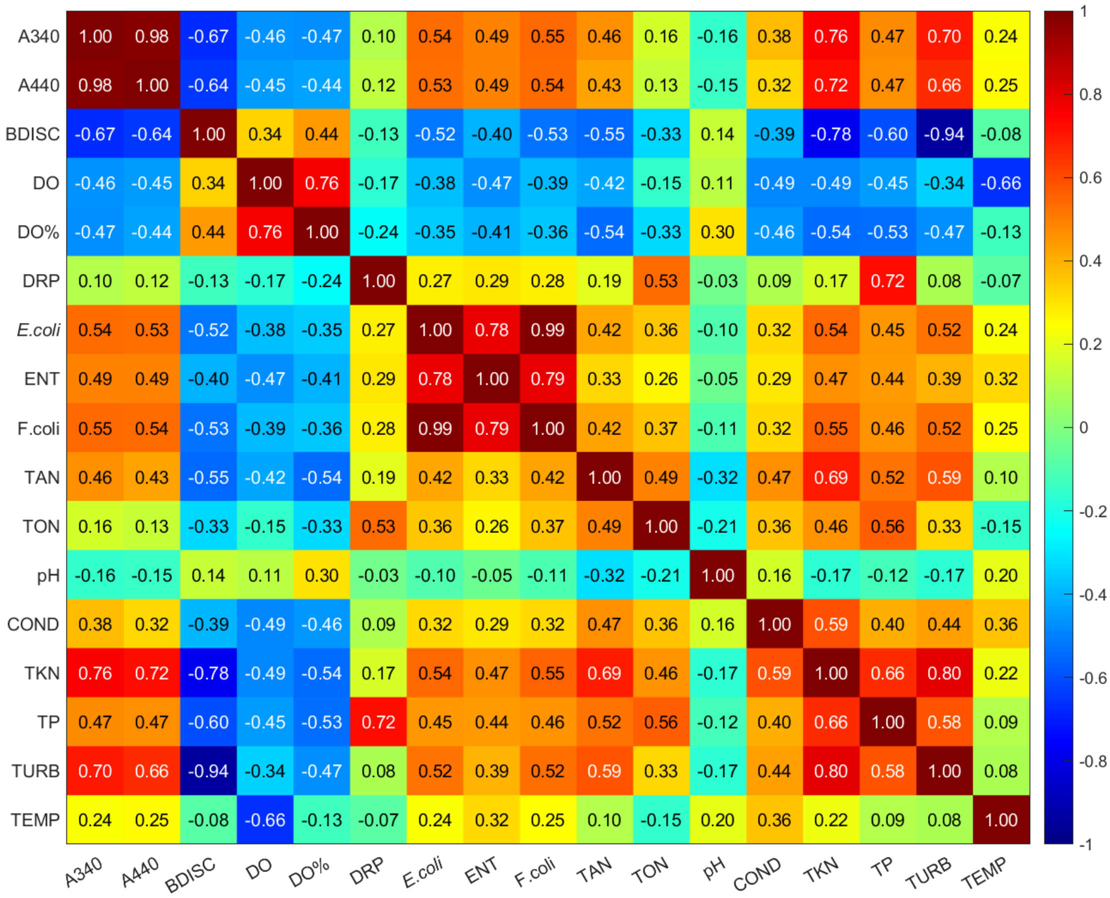

Figure 6 Spearman rank (r_s) correlations of water quality parameters from ReRiMP sites (n=110) over the last five hydrological years. Each cell in the matrix represents the correlation (r_s)

between variables. The colour and value of r_s indicate the strength and direction of the correlation.

Table 3 Loadings for the Varimax-Rotated Principal Components Analysis of Water Quality Parameters. The table displays the contributions of each parameter to the first five principal components after Varimax rotation (RC). Absolute loadings greater than or equal to 0.7 are strongly correlated, from 0.5 to 0.7 are moderately correlated, and from 0.4 to 0.5 are weakly correlated to the component, with values less than 0.4 consider non-significant to the component. Significant loadings are indicated in bold.

Parameter	RC1	RC2	RC3	RC4	RC5
A340	**0.47942**	0.16800	-0.00902	-0.21818	-0.25213
DO	-0.05057	**-0.52523**	-0.02768	0.16323	0.01075
DRP	**0.66708**	-0.04255	-0.16370	0.12043	0.09712
E.coli	0.01412	-0.14203	**0.52428**	0.09578	0.07798
TAN	-0.04936	0.15966	0.08504	**-0.53013**	0.14040
TON	0.11519	-0.22116	-0.01898	-0.10939	**0.75335**
pH	0.00448	0.15213	0.08371	**0.75882**	0.07964
COND	-0.09353	0.37746	0.00775	0.03104	**0.56622**
TKN	0.07495	0.13692	**0.47349**	-0.10285	-0.03038
TP	**0.53786**	-0.02263	0.20442	0.04864	0.05127
TURB	-0.05366	-0.01210	**0.64379**	-0.00492	-0.05093
TEMP	-0.01161	**0.64382**	-0.04873	0.13907	-0.02132

3.3 Ecosystem Health Water Quality Values

3.3.1 Nutrients (Nitrogen and Phosphorus)

Nitrogen and phosphorus play pivotal roles in the ecological health and functioning of riverine ecosystems (Mallin et al. 2006; Mallin et al. 2006; Elser et al. 2007; Withers and Jarvie 2008; Boyd 2020a; Boyd 2020b; Mallin and Cahoon 2020). However, in excessive quantities, they can lead to ecosystem impacts such as direct nitrogen toxicity (Camargo and Alonso 2006; Soucek and Dickinson 2012), hypoxia (Withers and Jarvie 2008; Mallin and Cahoon 2020), overstimulation of plant growth (cyanobacteria, macrophytes, and algae), habitat degradation, and declines in species abundance and diversity associated with shifts in trophic states (Biggs 2000).

A complex interplay of physical, biological, and chemical factors and processes influences the severity of eutrophication. These include flow regime, water depth, water clarity, temperature, sediment characteristics, shading, grazing pressures, nutrient demand of aquatic communities, and availability of carbon and silica. These variables collectively influence the cycling, transportation, and retention of nitrogen and phosphorus in riverine systems (Elser et al. 2007; Xia et al. 2018; Mallin and Cahoon 2020; Mallin and Cahoon 2020). Moreover, excess riverine nutrients can also impact down stream receiving environments, leading to eutrophication impacts in lakes and estuaries, and degradation of wetlands.

In freshwater systems, nitrogen and phosphorus exist in various forms. ReRiMP phosphorus monitoring includes DRP and TP. DRP is immediately available to aquatic organisms, while TP, which includes DRP, is less readily bioavailable. Organic phosphorus can represent a significant proportion of total and dissolved fractions, especially during periods of active decomposition of organic matter (e.g., algal bloom die-off) (Broberg and Persson 1988; Feng et al. 2023). Nitrogen forms reported are TKN, TAN, TON, and TN (see Section 2.2.5.3). The concentrations of these various forms of nitrogen and phosphorus are summarised in Table 2 for the Waikato region, with spatial variation and comparison to guidelines presented below.

3.3.1.1 Nitrogen (TN, TKN, TAN, TON)

Across monitored sites, TN ranged from 0.03 to 13.19 g/m^3, with a median of 0.85 g/m^3 (Table 2). Nitrogen concentrations were typically higher in the rivers of the lower Waikato and Hauraki catchments (Figure 7). TON was generally the predominant TN fraction, but TKN represented a large proportion of TN at several sites (Figure 7). High median TN (> 1 g/m3) and median TKN fractions >50% were observed at sites discharging the hypertrophic lakes Waahi (99%)[24], Whangape (95%)[25] and Waikare (100%)[26], Rotokauri (65%) and rivers of the lower Waikato draining agricultural peatland[27].

The NPS-FM (2020) includes nitrogen toxicity for ammonia and nitrate but does not include a nitrogen ecosystem health attribute. However, the initial drafting of the NPS-FM included the dissolved inorganic nitrogen (DIN) attribute. The DIN attribute used an equal-weighted, multiple-line evidence approach from a national dataset of ecosystem health metrics for macroinvertebrates, fish, periphyton, and ecosystem metabolism with nutrient concentrations. This work derived a national bottom line for DIN of 1.0 g/m^3 (MfE 2019).

Attribute drafting used DIN rather than TN, to represent the most biologically available form (MfE 2019). However, as particulate and organic nitrogen contribute to aquatic nitrogen impacts, and because TN tends to act more conservatively and is more strongly related to algal biomass and toxin production compared to DIN (Camargo and Alonso 2006), comparison of nitrogen ecosystem health is best suited to TN, particularly as organic fractions can represent a large proportion of TN in riverine systems across the Waikato region (Figure 7).

Camargo and Alonso (2006) concluded that TN lower than 0.5 to 1.0 g/m^3 might prevent aquatic ecosystem eutrophication. While Snelder et al. (2022) found that TN (and DIN) of 1.0 g/m^3 were saturating conditions for periphyton biomass (as chlorophyll *a*). Therefore, this report compares TN to 1.0 g/m^3 to highlight sites where the highest potential impact of TN on the riverine ecosystems occurs. Using this applied TN enrichment criteria, a total of 40% (n=44) of monitored sites exceeded 1 g/m^3 (Figure 8).

TAN and TON concentrations across the region displayed similar patterns to TN with NPS-FM (2020) median and 95th percentile data summarised in Figure 9 and Figure 10. In comparison to the NPS-FM (2020), a total of 3.6% (n=4) and 6.4% (n=7) of sites for ammonia and nitrate were below the national bottom line (Figure 11, Figure 12). Consequently, the risk of nitrogen toxicity to sensitive species appears to be confined to a select few locations within the Waikato region. Similarly, in comparison to a national dataset (to 2020), Whitehead et al. (2022) found very few sites (1-10%) were below the bottom line for the nitrogen toxicity attributes.

The seven sites with nitrate toxicity below the national bottom line:

- 1249_18 - Waitoa River Mellon Rd Recorder
- 1282_8 - Whakapipi Stm SH22 Br
- 240_5 - Kawaunui Stm SH5 Br
- 258_4 - Komakorau Stm Henry Rd
- 407_1 - Mangamingi Stm (Tokoroa) Paraonui Rd Br
- 481_7 - Mangawara Stm Rutherford Rd Br
- 749_15 - Piako River Paeroa-Tahuna Rd Br

The four sites with ammonia toxicity below the national bottom line:

- 1186_2 - Waiotapu Stm Campbell Rd Br
- 1236_2 - Waitawhiriwhiri Stm Edgecumbe Street
- 1293_7 - Whangamarino River Island Block Rd
- 258_4 - Komakorau Stm Henry Rd

[24] 1097_1 - Waahi Stm Te Ohaki Rd.

[25] 1302_1 - Whangape Stm Rangiriri-Glen Murray Rd.

[26] 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) DownStream of Control Gates and 1293_7 - Whangamarino River Island Block Rd.

[27] 1236_2 - Waitawhiriwhiri Stm Edgecumbe Street, 398_1 - Mangakotukutuku Stm (Rukuhia) Peacockes Rd, 481_7 - Mangawara Stm Rutherford Rd Br.

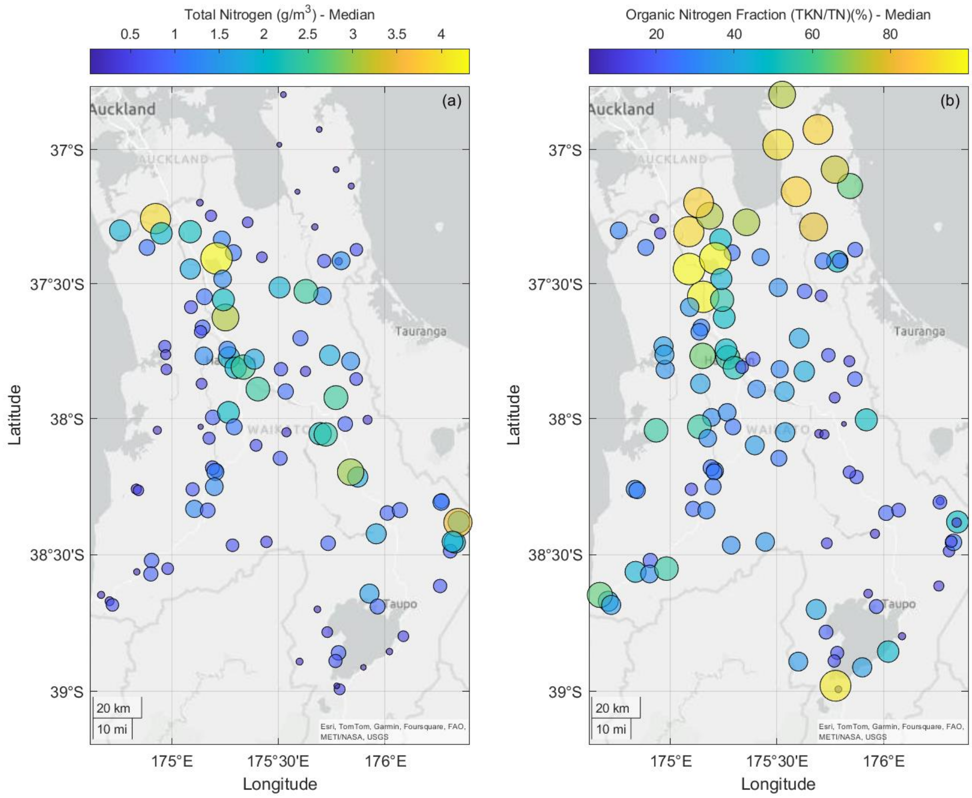

Figure 7 Total Nitrogen (TN) (g/m^3) median (a) and Organic Nitrogen (TKN) (%) median (b) from ReRiMP sites (n=110) over the last five hydrological years.

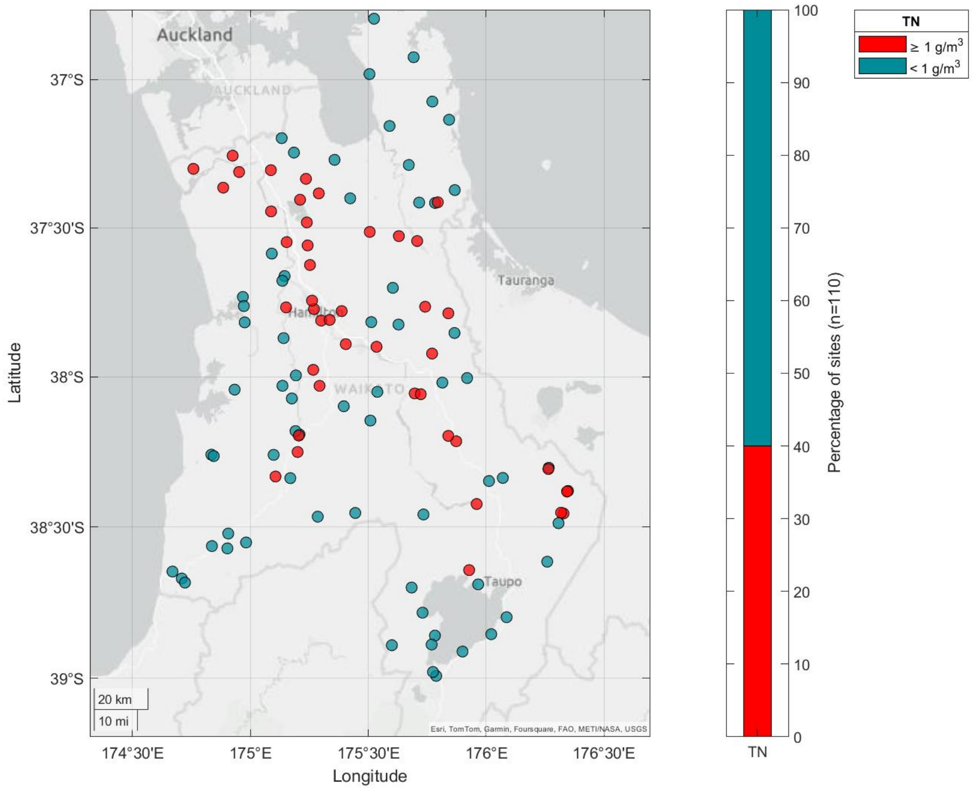

Figure 8 Total Nitrogen (TN) (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years compared to TN guideline of 1 g/m^3.

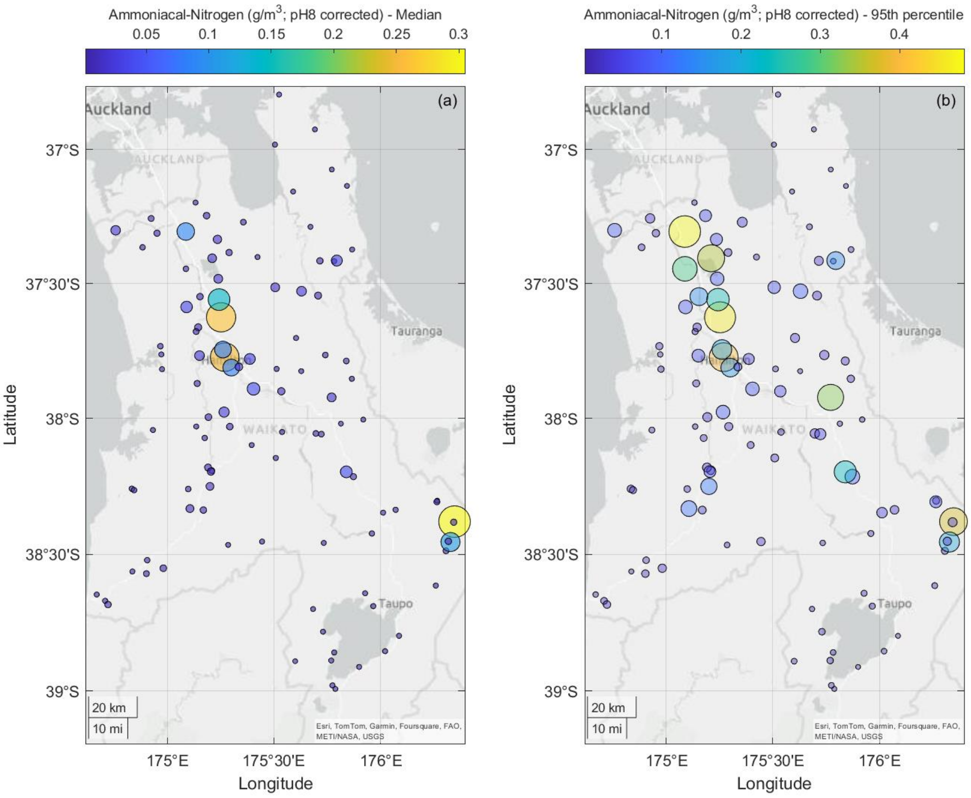

Figure 9 Total Ammoniacal-nitrogen (TAN) standardised to pH 8 (g/m³) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

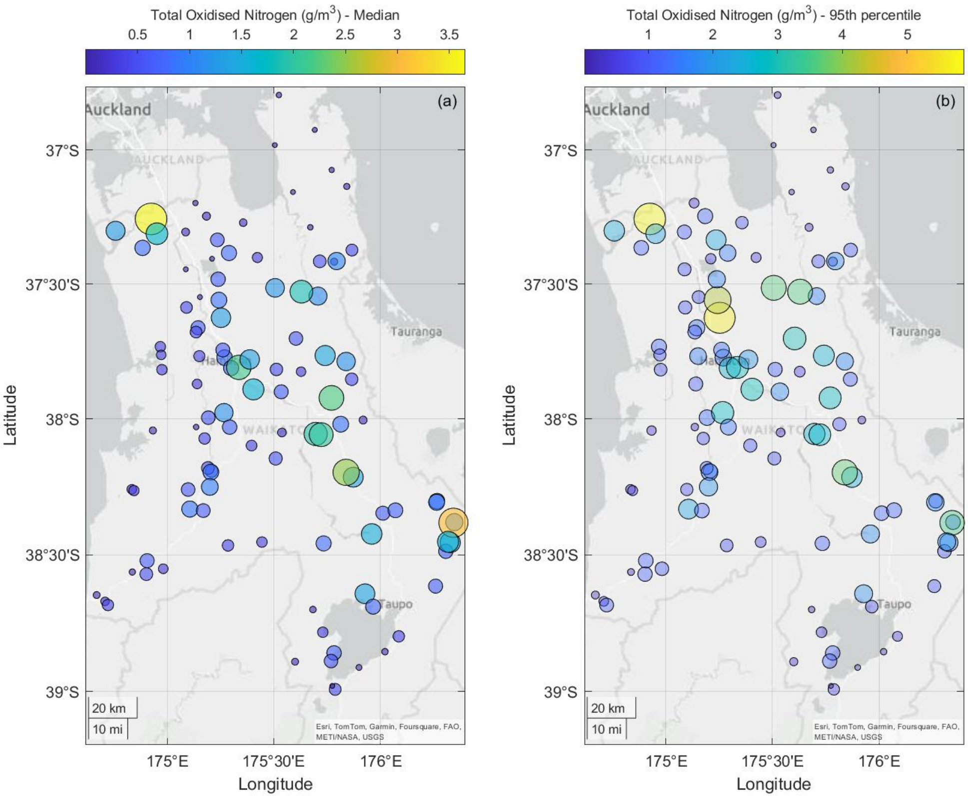

Figure 10 Total Oxidised Nitrogen (TON) (g/m³) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

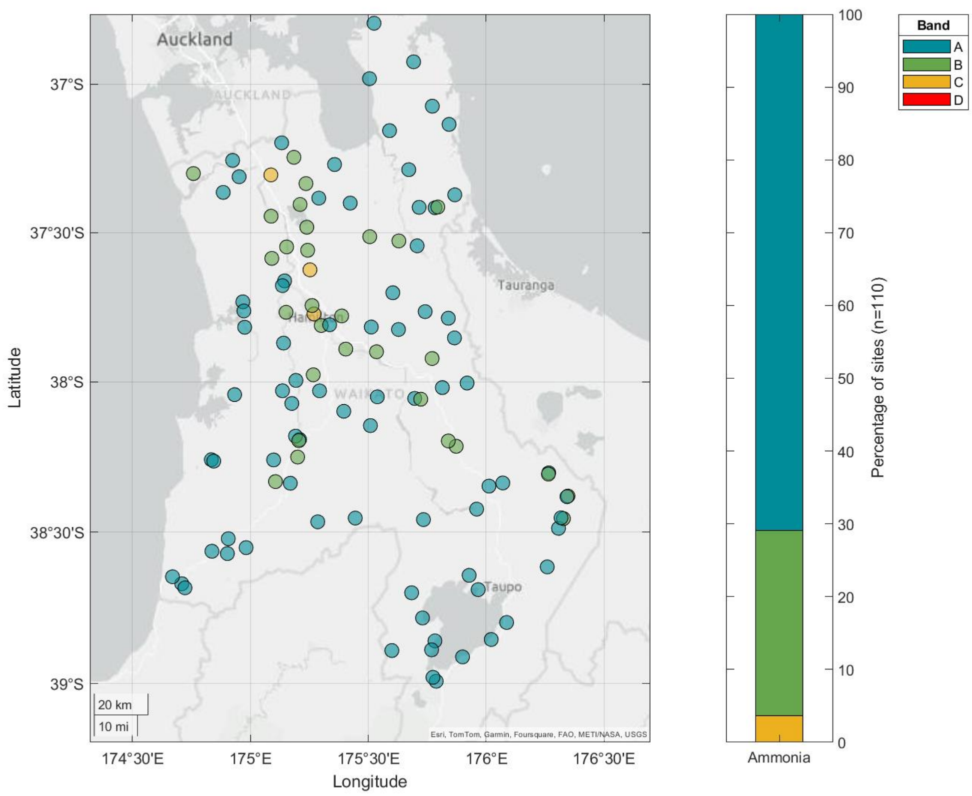

Figure 11 Ammonia attribute banding geospatial and proportional plot from ReRiMP sites (n=110) over the last five hydrological years.

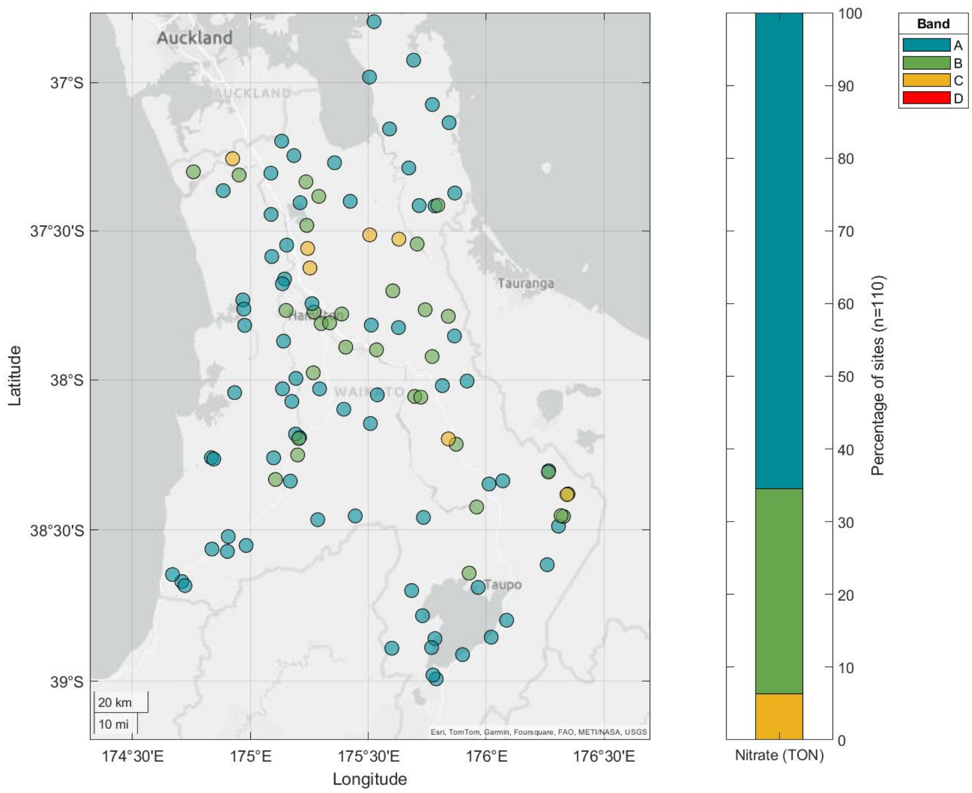

Figure 12 Nitrate (using nitrate + nitrite as a proxy) attribute banding geospatial and proportional plot from ReRiMP sites (n=110) over the last five hydrological years.

3.3.1.2 Phosphorus (TP and DRP)

TP across the Waikato region ranged from 0.001 to 2.300 g/m^3 with a median of 0.045 g/m^3 (Figure 13) and generally followed a similar geographical pattern as TN. Sites with relatively high TP typically had high DRP, which ranged from 0.002 to 2.000 g/m^3 with a median of 0.012 g/m^3 (Figure 14).

The NPS-FM (2020) phosphorus water quality attribute uses DRP with no prescribed national bottom line. Pooling DRP C and D bands showed that 59% (n=65) of monitored sites were moderately to substantially enriched, with potential implications for eutrophication impacts. In comparison, the 2017 baseline state for C and D bands was 66% (n= 73) (Ryan and Jenkins 2022) (Appendix F). This represents an improvement in the state of regional phosphorus since 2017, with eight fewer sites in the lower bands.

Whitehead et al. (2022) reported national DRP state data up to 2020 and found that 27% and 19% of sites received D grades for the median and 95th numeric attribute states, respectively. In comparison, the current assessment classifies 36% (n=40) and 31% (n=34) of Waikato regional sites graded as D band for median and 95th numeric attribute states, respectively. This finding suggests that DRP enrichment is relatively higher in the Waikato region compared to the national dataset.

The fraction of TP as DRP was highly variable, ranging from 1% to 100%. Four sites graded as A or B for DRP were characterised by very high median TP concentrations >0.1 g/m^3. Phosphorus enrichment typically focuses on the excessive growth of nuisance plants. However, studies have shown that phosphorus loading stimulates aquatic bacteria with associated biochemical oxygen demand and enhances the survival or reproduction of faecal bacteria (Mallin and Cahoon 2020). Moreover, large pools of TP can act as a source of internal loading of phosphorus to the water column under low DO conditions with concurrent release of reduced substances from sediments such as NH_4^+, Fe^{2+}, Mn^{2+}, MeHg, S^{2-}, and H_2S, which can further extend hypoxic conditions and deteriorate water quality (Beutel 2003). Therefore, assessing phosphorus water quality or trophic state should include DRP and TP (Withers and Jarvie 2008; Mallin and Cahoon 2020). The sites with very high TP graded as either A or B for DRP are:

- 1293_7 - Whangamarino River Island Block Rd
- 1302_1 - Whangape Stm Rangiriri-Glen Murray Rd
- 258_4 - Komakorau Stm Henry Rd
- 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) Down Stream of Control Gates

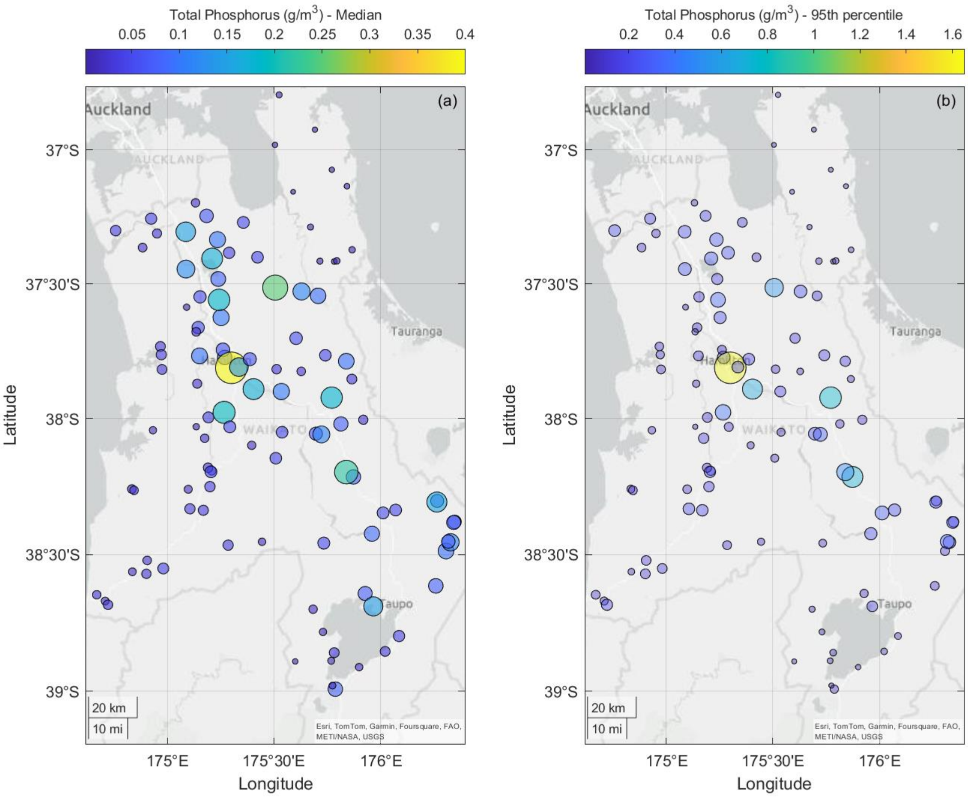

Figure 13 Total Phosphorus (TP) (g/m^3) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

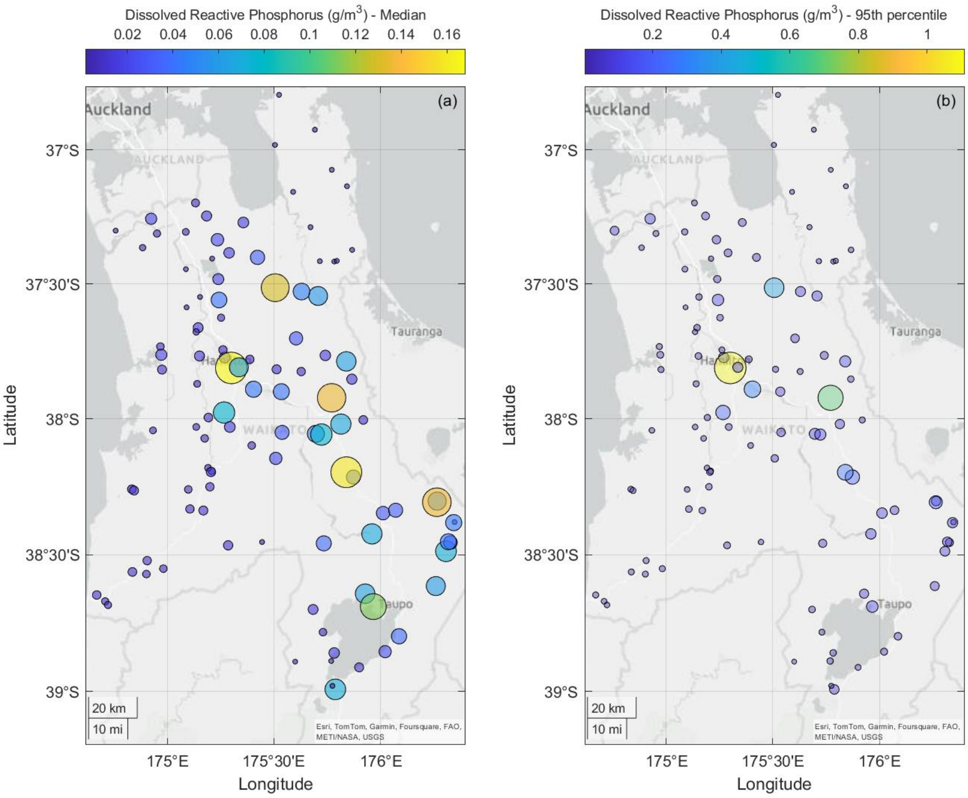

Figure 14 Dissolved Reactive Phosphorus (DRP) (g/m^3) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

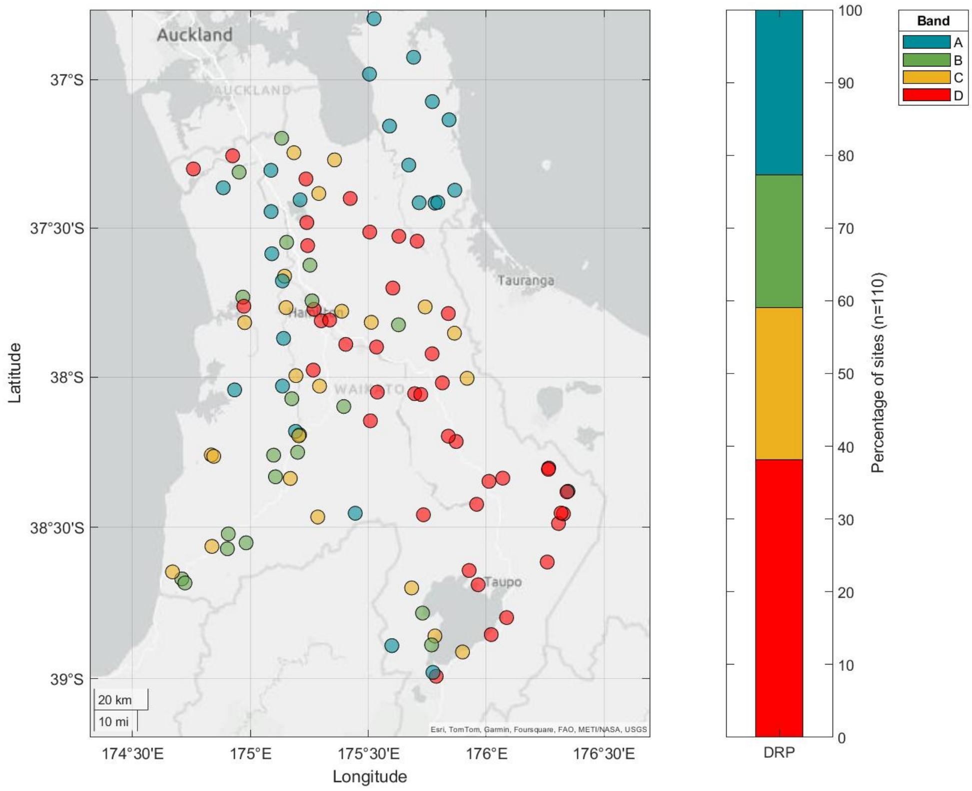

Figure 15 Dissolved Reactive Phosphorus (DRP) attribute banding geospatial and proportional plot from ReRiMP sites (n=110) for 2018 – 2023 hydrological years.

3.3.2 Dissolved Oxygen (DO)

DO is crucial for the health of river ecosystems, as it influences water quality (Søndergaard 2009) and is critical to support aquatic life (Wetzel 2001; Franklin 2014; Saari et al. 2018). The instantaneous level of DO reflects a balance of various physical, chemical, and biological processes and interrelationships (Odum 1956; Kelly et al. 1974; Schurr and Ruchti 1977; Weitkamp and Katz 1980; Butcher and Covington 1995; Harvey et al. 2011; Boyd 2020c; Diamond et al. 2023). The solubility of oxygen in water is limited and is influenced by temperature, elevation, and salinity – with higher levels of these factors leading to decreased oxygen solubility (Wetzel 2001; Verberk et al. 2011). The key DO sources in water are photosynthesis and diffusion across the air-water interface (Odum 1956). Diffusion is influenced by temperature-dependent diffusivity, the differential of air-water concentration, surface area, and the turbulence of the water body (Boyd 2020c). While DO consumption occurs via autotrophic respiration, microbial decay of organic matter biogeochemical reactions that require oxygen, and sediment oxygen demand (Cox 2003; Piatka et al. 2021; Ali et al. 2022).

The interplay of photosynthesis and respiration drives diurnal fluctuations in DO. Primary production in freshwater is often regarded as phosphorus-limited, with studies demonstrating algal and bacterial levels associated with phosphorus loading (Mallin et al. 2006). However, nitrogen concentrations also play an important role in freshwater primary production and ecosystem respiration (Elser et al. 2007). For example, Casanovas et al. (2022) found no significant relationships between ecosystem metabolism metrics and phosphorus in Auckland rivers. However, significant correlations between nitrogen levels and rates of primary production and ecosystem respiration were identified. Excessive photosynthesis can lead to DO supersaturation, whereas high rates of respiration and/or biochemical oxygen demand can result in hypoxic conditions (< 2 mg/L). Both supersaturation and hypoxia can lead to stress and mortality of aquatic biota (Boyd 2020c), with hypoxia being the most relevant DO challenge in Waikato rivers.

Waikato regional river discrete DO monitoring ranged widely, from 0.1 mg/L (1.5%) to 14.2 mg/L (162.9%), with a median of 9.6 mg/L (95%) (Table 2; Figure 16). Fish typically exhibit gasping behaviour at the water surface when DO drops to around 2 mg/L, and chronic levels below 5 mg/L (at 15°C) are generally considered a stressor for fish (Boyd 2020c). Therefore, low DO is an issue at monitored sites across the Waikato region.

It is important to note that SOE monitoring provides discrete measurements that do not capture diurnal variability and, consequently, do not capture daily DO minima and maxima. Additionally, as WRC DO data is discrete, direct comparison to the NPS-FM (2020) DO attribute is not applicable. However, discrete DO data identify rivers at risk of low DO (Wilding 2024). Using the 10^{th} percentile of discrete measurements, Wilding (2024) classified D band sites based on the <6.5 mg/L criterion from Davies-Colley et al. (2013) [28]. To validate this approach Wilding (2024) compared site gradings at locations with discrete and continuous records.

In this report, sites are graded based on the 5^{th} percentile of SOE data compared to the <6.5 mg/L as a more conservative approach than that of Wilding (2024). In total, 18 (16.4%) river sites had 5^{th} percentile DO below 6.5 mg/L (Figure 17). These sites were generally located in the lower Waikato and Hauraki rivers, reflecting the higher risk of riverine hypoxia in warmer, lower-gradient rivers and catchments with wetlands (Blaszczak et al. 2023). The river sites identified with the highest risk of low DO challenges are as follows:

- 1293_7 - Whangamarino River Island Block Rd
- 624_5 - Ohote Stm Whatawhata/Horotiu Rd
- 749_10 - Piako River Kiwitahi
- 1302_1 - Whangape Stm Rangiriri-Glen Murray Rd
- 1097_1 - Waahi Stm Te Ohaki Rd
- 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) Down Stream of Control Gates
- 1249_18 - Waitoa River Mellon Rd Recorder
- 258_4 - Komakorau Stm Henry Rd
- 41_9 - Awaroa River (Waiuku) Otaua Rd Br opp Moseley Rd
- 481_7 - Mangawara Stm Rutherford Rd Br
- 749_15 - Piako River Paeroa-Tahuna Rd Br
- 1293_9 - Whangamarino River Jefferies Rd Br
- 1282_8 - Whakapipi Stm SH22 Br
- 1186_2 - Waiotapu Stm Campbell Rd Br
- 253_4 - Kirikiriroa Stm Tauhara Dr
- 683_4 - Otamakokore Stm Hossack Rd
- 421_10 - Mangaonua Stm Hoeka Rd
- 39_11 - Awaroa Stm (Rotowaro) Sansons Br @ Rotowaro-Huntly Rd

[28] Davies-Colley et al. (2013) <6.5 mg/L D band criterion for comparison to daily mean of continuous DO data.

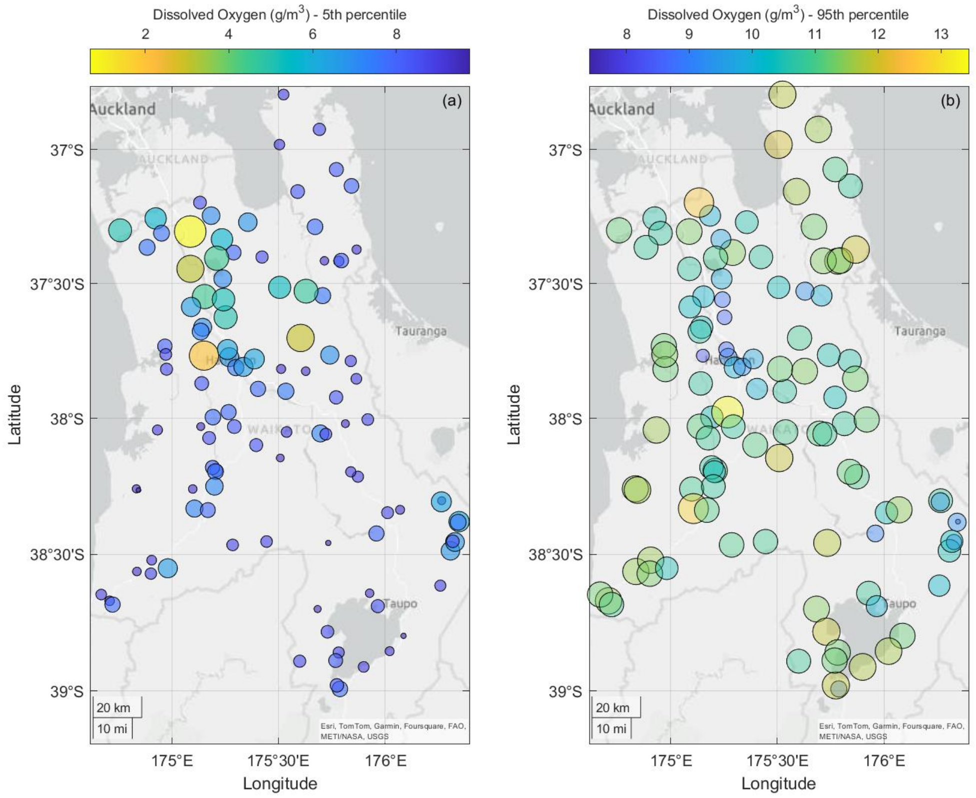

Figure 16 Dissolved Oxygen (DO) (mg/L) 5th percentile (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

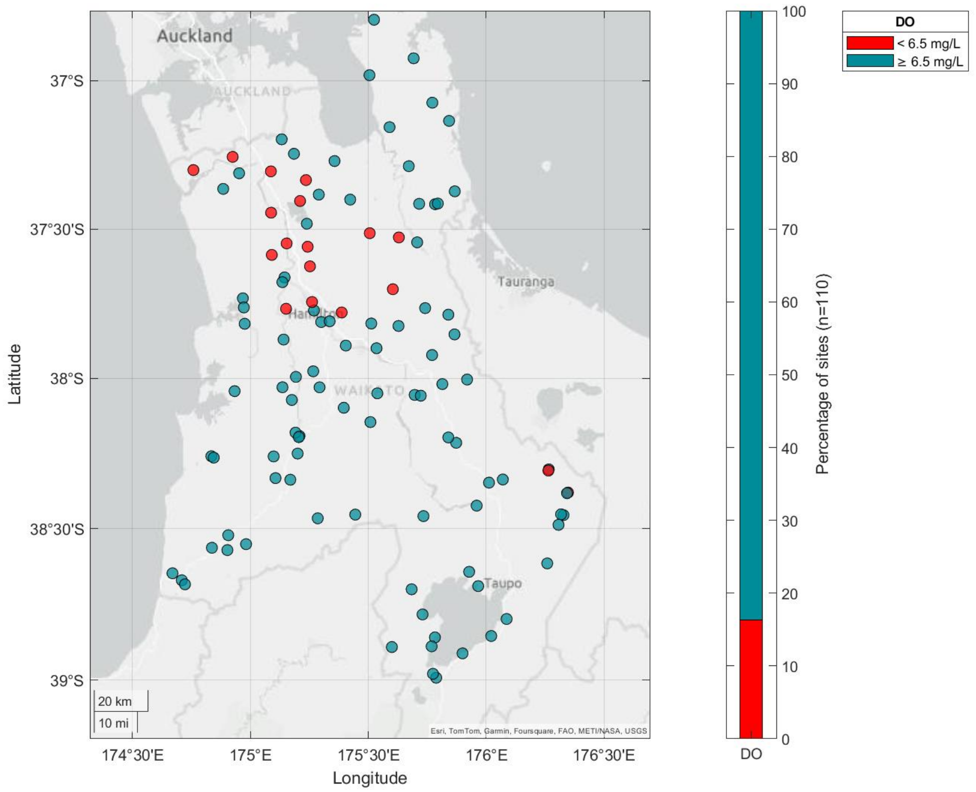

Figure 17 Dissolved Oxygen (mg/L) 5th percentile from ReRiMP sites (n=110) over the last five hydrological years compared to applied guideline of 6.5 mg/L.

3.3.3 Suspended Sediment Measures – Turbidity (TURB) and Black Disc (BDISC)

Suspended and deposited sediment causes multiple impacts on the health of aquatic ecosystems. For instance, direct effects on biota include mechanical and abrasive damage to gills, reduced food quality and feeding rate, impacted habitat, and hindered upstream migration, which can lead to the loss of diversity and changes to community structure. These effects depend on the species, life-stages present, and the concentration and duration of exposure (Wood 1997; Kemp et al. 2011; Chapman et al. 2014; Kjelland et al. 2015). Suspended sediment changes the optical characteristics of water with reduced visual clarity and light penetration, which can inhibit the growth of aquatic plants and algae, leading to ecosystem impacts and changes to ecosystem structure (Davies-Colley and Smith 2001).

A range of suspended sediment measures exists, specifically, suspended sediment concentration (SSC or TSS) (g/m^3), BDISC (also referred to as visual clarity) (m), and TURB (NTU/FNU). WRC routine river monitoring includes TURB (NTU) and BDISC (m) measures to quantify suspended sediment and river clarity. TURB is an index of water cloudiness, measuring light scattering by particulate matter. In comparison, BDISC measures total light attenuation from scattering and absorption, reflecting total particulate matter and light-absorbing organic matter (see Section 3.3.4 for further information). Of these measurements, BDISC is the preferred measure for suspended sediment monitoring due to its accuracy and ecological significance of optical characteristics in rivers (MfE 1994; Davies-Colley and Smith 2001) and is the metric used in the NPS-FM.

Suspended sediment measures varied widely across the Waikato regional rivers. TURB ranged from 0.025 to 1,180 NTU with a median of 3.95 NTU (Table 2; Figure 18). The median levels were generally highest in the catchments of the lower Waikato. In contrast, the 95th percentile indicated elevated TURB in the West Coast and Waipā catchments, a finding consistent with the Waikato regional assessment of sediment yields (Vale and Smith 2024). The BDISC data (gap-filled using TURB) ranged from 0.01 m to 30.76 m, with a median of 1.08 m (Table 2).

The Tokaanu Stream[29] was the site where the maximum BDISC of 30.76 m was reported and is an outlier value for this site and the region. Derived from gap-filled TURB measurements, this outlier underscores the limitations of applying regional or water quality zone regressions for gap-filling and highlights the need for site-specific regressions. Historical BDISC data for the Tokaanu Stream are limited, comprised of three measurements (1.6 m, 9.1 m, and 20.5 m) from 1993 (n=2) and 2016 (n=1). Given the insufficient data to confidently adjust or remove this outlier, it was retained in the summary statistics. Future work is underway to develop an in situ transmissometer to reduce data gaps.

The proportion of monitored sites classified as D band (i.e., failed/below the national bottom line) increased from 26.1% (n = 29) in 2017 (Ryan and Jenkins 2022) to 50.9% (n = 56) in this assessment. This shift suggests a marked deterioration in visual clarity across monitored sites. It may also reflect differences in gap-filling methods, and variations in flow regimes between assessment periods. As visual clarity is strongly inversely related to discharge (Smith et al. 1997), flow variation driven by climatic factors such as the El Niño Southern Oscillation can cause differences in attribute states between assessment periods (Snelder 2022). Therefore, it is important to develop robust gap-filling methods and account for environmental variability in baseline and target state assessments to understand how visual clarity changes with time.

[29] 1045_3 - Tokaanu Stm Off SH41 Turangi.

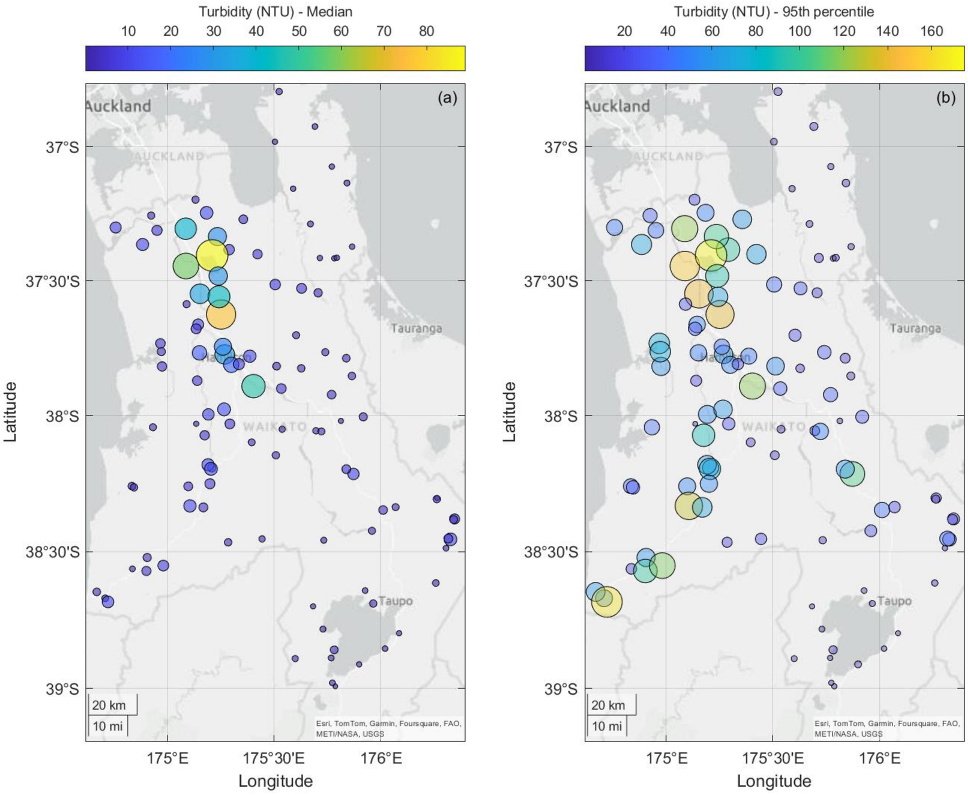

Figure 18 Turbidity (NTU) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

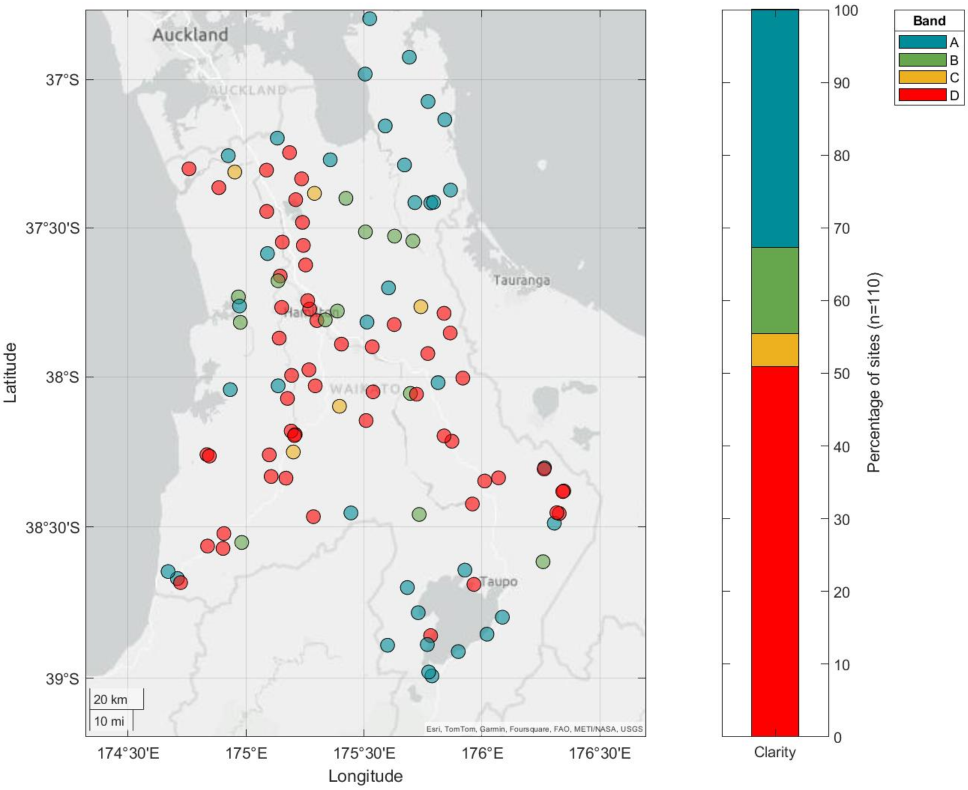

Figure 19 Visual clarity (fine suspended sediment) attribute (m) banding geospatial and proportional plot from ReRiMP sites (n=110) over the last five hydrological years.

3.3.4 Coloured Dissolved Organic Matter (CDOM)

Organic matter (OM) in freshwater plays an important role in the ecosystem functioning of freshwaters (McDowell 2023). Measures of OM include coloured (or chromophoric) dissolved organic matter (CDOM), which is a subset of dissolved organic matter (DOM) that strongly absorbs light at wavelengths above 250 nm, and fluorescent dissolved organic matter (fDOM) is the fraction of CDOM that fluoresces. CDOM and fDOM measures correlate with other water quality parameters such as TN, TP, and chemical oxygen demand (Zhang et al. 2011; Liu et al. 2014; Shao et al. 2017).

Key sources of OM in rivers include soils, vegetation, wetlands, peatlands, decay products, and organic waste. OM provides an important food source for instream biota (Leal et al. 2023) and binds to metals (Yamashita and Jaffé 2008) reducing bioavailability and toxicity (ANZG 2018). However, OM increases light attenuation, thereby reducing photosynthesis, absorbs ultraviolet radiation (UV) and increases thermal absorption (Zhang et al. 2009), and in excess can fuel microbial respiration leading to DO depletion (Dutton et al. 2018; Yu et al. 2021; Diamond et al. 2021).

CDOM is measured using spectrophotometric absorption at specific wavelengths such as 254, 350, 355, and 440 nm (Davies-Colley and Close 1990; Zhang et al. 2009; Zhang et al. 2011; Liu et al. 2014; Shao et al. 2017). The light absorption coefficients of CDOM at 340nm and 440 nm wavelengths [aCDOM(λ)] have been suggested as standard measures of colour in aquatic ecosystems (Davies-Colley and Close 1990). WRC measures absorbance at 340 nm (near-UV) and 440 nm (blue light), with a particle correction measure at 780 nm[30].

Table 2 summarises the range of absorbance values for the three wavelengths across the Waikato region. Notably, the 780 nm data is predominately at analytical detection, limiting its applicability for the correction of residual particulates. Analytical detection limit also affects measurements at 440 nm, with 14 sites with median values at LOD, although at the 95th percentile, all data were above the LOD. In contrast, absorption at 340 nm, and thus its precision, is five to six times higher than at 440 nm. Therefore, when examining the optical impacts of CDOM at low concentrations, 340 nm should be used, or the relationship between these highly correlated parameters considered for gap-filling at low levels. To reduce the effects of LOD on absorbance parameters a simple method change to a longer cuvette path length (specifically switching from the current 1 cm cell to a 4 cm cell) is recommended.

Literature reporting absorbance in New Zealand rivers is focussed on the absorption coefficient at 440 nm, as this wavelength represents the aquatic humus fraction of OM that most strongly absorbs blue light, which imparts a yellow colour to water and reduces photosynthetically available radiation for primary producers. Therefore, this report focuses on absorbance at 440 nm and derives the absorption coefficient at 440 nm (aCDOM(440)) using Equation 9 from Shao et al. (2017a). The data is not corrected to residual light scattering because absorbance at 780 nm with 1 cm cell size is predominately censored data. It is important to note that while absorbance is an optical metric, it can also be used as a proxy for OM concentration. The data here represents the optical differences related to OM in rivers across the Waikato region.

Equation 9 $$a_{CDOM}(\lambda') = \frac{(ln10\times OD(\lambda))}{l}$$

Where,

aCDOM(λ') = uncorrected CDOM absorption coefficient at wavelength λ,

OD(λ) = optical density at the same wavelength, and

l is the cuvette path length in meters (m).

The median uncorrected absorption coefficient at 440 nm aCDOM(440') across all sites ranged from 0.04 m^{-1} to 9.02 m^{-1}, with a median of 0.96 m^{-1}. This is similar to Smith and Maasdam (1994), who reported aCDOM(440') ranging from 0.01 m^{-1} to 9.35 m^{-1}. Davies-Colley and Close (1990)

[30] CDOM absorption is negligible in the near-infrared region of the spectrum, so measurement at 780 nm is used to correct for residual light scattering by small particles and colloids.

suggested that aCDOM(440) > 1 m^{-1} can be regarded as high and reported that approximately 26% of New Zealand rivers (n=96) had high concentrations. In comparison, 52.7% (n=58) of monitored rivers in the Waikato exceed 1 m^{-1}, highlighting that CDOM optical influence is relatively pronounced in the region. Seven of these sites showed very high aCDOM(440) values, with median and 95th percentiles exceeding 4 m^{-1} and 10 m^{-1}, respectively. Visual clarity at these sites was very low, with BDISC <0.45 m, well below the national bottom line for all sediment classes. As BDISC is a function of both absorption and scattering, the high contribution of CDOM to reduced clarity may present challenges for meeting target attribute states and highlights a research need to understand the sources and contributions of CDOM to visual clarity to develop and achieve NPS-FM (2020) targets. The seven sites identified with high CDOM are as follows:

- 398_1 - Mangakotukutuku Stm (Rukuhia) Peacockes Rd
- 1293_7 - Whangamarino River Island Block Rd
- 488_1 - Mangawhero Stm (Cambridge) Cambridge-Ohaupo Rd
- 1236_2 - Waitawhiriwhiri Stm Edgecumbe Street
- 481_7 - Mangawara Stm Rutherford Rd Br
- 258_4 - Komakorau Stm Henry Rd
- 624_5 - Ohote Stm Whatawhata/Horotiu Rd

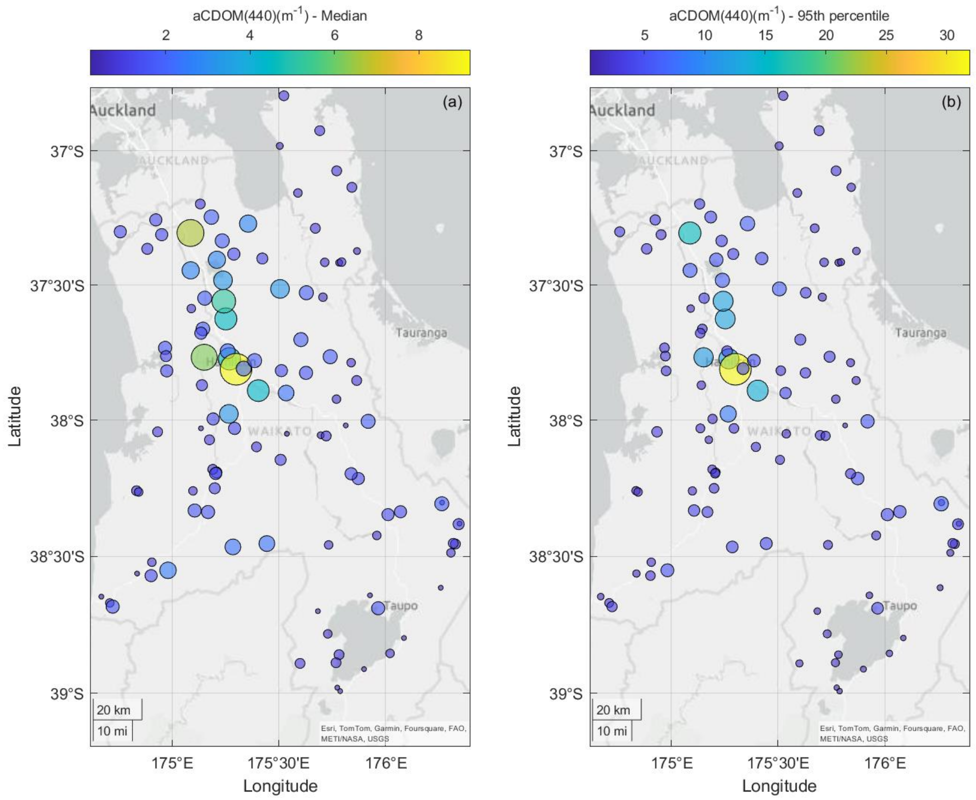

Figure 20 Uncorrected absorbance coefficient aCDOM(440’) (m^{-1}) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

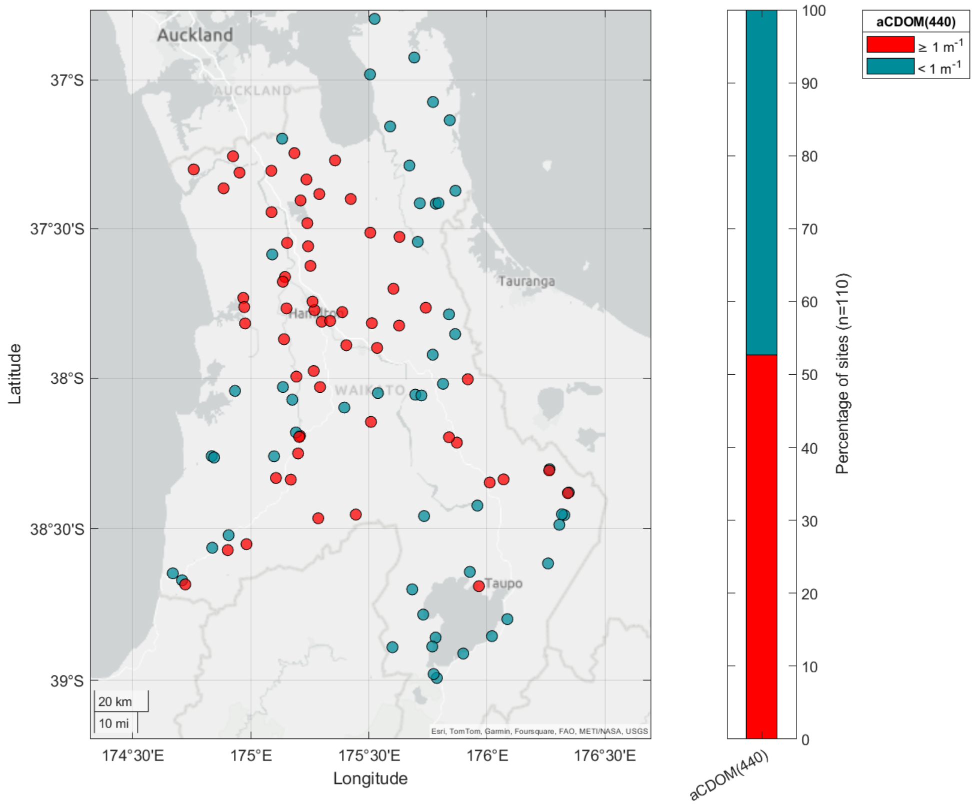

Figure 21 Uncorrected absorbance coefficient aCDOM(440') (m^{-1}) compared to 1 m^{-1}, from ReRiMP sites (n=110) over the last five hydrological years.

3.3.5 Conductivity (COND)

Electrical conductivity (COND) measures the total ionic content of water, reflecting the concentration of dissolved ions and TEMP. It is predominately influenced by the major cations, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), as well as the major anions including chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}). The anions nitrate (NO_3^-) and phosphate (PO_4^{3-}) and metal cations (Fe^{2+}, Fe^{3+}, Mn^{2+}, Al^{3+}) are generally minor contributors to conductivity (Boyd 2020d; Mitryasova and Pohrebennyk 2020). In the Waikato, geothermal inputs can increase arsenic, alkalinity (as bicarbonate), boron, chloride, lithium, potassium, sodium, silica, and sulphate (WVA 1979; Huser 1990).

COND has been shown to correlate with major ions (Maasdam and Smith 1994), total dissolved solids, dissolved nutrients (see Section 3.2), periphyton biomass (Biggs 1990; Biggs 2000; Kilroy 2017; Kilroy et al. 2020), and ecosystem metabolism (Clapcott and Doehring 2017). Subsequently, COND is commonly used as a surrogate indicator of cumulative land-use impacts (e.g., urban inputs, industrial discharges, mining, and agricultural activities) and geothermal inputs.

In the Waikato regional rivers, COND ranged from 8 to 1,418 µS/cm with a median of 120 µS/cm (Table 2). For comparison, the COND across a New Zealand wide network of sites ranged from 51 to 180 µS/cm (10th to 90th percentile), with a median of 85 µS/cm (Maasdam and Smith 1994). For direct comparison, the comparable 10th to 90th percentile COND in Waikato rivers was 66.65 to 238.35 µS/cm.

ANZG (2018) provides COND guideline values ranging from 83 to 145 µS/cm, depending on REC derived from 80th percentiles from reference sites. To highlight sites with elevated COND this report compares 95th percentile data to the 300 µS/cm proposed by Nietch et al. (2023) as an aquatic life benchmark. A total of 13 sites (11.8%) were characterised by 95th percentile COND > 300 µS/cm. It is recommended that these sites be included in supplementary monitoring to quantify and track changes in major ions and metalloids. These sites are listed below, with sites known to be geothermally influenced identified:

- 39_11 - Awaroa Stm (Rotowaro) Sansons Br @ Rotowaro-Huntly Rd
- 619_19 - Ohinemuri River Queens Head
- 1097_1 - Waahi Stm Te Ohaki Rd
- 258_4 - Komakorau Stm Henry Rd
- 41_9 - Awaroa River (Waiuku) Otaua Rd Br opp Moseley Rd
- 619_16 - Ohinemuri River Karangahake
- 481_7 - Mangawara Stm Rutherford Rd Br
- 1302_1 - Whangape Stm Rangiriri-Glen Murray Rd

Geothermal influenced sites:

- 1186_2 - Waiotapu Stm Campbell Rd Br (geothermal influence)
- 1186_4 - Waiotapu Stm Homestead Rd Br (geothermal influence)
- 1249_18 - Waitoa River Mellon Rd Recorder (geothermal influence)
- 1202_7 - Waipapa Stm (Mokai) Tirohanga Rd Br (geothermal influence)
- 683_4 - Otamakokore Stm Hossack Rd (geothermal influence)

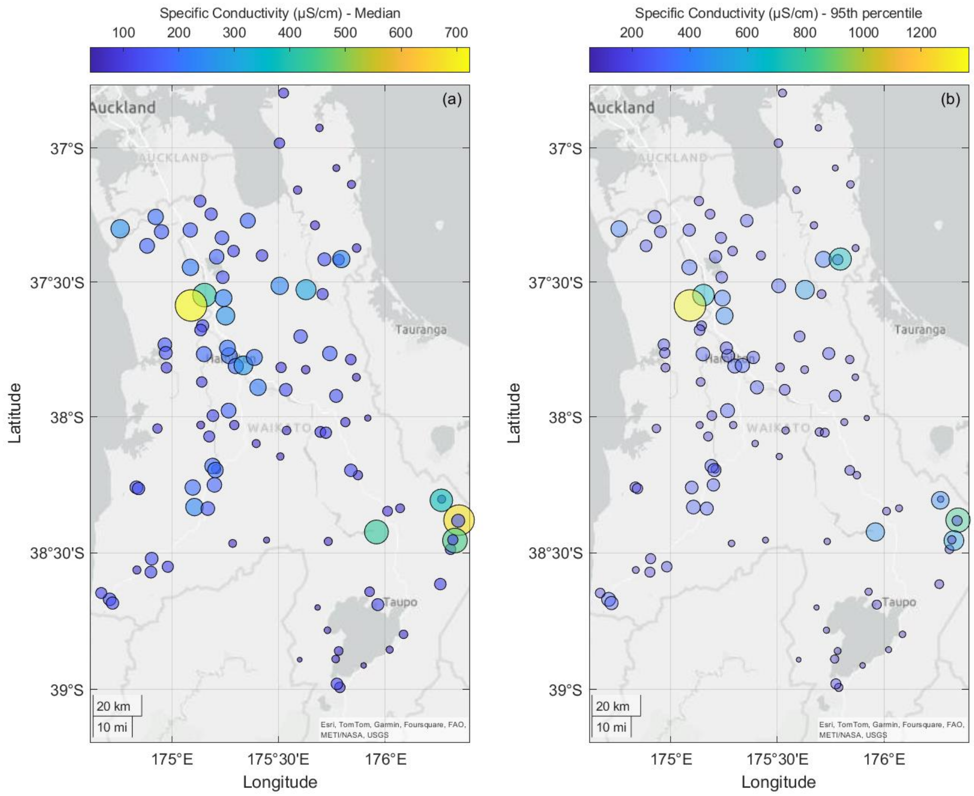

Figure 22 Specific Conductivity (µS/cm) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

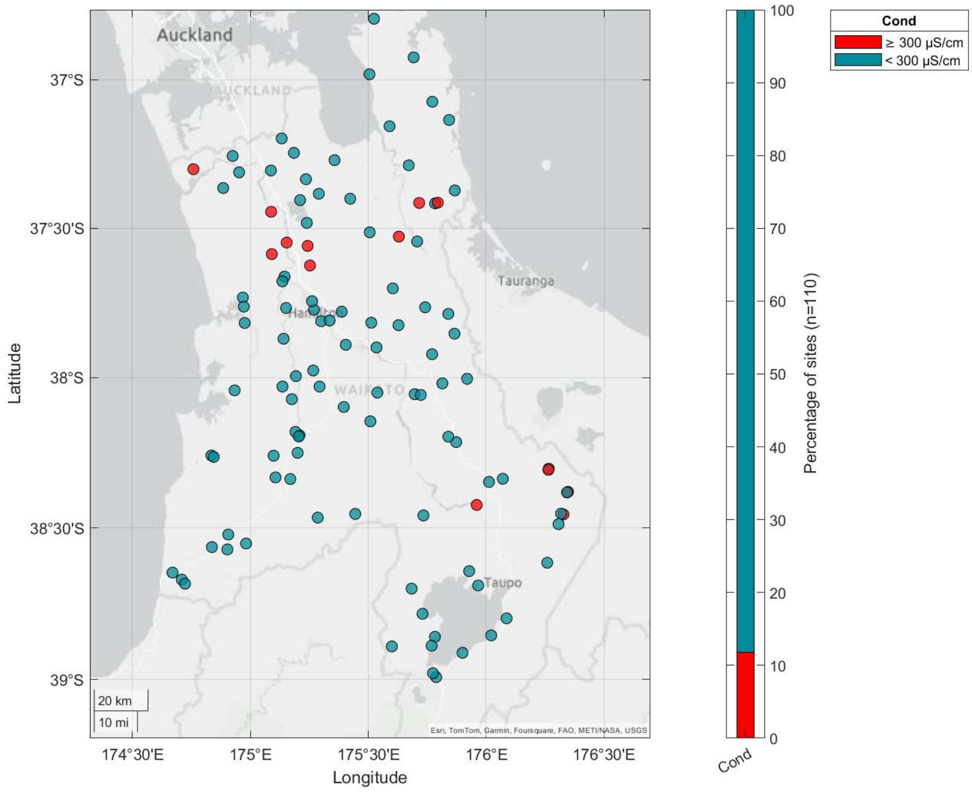

Figure 23 Specific Conductivity (µS/cm) compared to 300 µS/cm ecological benchmark, from ReRiMP sites (n=110) over the last five hydrological years.

3.3.6 Water Temperature (TEMP)

TEMP is an important biophysical parameter in river environments, influencing biogeochemical processes, species abundance and distribution, and ecosystem processes. The key drivers of TEMP include air temperature, atmospheric heat exchange, solar radiation and shading, humidity, TURB, flow, structures (e.g., dams), precipitation, turbulence, surface area and depth (Edinger et al. 1968; Schmid et al. 2014; Kędra and Wiejaczka 2018; Boyd 2020e).

Increasing TEMP reduces the solubility of oxygen in water (Verberk et al. 2011), affecting a wide range of biogeochemical processes such as nitrification and denitrification (Wetzel 2001; Comer-Warner et al. 2019). Furthermore, elevated TEMP can also amplify the effects of several toxicants, such as ammonia, hydrogen sulphide, and glyphosate (ANZG 2018).

Most aquatic life are ectotherms, meaning that as TEMP rises, the metabolic rates of aquatic organisms increase (Dean and Richardson 1999; Verberk et al. 2011). Extreme TEMP and rapid fluctuations can induce thermal stress in aquatic biota, affecting foraging efficiency, competitive interactions, predatory dynamics, and increasing susceptibility to parasites and diseases (Kishi et al. 2005; Breau et al. 2011; Moore et al. 2013; Hette-Tronquart et al. 2013). For instance, the ubiquitous pathogenic bacteria *Plesiomonas shigelloides* (Chen et al. 2022) is found to be positively correlated with TEMP (Ekundayo and Okoh 2019) and has been associated with fish kill events in the lower Waikato. Similarly, botulism outbreaks in lower Waikato rivers have been associated with higher temperatures, which is consistent with studies of outbreak drivers (e.g., Rocke et al. 1999; Rocke and Samuel 1999; Pérez-Fuentetaja et al. 2011; Espelund and Klaveness 2014; Uzal et al. 2024). TEMP, along with light, flow and nutrients, controls periphyton and macrophyte abundance and community composition (Matheson and Wells 2017) and can modify phytoplankton communities and favour cyanobacteria (Moss 2011).

In New Zealand, maximum temperatures of <20°C in upland streams and <25°C in lowland streams protect the most sensitive native aquatic taxa (Olsen et al. 2012). Across the monitored sites, discrete TEMP ranged from 5.1°C to 32°C, with a median of 14.3°C (Table 2; Figure 24).

Davies-Colley et al. (2013) proposed TEMP attribute bands based on the Cox-Rutherford Index (CRI), see Table 4.

Table 4. Water temperature attribute bands proposed Davies-Colley et al. (2013).

Attribute band	Numeric attribute state	Description
A	≤ 18°C	No thermal stress on any aquatic organisms that are present at matched reference (near-pristine) sites.
B	>18°C ≤ 20°C	Minor thermal stress on occasion (clear days in summer) on particularly sensitive organisms such as certain insects and fish.
C	> 20°C ≤ 24°C	Some thermal stress on occasion, with elimination of certain sensitive insects and absence of certain sensitive fish.
D	>24°C	Significant thermal stress on a range of aquatic organisms. Risk of local elimination of keystone species with loss of ecological integrity.

Applying these proposed bands to the 95th percentile of routine discrete data classifies 49 sites (44.6%) as C band and eight sites (7.3%)[31] as D band (Figure 25). Excluding three geothermally influenced rivers[32], the sites classified as D band are as follows:

- 438_3 - Mangapiko Stm (Pirongia/Te Awamutu) Bowman Rd
- 619_16 - Ohinemuri River Karangahake
- 1293_7 - Whangamarino River Island Block Rd
- 1097_1 - Waahi Stm Te Ohaki Rd
- 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) Down Stream of Control Gates

Prioritising these sites for continuous temperature monitoring is recommended to quantify the diurnal variation. Because TEMP data are discrete, routine measurements likely underestimates the number of D band rivers. Thermal stress is a key stressor in the Waikato, as over 50% of rivers fall into the pooled C and D bands based on discrete data only. Climate-driven change is likely to worsen thermal stress. Therefore, rivers classified in the C and D bands should be targeted for thermal stress mitigation (e.g., riparian planting) to reduce peak summer temperatures.

[31] 1186_2 - Waiotapu Stm Campbell Rd Br, 1202_7 - Waipapa Stm (Mokai) Tirohanga Rd Br, 438_3 - Mangapiko Stm (Pirongia/Te Awamutu) Bowman Rd, 619_16 - Ohinemuri River Karangahake, 1293_7 - Whangamarino River Island Block Rd, 683_4 - Otamakokore Stm Hossack Rd, 1097_1 - Waahi Stm Te Ohaki Rd, 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) DownStream of Control Gates.

[32] 1186_2 - Waiotapu Stm Campbell Rd Br, 1202_7 - Waipapa Stm (Mokai) Tirohanga Rd Br, 683_4 - Otamakokore Stm Hossack Rd.

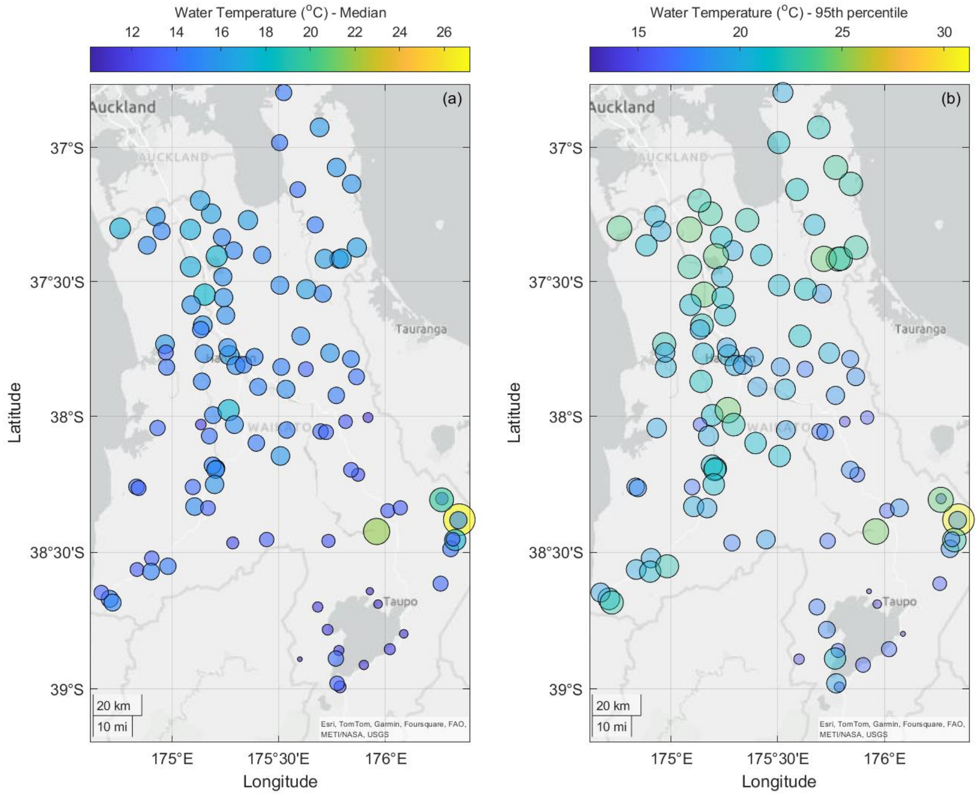

Figure 24 Water Temperature (°C) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

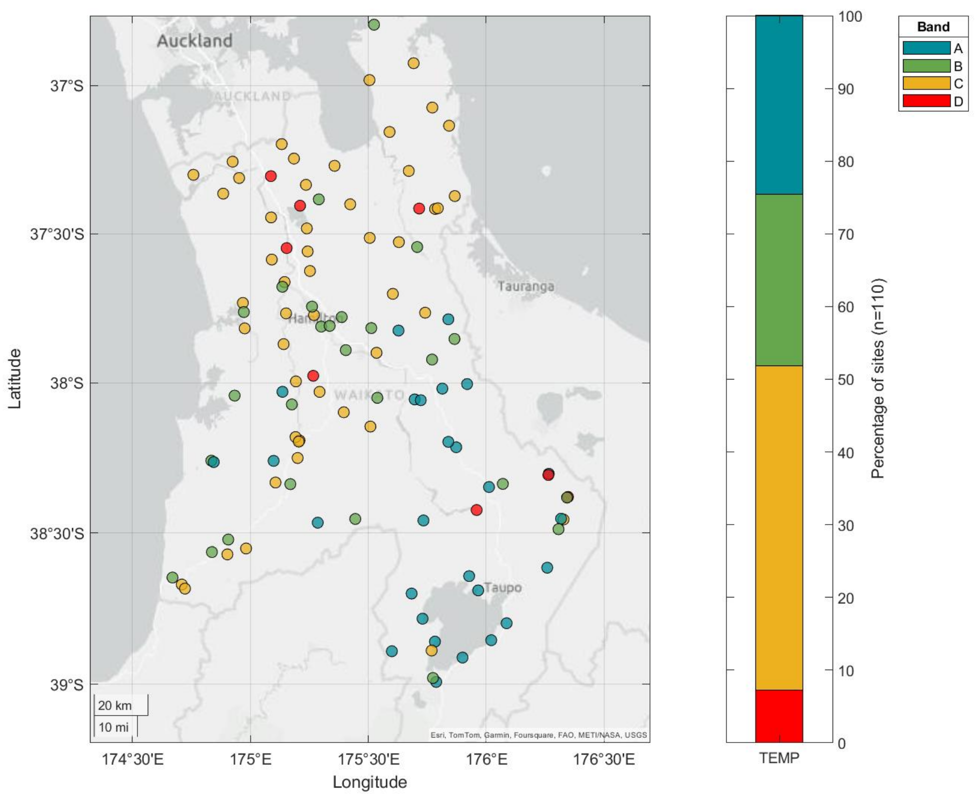

Figure 25 Water Temperature (TEMP) (°C) proposed attribute classification using 95th percentile of discrete data from ReRiMP sites (n=110) over the last five hydrological years.

3.3.7 Water pH

The pH of water is an important parameter for riverine aquatic life (Boyd 2020f), community structure (Olsson et al. 2006), and ecosystem processes (Le et al. 2019). It is affected by several factors, including atmospheric conditions, catchment (e.g., wetland), land-use practices (e.g., mining), geology (e.g., geothermal, limestone, acid sulphate soils) and point-source discharges (Davies-Colley et al. 2013).

Riverine pH directly influences the toxicity of metals, ammonia, and hydrogen sulphide (Davies-Colley et al. 2013; ANZG 2018) and plays a critical role in phosphorus cycling and nitrification (Le et al. 2019). Extreme pH levels can damage fish gills, disrupting chemosensory abilities, ion exchange and respiratory gas transfer. The optimum pH range for most aquatic organisms is 6.5–8.5 (Boyd 2020f). In New Zealand, freshwater biota prefer pH levels between 6.5 and 9.5 (West et al. 1997) and are generally adapted to low pH in naturally acidic streams. However, anthropogenic acidity can have more severe effects, likely due to the combined effects of acidity and metal toxicity from anthropogenic sources, compared to natural acidity, where organic matter likely mitigates metal toxicity (Collier et al. 1990).

Riverine pH undergoes diurnal variations as respiration and photosynthesis regulate carbon dioxide levels, which dissociate in water, increasing acidity. The buffering capacity of water (alkalinity) to pH changes is influenced by the concentration of calcium carbonate (carbonates and bicarbonates) from sources such as limestone. It is important to note that pH is a logarithmic, unitless scale, where a one-unit change in pH represents a 10-fold difference in hydrogen ion concentration (Boyd 2020f).

Across monitored sites, pH ranged from 4.1 to 9.8, with a median of 7.3 (Table 2; Figure 26). Davies-Colley et al. (2013) proposed thresholds for pH of < 6 and > 9, beyond which freshwater biota may experience significant stress. Applying these to the 5^{th} and 95^{th} percentiles highlighted three sites with low pH and one with high pH[33]. The sites with low pH were Waiotapu[34], Komakorau[35], and Mangakotukutuku[36]. Low pH at Waiotapu reflects geothermal influence, while Komakorau and Mangakotukutuku drain peat-land catchments. Davies-Colley et al. (2013) proposed pH ranges between 4.0 to 6.5 for peat streams. The Komakorau and Mangakotukutuku 5^{th} percentile pH values were within this criterion. High pH (> 9) occurred at the Northern Outlet Canal[37], driven by high primary production in the hypertrophic Lake Waikare.

It is well established that as pH rises, ammonia toxicity increases. As pH exhibits pronounced diurnal fluctuations, continuous pH monitoring during summer months is required to characterise diel variability. Moreover, this study identified a regional association between higher pH and lower ammonia concentrations (see Section 3.2), a finding that requires further assessment. To improve understanding of pH, sites with ammonia toxicity below the national bottom line (see Section 3.3.1.1) and sites with high pH and large variation are recommended for continuous monitoring. The sites high pH and variation are as follows:

- 41_9 - Awaroa River (Waiuku) Otaua Rd Br opp Moseley Rd
- 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) Down Stream of Control Gates
- 619_19 - Ohinemuri River Queens Head
- 438_3 - Mangapiko Stm (Pirongia/Te Awamutu) Bowman Rd
- 398_1 - Mangakotukutuku Stm (Rukuhia) Peacockes Rd
- 619_16 - Ohinemuri River Karangahake
- 818_40 - Puniu River Wharepapa Rd Bridge
- 619_20 - Ohinemuri River SH25 Br
- 1293_7 - Whangamarino River Island Block Rd

[33] This contrasts to the recommended approach by Davies-Colley et al. (2013) for discrete data using pH maxima if continuous data is not available. Maximum pH values were reviewed not available, see Figure 45. Davies-Colley et al. (2013) recommends continuous monitoring of pH in summer to provide reliable data on diel pH variability.

[34] 1186_2 - Waiotapu Stm Campbell Rd Br.

[35] 258_4 - Komakorau Stm Henry Rd.

[36] 398_1 - Mangakotukutuku Stm (Rukuhia) Peacockes Rd.

[37] 3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal) DownStream of Control Gates.

- 477_10 - Mangauika Stm Te Awamutu Borough W/S Intake

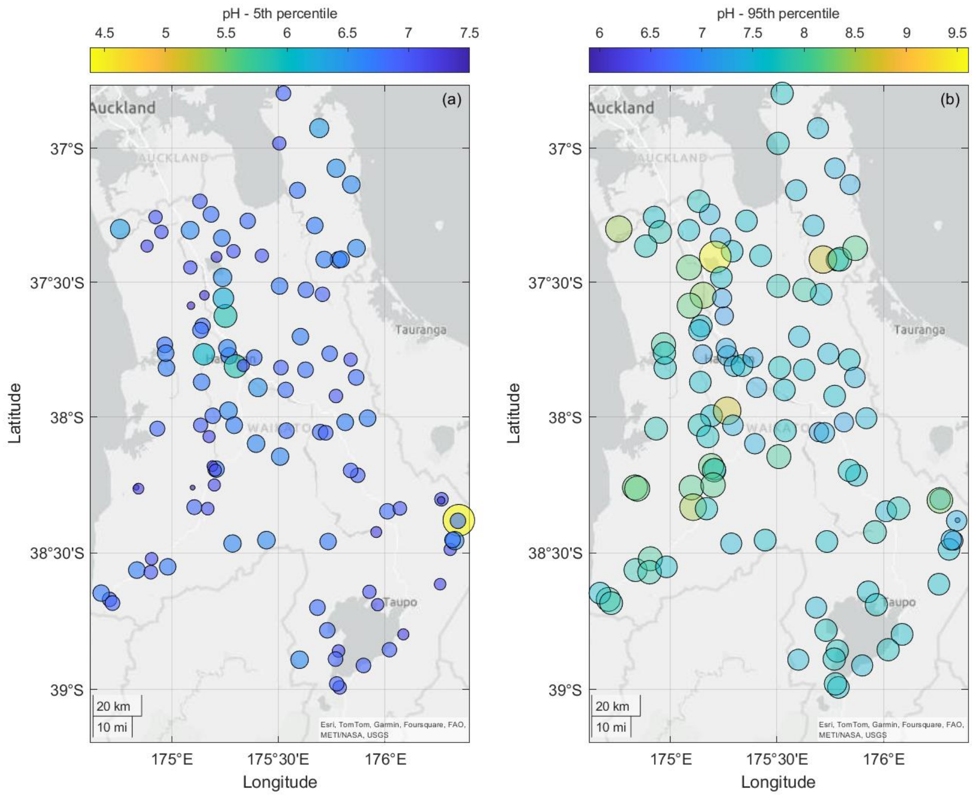

Figure 26 pH median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.

3.4 Human Health Water Quality Value

3.4.1 Escherichia coli (E. coli)

E. coli is a faecal coliform used as an indicator to evaluate potential faecal contamination and the possible presence of other harmful pathogens that can lead to illnesses such as gastroenteritis or infections of the ears, eyes, nose, skin, and respiratory tract. This bacterium is commonly found in the intestines of warm-blooded mammals (including people) and birds (MfE 2003b). While *E. coli* indicates faecal contamination, it does not differentiate between sources such as birds, animals, or humans. Techniques such as polymerase chain reaction (PCR) for DNA and sterol composition of animal faeces can be used to discriminate faecal sources.

E. coli across the Waikato region ranged from 0.5 to 220,000 cfu/100mL, with a median of 260 cfu/100mL. The highest counts generally found in the rivers of the lower Waikato.

The NPS-FM (2020) *E. coli* attribute banding ranges from A to E, with associated risks of *Campylobacter* infection ranging from 1% to more than 7%, respectively. Although the NPS-FM (2020) does not include a national bottom line for *E. coli*, 51.8% (n=57) of sites across the Waikato region were classified as E band, indicating a predicted average infection rate >7%. Combined, over 80% of sites fell within the lowest quality D and E bands.

A comparison of the 2017 baseline to the 2023 assessment shows a general shift toward poorer *E. coli* states (Appendix F). Further investigation into the drivers of overall attribute bands and their underlying numeric states[38] is recommended to understand climate-driven state changes and develop target states and improvement strategies.

[38] The overall *E. coli* attribute band is determined by four numeric attribute states, with the worst-performing of these used to assign the overall band.

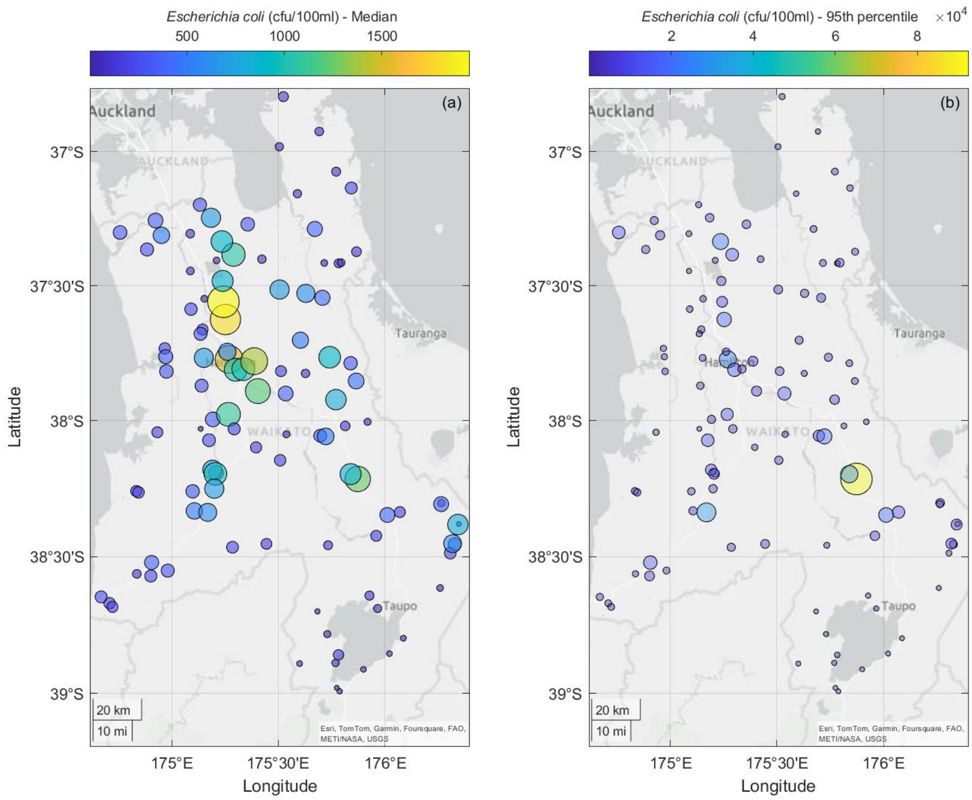

Figure 27 ***Escherichia coli*** **(*E. coli*) (cfu/100mL) median (a) and 95th percentile (b) from ReRiMP sites (n=110) over the last five hydrological years.**

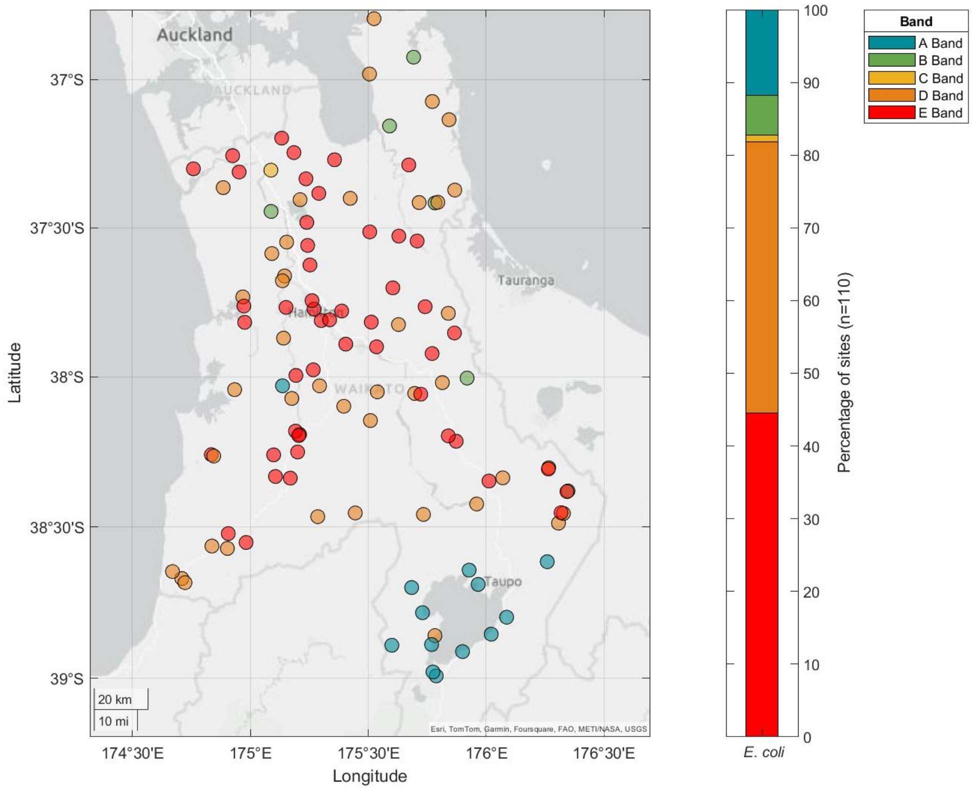

Figure 28 ***Escherichia coli*** **(*E. coli*) attribute banding geospatial and proportional plot from ReRiMP sites (n=110) over the last five hydrological years.**

4 Recommendations

Based on the report findings, we recommend:

- Evaluate how censored data processing methods (i.e., substitution versus maximum likelihood estimation and regression on order statistics) impact state and trend results for water quality parameters (i.e., TAN and DRP) across the Waikato region.
- Complete further analysis of water quality data that includes catchment attributes and climate variables at catchment scale to improve understanding of associations with water quality parameters and provide insights for optimising monitoring programme and simplifying communication of attribute targets.
- Develop a plan for improving water clarity monitoring that includes:
    - Paired sampling of absorbance at 340, 440 and 780 nm using 1 cm and 4 cm cuvette cells to improve low-level CDOM measurement and inform a method change to 4 cm path length.
    - Develop and evaluate a field beam transmissometer to deploy at sites missing BDISC due to access and water depth restrictions. A project to complete this recommendation was initiated in November 2024.
    - Derive site-specific regression models between visual clarity measures for gap-filling visual clarity data and quantify organic matter contributions for visual clarity target setting.
- Evaluate deploying continuous in situ monitoring at sites identified with poor physio-chemical water quality, specifically:
    - Dissolved oxygen loggers at sites with hypoxic risk.
    - Temperature and pH loggers at sites with ammonia toxicity below the national bottom line.
    - Temperature loggers at non-geothermal sites identified with high thermal stress risk, and undertake optioneering for mitigation measures (e.g., riparian planting).
    - Conductivity loggers at the 13 sites exceeding the applied ecological benchmark, and addition of these sites to the supplementary major ions and metal(loid)s monitoring programmes to understand ions contributing to conductivity and changes over time.

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Appendix A

Table 5 Tributaries to the Lower Waikato water quality zone monitoring site identification and positional data (New Zealand Transverse Mercator Projection [NZTM], and World Geodetic System 1984 [WGS84]).

Site_Station	Site Name	Station Name	NZTM		WGS84	
			Easting	Northing	Longitude	Latitude
1045_3	Tokaanu Stm	Off SH41 Turangi	1841470	5680399	175.7881	-38.9921
1057_6	Torepatutahi Stm	Vaile Rd Br	1888409	5734946	176.3065	-38.4872
1097_1	Waahi Stm	Te Ohaki Rd	1790273	5842096	175.1539	-37.5485
1098_1	Waerenga Stm	Taniwha Rd	1802756	5860005	175.2902	-37.3845
1105_3	Waiau River	E309 Rd Ford	1825236	5925022	175.5244	-36.7939
1106_4	Waihaha River	SH32	1833389	5713044	175.6838	-38.7004
1122_18	Waihou River	Okauia	1850033	5813970	175.8394	-37.7874
1122_34	Waihou River	Te Aroha	1839179	5841242	175.7073	-37.5448
1122_41	Waihou River	Whites Rd	1847029	5788310	175.8141	-38.0193
1167_4	Waingaro River (Pukemiro)	Ruakiwi Rd Off SH22	1773441	5822030	174.9682	-37.7326
1173_2	Waiohotu Stm	Waiohotu Rd (Off SH5)	1856291	5789715	175.919	-38.004
1174_4	Waiomou Stm	Matamata-Tauranga Rd	1852108	5806591	175.8655	-37.8533
1186_2	Waiotapu Stm	Campbell Rd Br	1892343	5746710	176.3467	-38.3801
1186_4	Waiotapu Stm	Homestead Rd Br	1890373	5738454	176.3275	-38.455
1191_12	Waipa River	SH3 Otorohanga	1793417	5770550	175.2086	-38.1922
1191_2	Waipa River	Pukehoua Bridge on Baffin Road	1792588	5792454	175.1933	-37.9951
1191_5	Waipa River	Mangaokewa Rd	1813330	5741060	175.4448	-38.4533
1191_6	Waipa River	Ngaruawahia Br	1789220	5829466	175.1453	-37.6625
1202_7	Waipapa Stm (Mokai)	Tirohanga Rd Br	1858355	5743037	175.9594	-38.4236
1226_1	Waitahanui River	Blake Rd	1868051	5701057	176.0865	-38.7985
1230_1	Waitakaruru River (Hauraki Plains)	Coxhead Rd Br	1808982	5872419	175.357	-37.2714
1236_2	Waitawhiriwhiri Stm	Edgecumbe Street	1799902	5816915	175.2697	-37.7733
1239_32	Waitekauri River	U/S Ohinemuri Conflu	1846306	5855261	175.7832	-37.4167
124_8	Firewood Creek	Waingaro Road Bridge	1788353	5827726	175.1359	-37.6783
1247_2	Waitetuna River	Te Uku-Waingaro Rd	1773923	5812566	174.976	-37.8177
1249_15	Waitoa River	Landsdowne Rd Br	1841455	5816681	175.7412	-37.7653
1249_18	Waitoa River	Mellon Rd Recorder	1832368	5843261	175.6296	-37.5284
1253_5	Waitomo Stm	SH31 Otorohanga	1791948	5771850	175.1915	-38.1808
1253_7	Waitomo Stm	Tumutumu Rd	1783624	5763236	175.0988	-38.2602

Site_Station	Site Name	Station Name	NZTM		WGS84	
			Easting	Northing	Longitude	Latitude
1257_3	Waiwawa River	SH25 Coroglen	1839816	5910119	175.6923	-36.9245
1282_8	Whakapipi Stm	SH22 Br	1770704	5874826	174.925	-37.2575
1287_7	Whakauru Stm	U/S SH1 Br	1851510	5766456	175.8728	-38.2147
1293_7	Whangamarino River	Island Block Rd	1784968	5869103	175.0871	-37.3063
1293_9	Whangamarino River	Jefferies Rd Br	1798066	5865561	175.2358	-37.3355
1300_1	Whangamata Stm (Kinloch)	Whangamata Rd	1854803	5718799	175.9276	-38.6427
1301_1	Whanganui Stm	Lakeside Lake Taupo T8	1837143	5703708	175.7301	-38.7835
1302_1	Whangape Stm	Rangiriri-Glen Murray Rd	1784703	5853683	175.088	-37.4453
1312_3	Wharekawa River	SH25	1852498	5886250	175.8426	-37.1361
1318_4	Whareroa Stm (Taupo)	Lakeside Lake Taupo T9	1841456	5695161	175.7827	-38.8593
1323_1	Whirinaki Stm	Corbett Rd	1885524	5755511	176.2652	-38.3031
1391_1	Mangarama Stm	Gadsby Rd	1784134	5755235	175.1067	-38.3321
1491_1	Tokaanu Power Station Tailrace Canal	SH41 Bridge Over Canal	1840329	5681866	175.7744	-38.9792
169_2	Hikutaia River	Old Maratoto Rd	1836841	5869743	175.6717	-37.2888
171_5	Hinemaiaia River	SH1	1862185	5695020	176.0214	-38.8546
222_16	Kaniwhaniwha Stm	Wright Rd	1788300	5806382	175.1408	-37.8706
230_5	Karapiro Stm	Hickey Rd Bridge - Cambridge	1822883	5802300	175.5349	-37.8995
234_11	Kauaeranga River	Smiths Cableway Recorder	1830013	5884555	175.5902	-37.1571
240_5	Kawaunui Stm	SH5 Br	1891976	5746482	176.3426	-38.3822
253_4	Kirikiriroa Stm	Tauhara Dr	1799248	5820070	175.2615	-37.745
258_4	Komakorau Stm	Henry Rd	1798800	5833361	175.2527	-37.6254
282_4	Kuratau River	SH41 Moerangi	1825502	5692096	175.6	-38.8911
282_5	Kuratau River	Te Rae Street T10	1840133	5691927	175.7686	-38.8887
3021_3	Northern Outlet Canal (a.k.a.Pungarehu Canal)	Down Stream of Control Gates	1795678	5857803	175.2109	-37.4059
33_6	Awakino River	Gribbon Rd	1760059	5730104	174.8371	-38.5631
33_9	Awakino River	SH3 Awakau Rd Junction	1748705	5718389	174.7094	-38.6706
335_1	Little Waipa Stm	Arapuni - Putaruru Rd	1836614	5784613	175.6968	-38.0553
359_1	Mangaharakeke Stm (Atiamuri)	SH30 (Off Jct SH1)	1863201	5751371	176.0118	-38.3472
380_2	Mangakara Stm (Reporoa)	SH5	1889506	5738783	176.3175	-38.4523
388_1	Mangakino Stm (Whakamaru)	Sandel Rd	1838547	5739797	175.7339	-38.4583

Site_Station	Site Name	Station Name	NZTM		WGS84	
			Easting	Northing	Longitude	Latitude
39_11	Awaroa Stm (Rotowaro)	Sansons Br @ Rotowaro-Huntly Rd	1784617	5837950	175.091	-37.587
398_1	Mangakotukutuku Stm (Rukuhia)	Peacockes Rd	1802506	5812573	175.3005	-37.8118
407_1	Mangamingi Stm (Tokoroa)	Paraonui Rd Br	1848650	5768522	175.8394	-38.1969
41_9	Awaroa River (Waiuku)	Otaua Rd Br opp Moseley Rd	1755860	5870203	174.7586	-37.3017
410_4	Manganui River	Off Manganui Rd	1745321	5721017	174.6699	-38.6475
411_9	Mangaohoi Stm	South Branch Maru Rd	1822734	5785595	175.5384	-38.05
414_6	Mangaokewa Stm	Lawrence Street Br	1789612	5754501	175.1695	-38.3376
417_7	Mangaone Stm (Waikato)	Annebrooke Rd Br	1805661	5812778	175.3363	-37.8092
421_10	Mangaonua Stm	Hoeka Rd	1810244	5815925	175.3874	-37.7799
421_16	Mangaonua Stm	Te Miro Rd (a.k.a Waitakaruru stm)	1821181	5811525	175.5128	-37.8169
428_3	Mangaotaki River	SH3 Br	1766193	5734587	174.9064	-38.5216
438_3	Mangapiko Stm (Pirongia/Te Awamutu)	Bowman Rd	1799086	5794363	175.2667	-37.9765
443_3	Mangapu River	Otorohanga	1793118	5770149	175.2053	-38.1959
444_1	Mangarapa Stm	Otorohanga Rd	1792544	5764098	175.2004	-38.2505
453_6	Mangatangi River	SH2 Maramarua	1793779	5875482	175.1848	-37.2471
459_6	Mangatawhiri River	Lyons Rd At Buckingham Br	1789293	5881001	175.1329	-37.1983
476_7	Mangatutu Stm (Waikeria)	Walker Rd Br	1810109	5780575	175.3961	-38.0982
477_10	Mangauika Stm	Te Awamutu Borough W/S Intake	1787494	5788722	175.1363	-38.0298
481_7	Mangawara Stm	Rutherford Rd Br	1798115	5840673	175.243	-37.5597
488_1	Mangawhero Stm (Cambridge)	Cambridge-Ohaupo Rd	1811449	5803595	175.4046	-37.8906
489_2	Mangawhero Stm (Kaihere)	Mangawara Rd	1814506	5857854	175.4234	-37.4013
504_2	Mapara Stm (Lake Taupo)	Off Mapara Rd (Whakaipo Res) T1	1857975	5713452	175.966	-38.69
513_3	Marokopa River	Speedies Rd (Off Te Anga Rd)	1760521	5763807	174.8347	-38.2594
516_5	Matahuru Stm	Waiterimu Road Below Confluence	1798000	5849274	175.2394	-37.4822
553_12	Moakurarua Stm	Warratah Farm Bridge	1790853	5783949	175.1758	-38.0721
556_2	Mokau River	Awakau Rd	1749850	5716869	174.7228	-38.6841

Site_Station	Site Name	Station Name	NZTM		WGS84	
			Easting	Northing	Longitude	Latitude
556_5	Mokau River	Mangaokewa Rd (Off SH30)	1799420	5740045	175.2858	-38.4656
556_9	Mokau River	Totoro Rd Recorder	1765756	5729127	174.9027	-38.5709
557_5	Mokauiti Stm	Three Way Point - Aria	1772711	5731165	174.982	-38.5512
612_9	Ohaeroa Stm	SH22 Br	1773012	5868668	174.9524	-37.3125
616_1	Ohautira Stm	Waingaro Te Uku Rd	1773746	5818631	174.9725	-37.7631
619_16	Ohinemuri River	Karangahake	1840337	5855574	175.7157	-37.4155
619_19	Ohinemuri River	Queens Head	1847342	5855482	175.7948	-37.4144
619_20	Ohinemuri River	SH25 Br	1853847	5859843	175.8667	-37.3734
624_5	Ohote Stm	Whatawhata/Horotiu Rd	1789493	5817795	175.1514	-37.7675
658_1	Oparau River	Langdon Rd (Off Okupata Rd)	1769651	5787687	174.9333	-38.0427
665_5	Opuatia Stm	Ponganui Rd	1766922	5862941	174.885	-37.3652
669_6	Oraka Stm	Lake Rd	1843532	5799203	175.7706	-37.9221
683_4	Otamakokore Stm	Hossack Rd	1885383	5755059	176.2637	-38.3072
749_10	Piako River	Kiwitahi	1829580	5824039	175.6042	-37.7021
749_15	Piako River	Paeroa-Tahuna Rd Br	1821502	5845142	175.5062	-37.5141
753_4	Piakonui Stm	Piakonui Rd	1831309	5810336	175.6281	-37.8251
786_2	Pokaiwhenua Stm	Puketurua	1838866	5784259	175.7225	-38.0579
802_1	Pueto Stm	Broadlands Rd Br	1883743	5720920	176.2588	-38.6149
818_2	Puniu River	Bartons Corner Rd Br	1801295	5788365	175.2935	-38.0301
818_40	Puniu River	Wharepapa Rd Bridge	1819868	5775028	175.5091	-38.1458
934_1	Tahunaatara Stm	Ohakuri Rd	1868367	5752370	176.0704	-38.3366
940_10	Tairua River	Morrisons Br Hikuai	1846396	5893251	175.7717	-37.0747
954_5	Tapu River	Tapu-Coroglen Rd	1822967	5904237	175.5051	-36.9816
971_5	Tauranga-Taupo River	20 Metres U/S SH1 Bridge	1851416	5688991	175.8996	-38.912
976_1	Tawarau River	Off Speedies Rd	1761387	5763275	174.8447	-38.2641

Appendix B

The Regional Rivers Monitoring Programme (ReRiMP) began in January 1993 with 70 sites. Table 6 provides a historical timeline from ReRiMP data reports spanning 1993 to present. It is critical to document changes in analytical methods and detection limits due to their potential impact on state and trend analyses. Table 7 to Table 9 outline significant changes in nutrient analytical methods over time. Additionally, Vant (2021) detailed several key programme and methodology changes, which are summarised below:

Programme methods overview: *'Since 1991 most of the methods used have remained essentially unchanged; however, there are some changes to database and laboratory procedures that need to be accounted for. Note that these comments only apply to results from sites monitored by Waikato Regional Council, and not to the five sites that have been monitored by NIWA.'*

Visual clarity: *'Visual clarity did not begin at any site until 1995'.*

Escherichia coli: '*Escherichia coli did not begin until 1998. E. coli concentrations have been determined in monthly samples from the ten Waikato River sites since 1998; they have also been determined in monthly samples from the five NIWA sites since 2005. At 72 regional river sites, however, concentrations were determined in samples collected quarterly during 1998–2012 (in March, June, September and December each year), and monthly during 2013–20.*

Turbidity: *A new turbidity meter (Hach 2100N) was purchased in the middle of 1995 to replace an earlier model that had been superseded (Hach 2100A). Although an attempt was made to cross-calibrate the meters, the resulting relationships were imprecise. The turbidity data obtained prior to mid-1995 were therefore ignored.*

Phosphorus: '*During 2004–12 changes were made to the laboratory methods used for analysing both total phosphorus (TP) and dissolved reactive phosphorus (DRP). For TP, in late 2004 a modified method was introduced which did not include the procedure for dealing with possible interferences caused by the presence of arsenic; this procedure was reinstated in 2012. Furthermore, in 2005 the reagent used to digest particulate forms of phosphorus was changed from potassium persulphate to ammonium persulphate. For DRP, the change—in 2005—involved sample handling rather than chemical reactions, with sample handling changing from "flow injection" analysis to "discrete" analysis. Inspection of the datasets showed that at some sites these changes to laboratory procedures had noticeably affected the long-term records of TP and DRP. At other sites, changes in the long-term records were apparent, but the reasons for these was not clear. The effects of the changes were investigated in studies undertaken during 2012–13* (Vant 2014) *and 2017–18 (WRC documents #11214122 and 11735651). The first study produced a method that has been used to adjust the reported total phosphorus results from 2004–12 for the Waikato River sites for the interference by arsenic. The second study suggested that the ammonium persulphate digestant could be less effective than the potassium persulphate digestant, but the conditions under which this occurred were unclear. However, it did show that reanalysis of the same sample for total phosphorus at different times could produce erratic results. At this point, the reliability of the long-term records of total phosphorus at the monitoring sites is uncertain. These records have been analysed for trends, and the results are presented in this report; however, these results should be regarded as being provisional.*'

Table 6 Historical timeline of the Regional River Monitoring Programme (ReRiMP). Italicised text indicates direct excerpts from previous ReRiMP data reports, with key points presented in bold for ease of reference.

Date	Programme Details
1993 to 1995	*One hundred sites currently make up the monitoring programme. Ninety-five sites are routinely sampled by Environment Waikato. Five sites within the Waikato region are routinely sampled by NIWA as part of the 'National Water Quality Network for New Zealand'. Environment Waikato* ***originally sampled 70 sites from January 1993. A further twenty-five sites were added to the programme in January 1994.***

Date	Programme Details
	Water quality in the Waikato region was assessed by ***measuring 25 physical-chemical*** *variables. At each site the following parameters were determined: level and flow (gauging sites only), temperature, black disk, dissolved oxygen, percentage dissolved oxygen, turbidity, pH, conductivity, dissolved organic carbon (quarterly), ammonium, nitrate-nitrite nitrogen, total Kjeldahl nitrogen, dissolved reactive phosphorus, total phosphorus, and absorbance (filtered) at 270nm, 400nm, and 740nm. In the first year of sampling (and* ***every five years from then on) the following variables were sampled: alkalinity, calcium, magnesium, potassium, sodium, sulphate, chloride****. In addition,* ***microbiological sampling (enterococci bacteria) is undertaken quarterly at 69 selected sites).***
1996	*One-hundred sites, selected to represent both reference ("pristine") and impacted sites in all eco-districts, are visited monthly and the water is measured for up to 25 physical-chemical variables. Microbiological water quality (enterococci) is examined quarterly at 69 sites.* *One hundred sites currently make up the monitoring programme.* ***Ninety-five sites are routinely sampled by Environment Waikato. Five sites within the Waikato region are routinely sampled by NIWA*** *as part of the 'National Water Quality Network for New Zealand'. Environment Waikato originally sampled 70 sites from January 1993. A further twenty-five sites were added to the programme in January 1994.*
1998	**Escherichia coli (E. Coli) records began, only sampled quarterly (March, June, September, December).** *The report provides information on the routine monthly monitoring of water quality at 100 locations across the Waikato Region. Ninety-five locations are sampled regularly by Environment Waikato. The remaining 5 locations form part of N.I.W.A.'s National Water Quality Network.* ***Water quality of the Region's rivers are assessed by measuring up to 32 parameters (16 routinely).*** *Seventy locations are measured quarterly for enterococci bacteria. Major ions - every five years only, i.e.:1993/94, 1999, etc. Mg, Ca, Si,SO_4, K, Na, HCO_3, Fe, Mn, Hardness, Alkalinity.*
2003	***One hundred locations*** *were sampled regularly by Environment Waikato****. A further 5 locations form part of N.I.W.A.'s*** *National Water Quality Network*
2009	**Monitoring of metals and metalloids at a subset of ReRiMP sites (n=11).**
2013	**Sampling of *E. Coli* updated from quarterly to monthly.**
2018 to 2020	***One hundred and ten sites were sampled monthly by Waikato Regional Council****. A further five locations form part of NIWA's National Rivers Water Quality Network* In 2018-2019, pesticide screening was completed at four of the 11 sites of metal and metalloid monitoring.
2023	Addition of four sites from the NIWA National River Water Quality Network (NRWQN) that are being absorbed by WRC and are currently being evaluated.

Table 7 Regional River Monitoring Programme (ReRiMP) Total Phosphorus (TP) method timeline.

Date	WRC Method Code	Method Standard	Detection Limit (g/m^3)
1994-1997	144	APHA 4500-P E (modified)	0.003
1997-2002	148	NAWASCO Method 8	0.004
2002 – 2004	144	APHA 4500-P E (modified)	0.003
2004 -2012	149	APHA 4500-P E	0.004
2012 -2022	1256	APHA 4500-P B&E	0.004
2022 - present	1332	APHA 4500-P H 23rd ed. 2	0.002

Table 8 Regional River Monitoring Programme (ReRiMP) Dissolved Reactive Phosphorus (DRP) method timeline.

Date	WRC Method Code	Method Standard	Detection Limit (g/m^3)
1994 – 2002	139	APHA 4500-P	0.004
2002 – 2005	140	APHA 4500-P G	0.004
2005 – 2017	142	APHA 4500-P E	0.004
2017 - present	140	APHA 4500-P G	0.004

Table 9 Regional River Monitoring Programme (ReRiMP) Total Ammoniacal-Nitrogen (TAN) method timeline.

Date	WRC Method Code	Method Standard	Detection Limit (g/m^3)
1994 – 2005	121	APHA 4500-NH3-G	0.01
2005 – 2017	122	APHA 4500-NH3-F	0.01
2017 – present	1275	APHA 4500-NH3-H	0.01

Appendix C

Table 10 Analytical methods and detection limits.

Parameter	**Methodology**	**Detection limits**
Faecal Coliforms	Membrane Filtration, Count on CCA agar, Incubated at 44.5°C for 21-24 hours. APHA 9222 D (modified): Online Edition.	1 cfu/100mL
E.Coli	Membrane Filtration, Count on CCA agar, Incubated at 44.5°C for 21-24 hours. APHA 9222 I (modified): Online Edition.	1 cfu/100mL
Enterococci	Membrane filtration, Count on mEI agar, Incubated at 42°C for 24 hours. APHA 9230 C (modified) Online Edition.	1 cfu/100mL
Absorbance (340nm, 440nm, 780nm)	Filtered sample. Spectrophotometry, 1cm cell. APHA 5910 B	0.002 AU cm^{-1}
Turbidity - NTU	Analysis by Turbidity meter. APHA 2130 B (modified): Online Edition.	0.05 NTU
pH	pH meter. APHA 4500-H+ B (modified): Online Edition.	0.1 pH Units
Specific Conductivity	Conductivity meter, 25°C. APHA 2510 B: Online Edition.	0.1 µS/cm
Ammoniacal-N	Phenol/hypochlorite colourimetry. Flow injection analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500-NH3 H (modified): Online Edition.	0.01 g/m^3
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO3- I (modified): Online Edition.	0.002 g/m^3
Total Kjeldahl Nitrogen	Total Kjeldahl digestion, phenol/hypochlorite colorimetry (Discrete Analysis). Trace level. APHA 4500-Norg D (modified) 4500 NH3 F (modified): Online Edition.	0.05 g/m^3
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified): Online Edition.	0.004 g/m^3
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry, screen level. Flow Injection Analyser. APHA 4500-P H (modified): Online Edition.	0.002 g/m^3

Appendix D

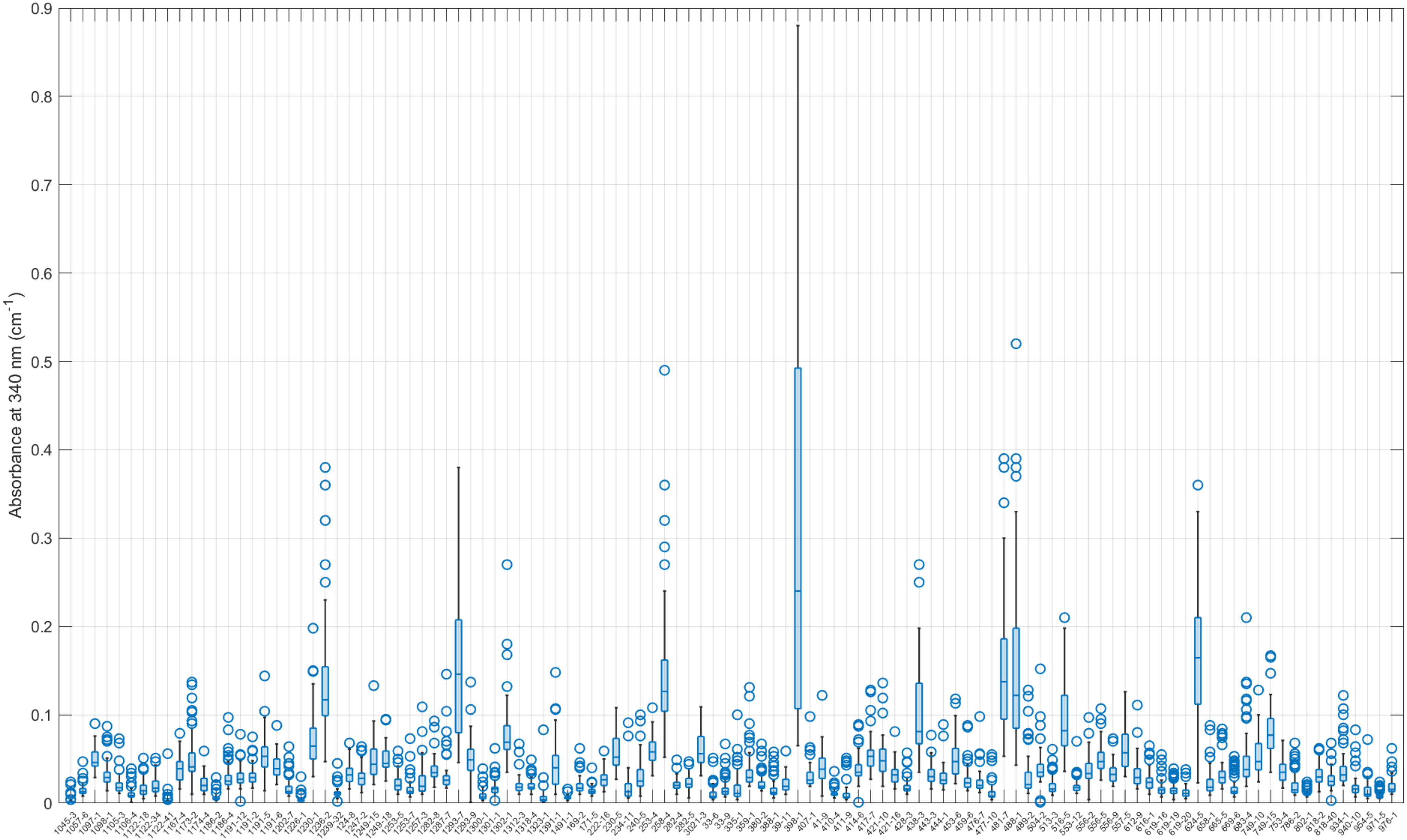

Figure 29 Boxplots of Absorbance at 340 nm (cm^{-1}) from ReRiMP sites (n=110) over the last five hydrological years.

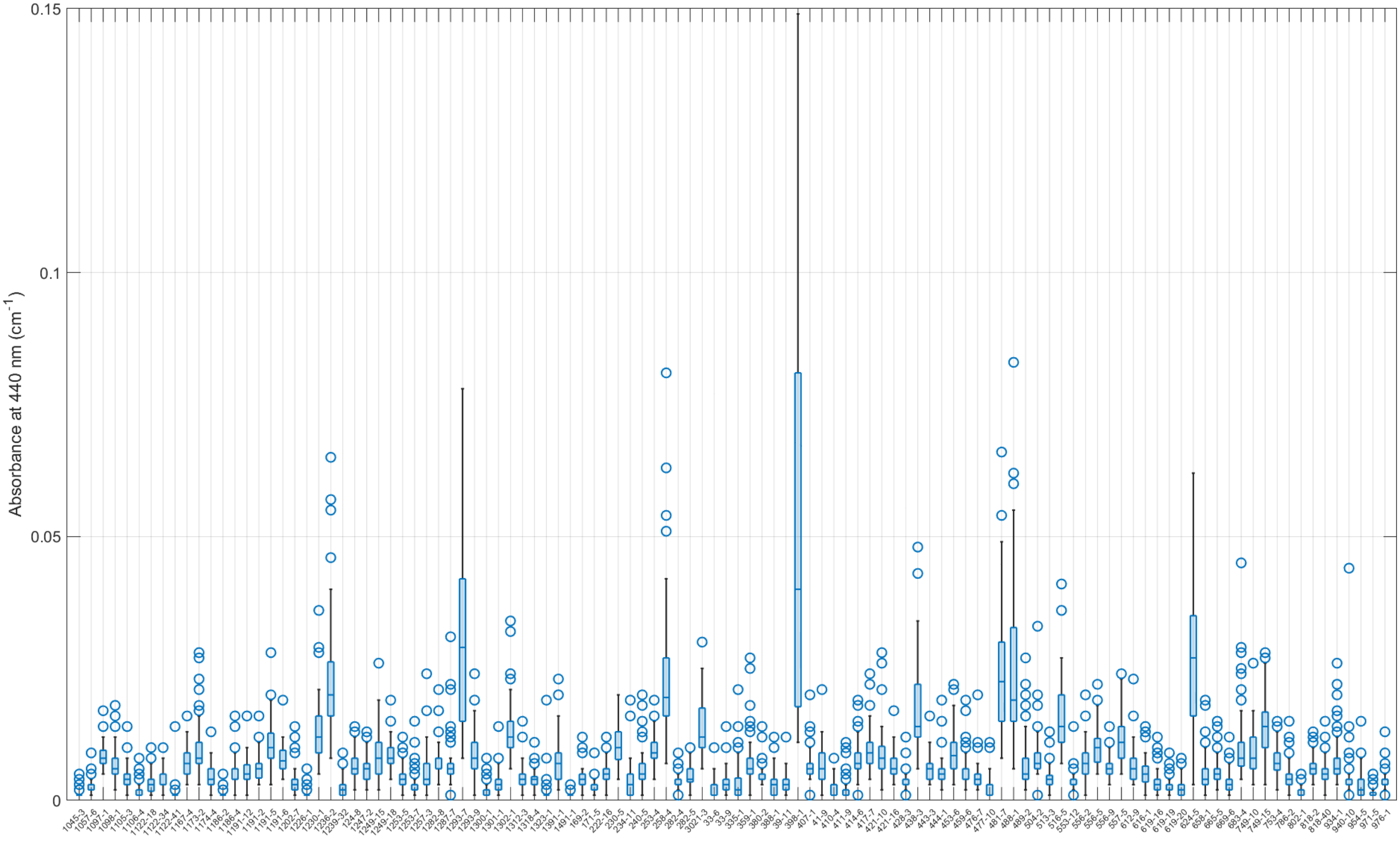

Figure 30 Boxplots of Absorbance at 440 nm (cm^{-1}) from ReRiMP sites (n=110) over the last five hydrological years.

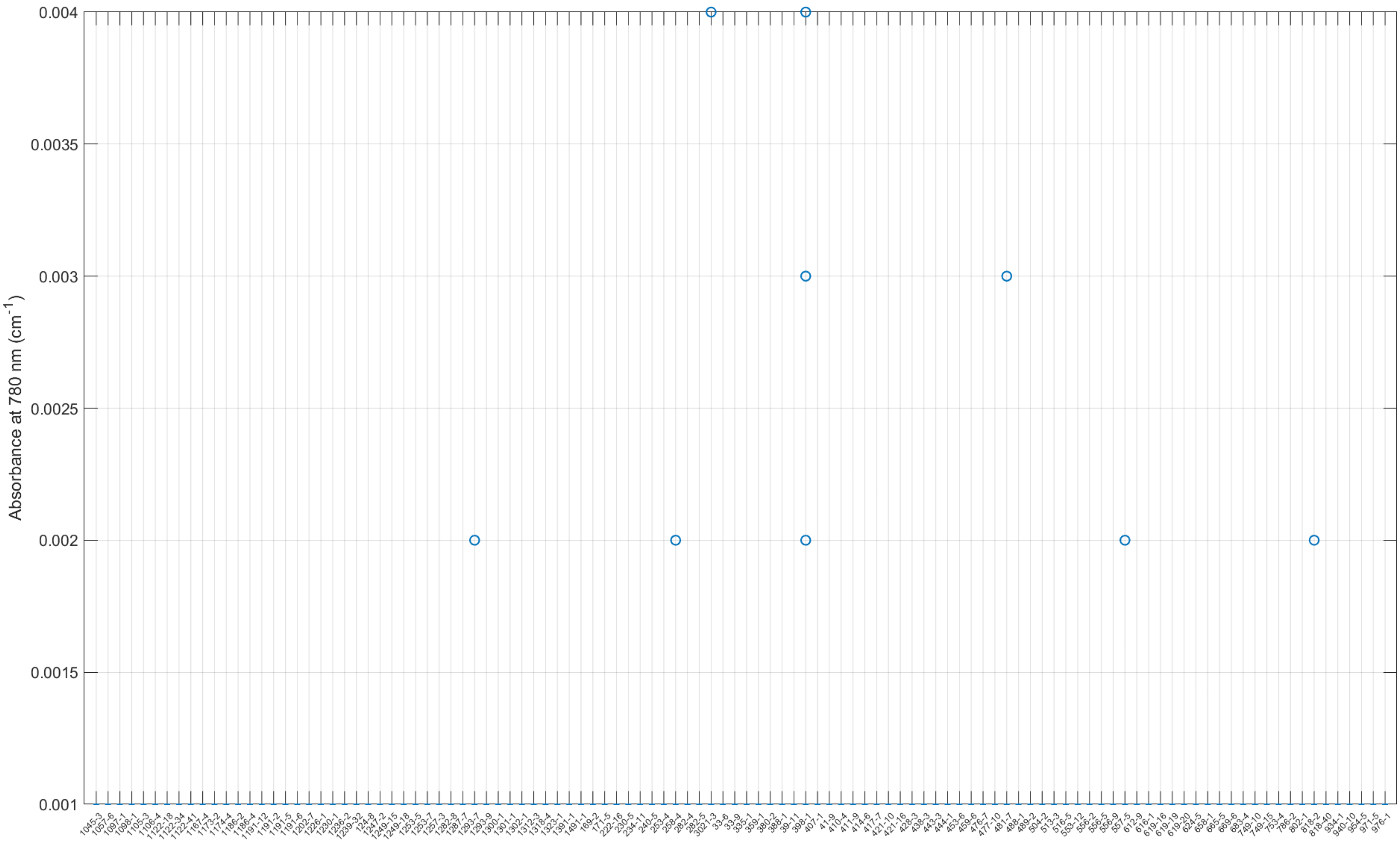

Figure 31 Boxplots Absorbance at 780 nm (cm^{-1}) from ReRiMP sites (n=110) over the last five hydrological years.

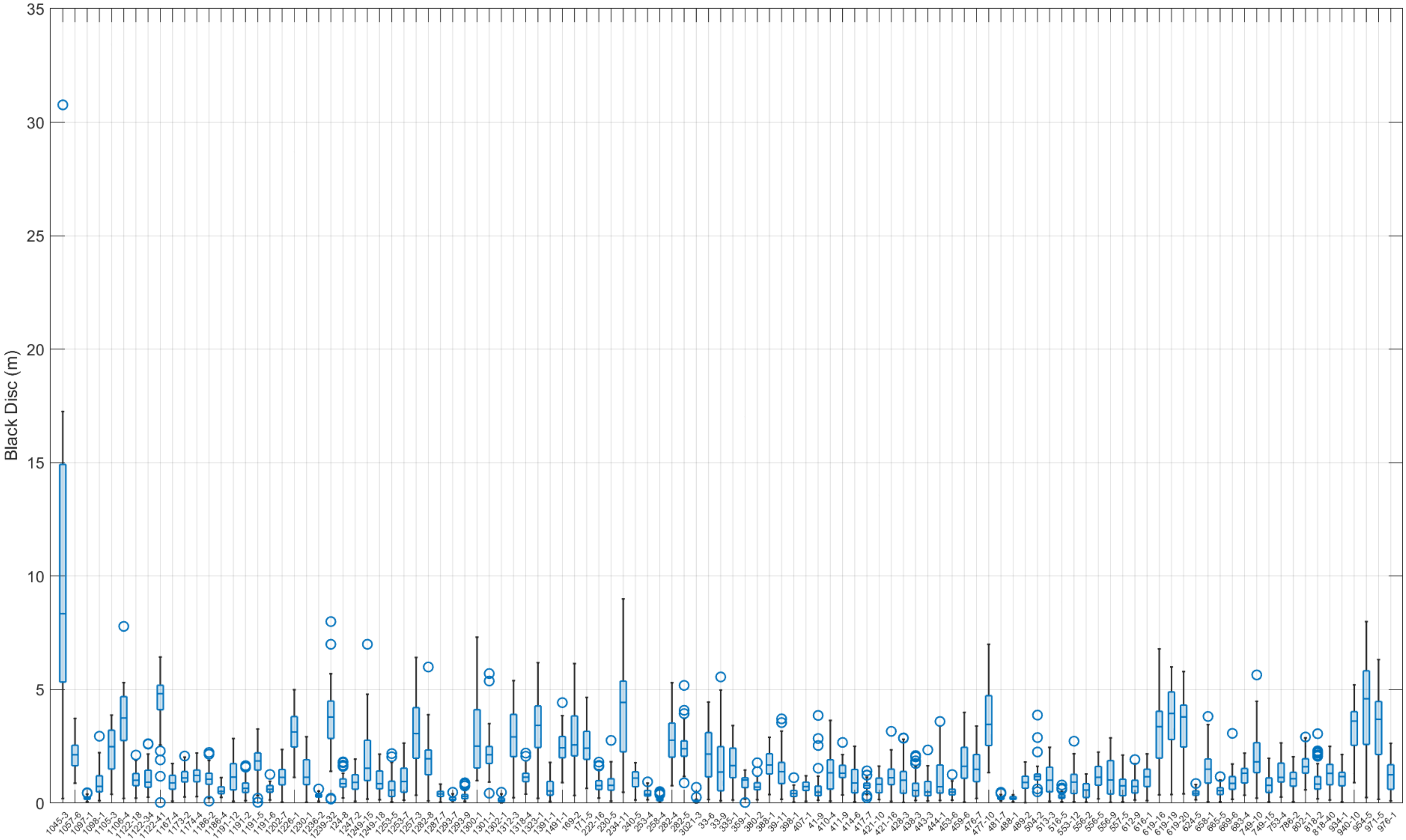

Figure 32 Boxplots of black disc (m) from ReRiMP sites (n=110) over the last five hydrological years.

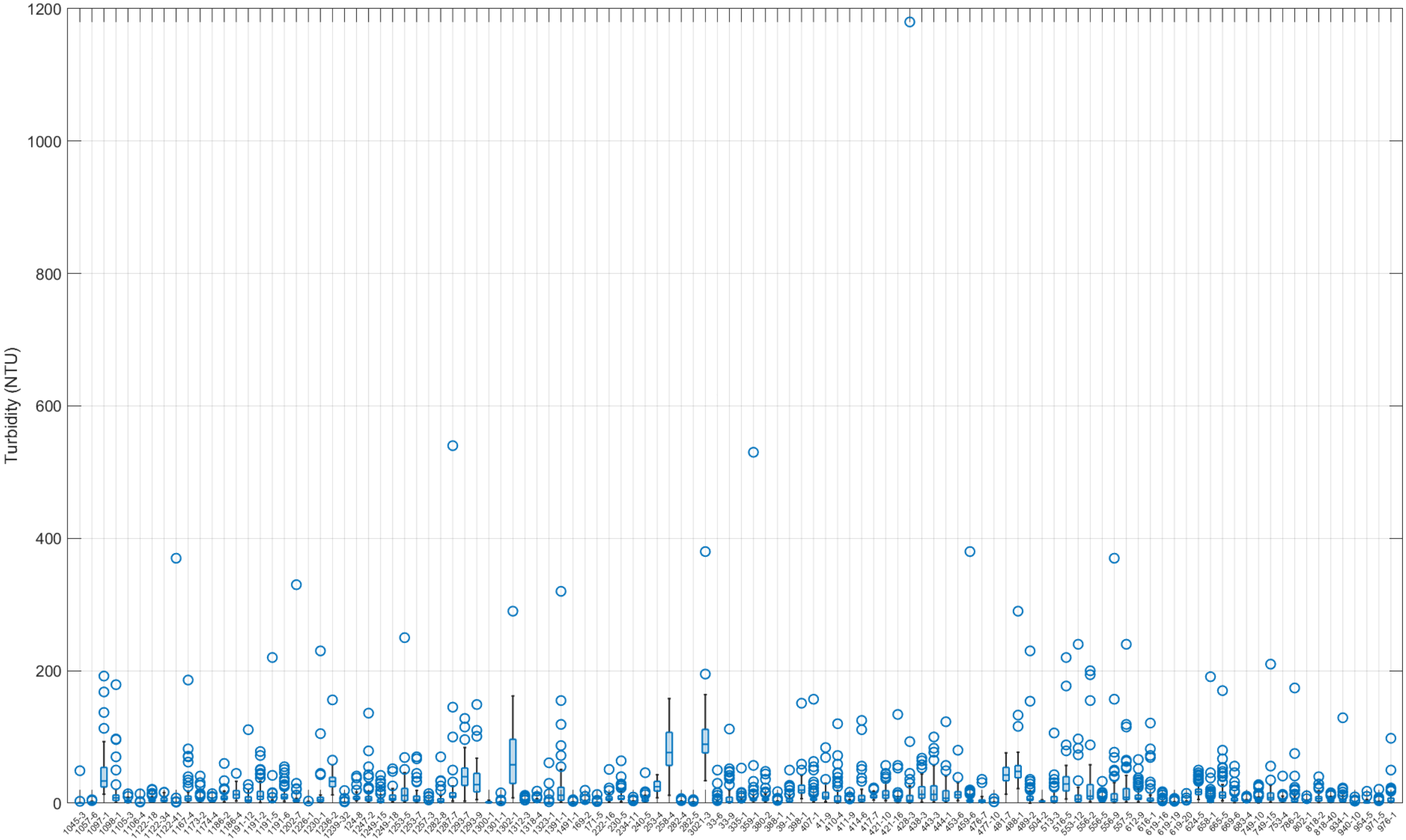

Figure 33 Boxplots of turbidity (NTU) from ReRiMP sites (n=110) over the last five hydrological years.

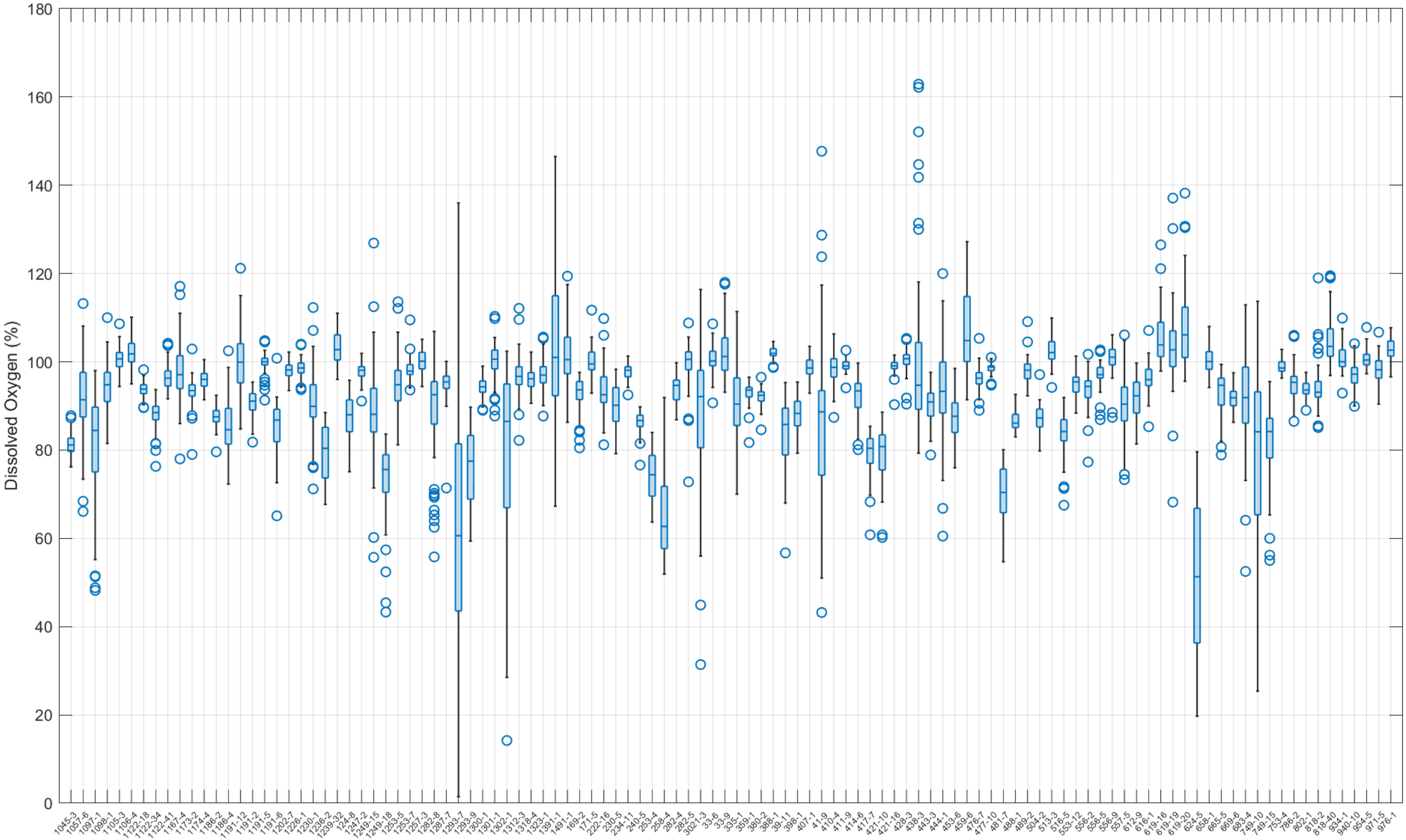

Figure 34 Boxplots of dissolved oxygen (%) from ReRiMP sites (n=110) over the last five hydrological years.

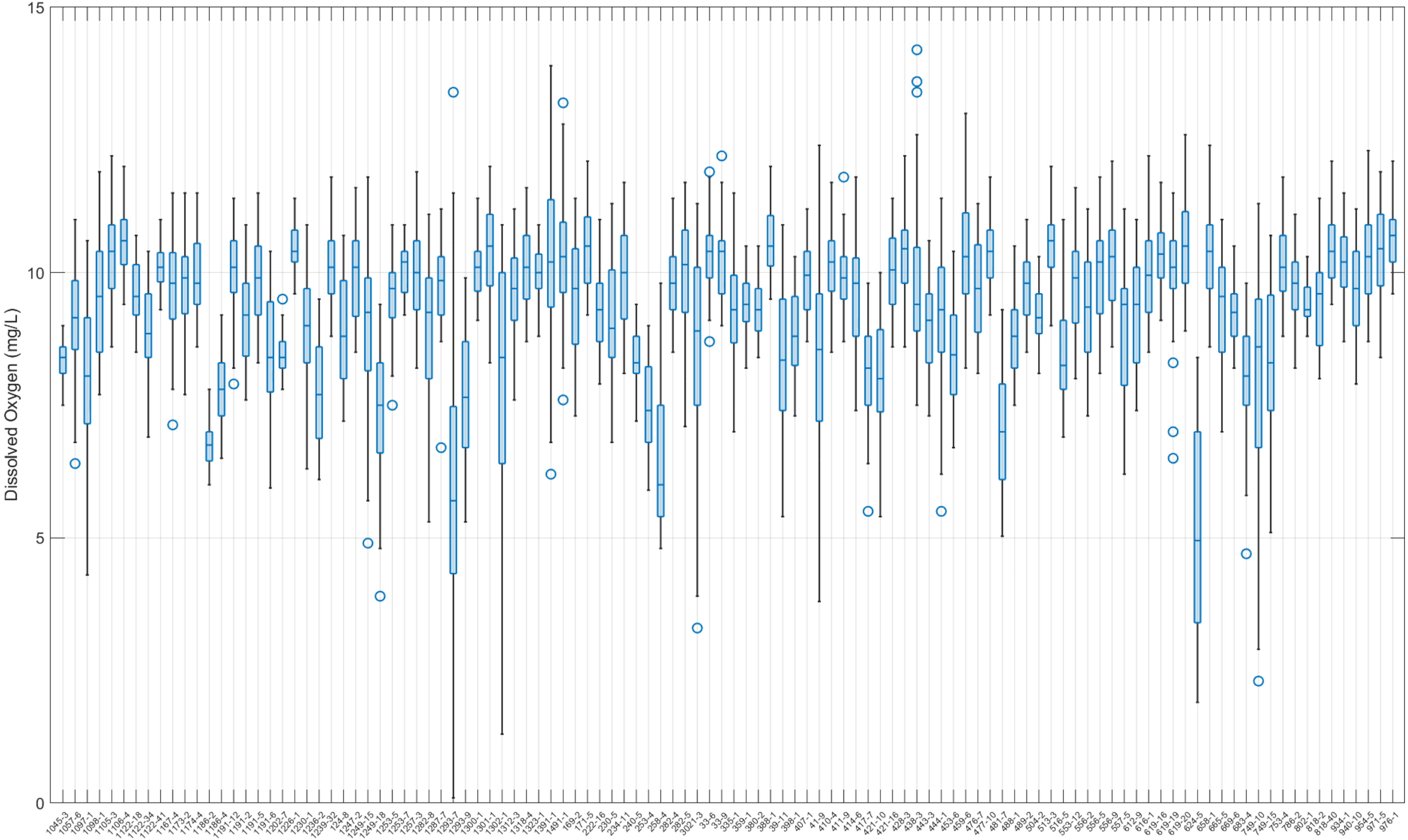

Figure 35 Boxplots of dissolved oxygen (mg/L) from ReRiMP sites (n=110) over the last five hydrological years.

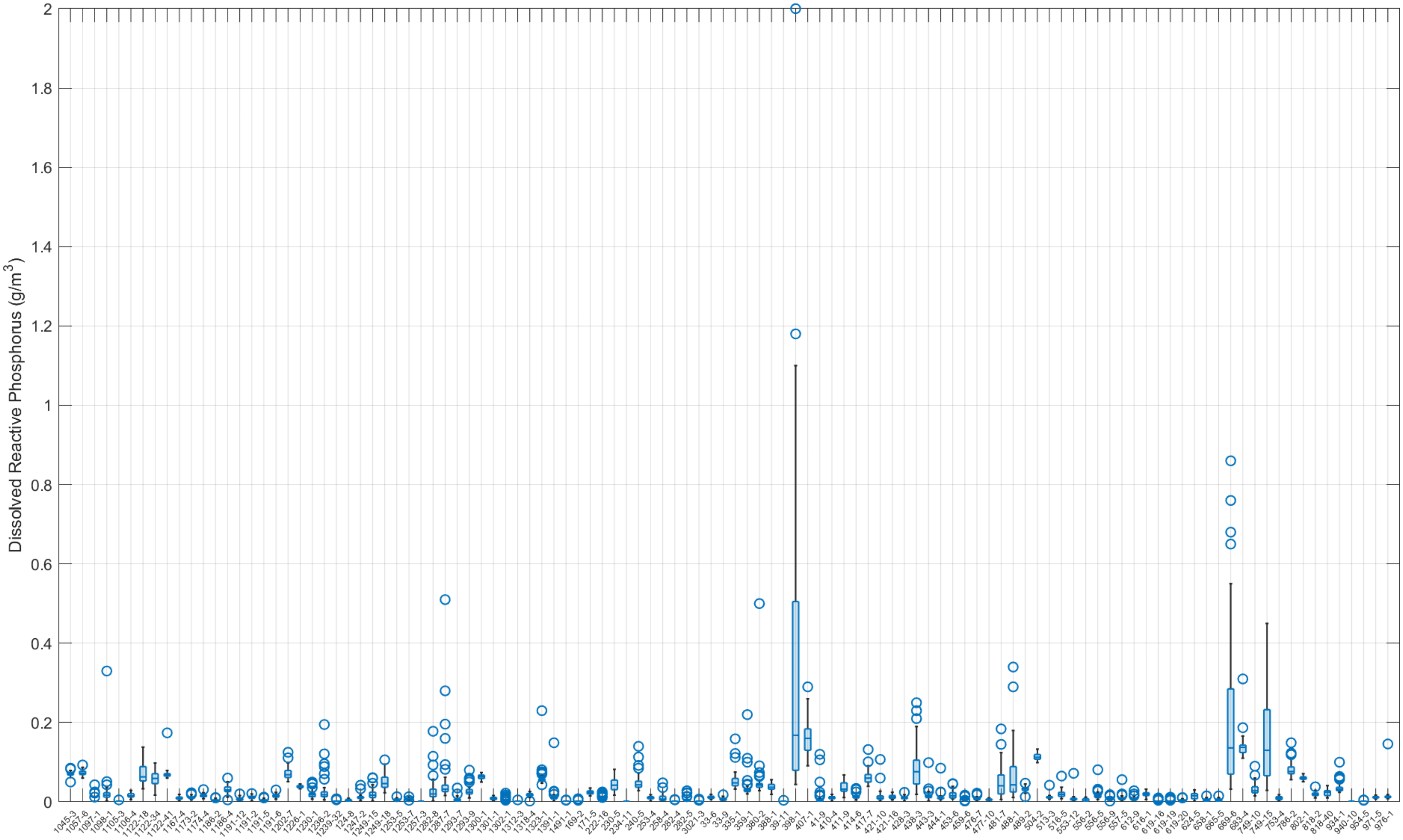

Figure 36 Boxplots of dissolved reactive phosphorus (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years.

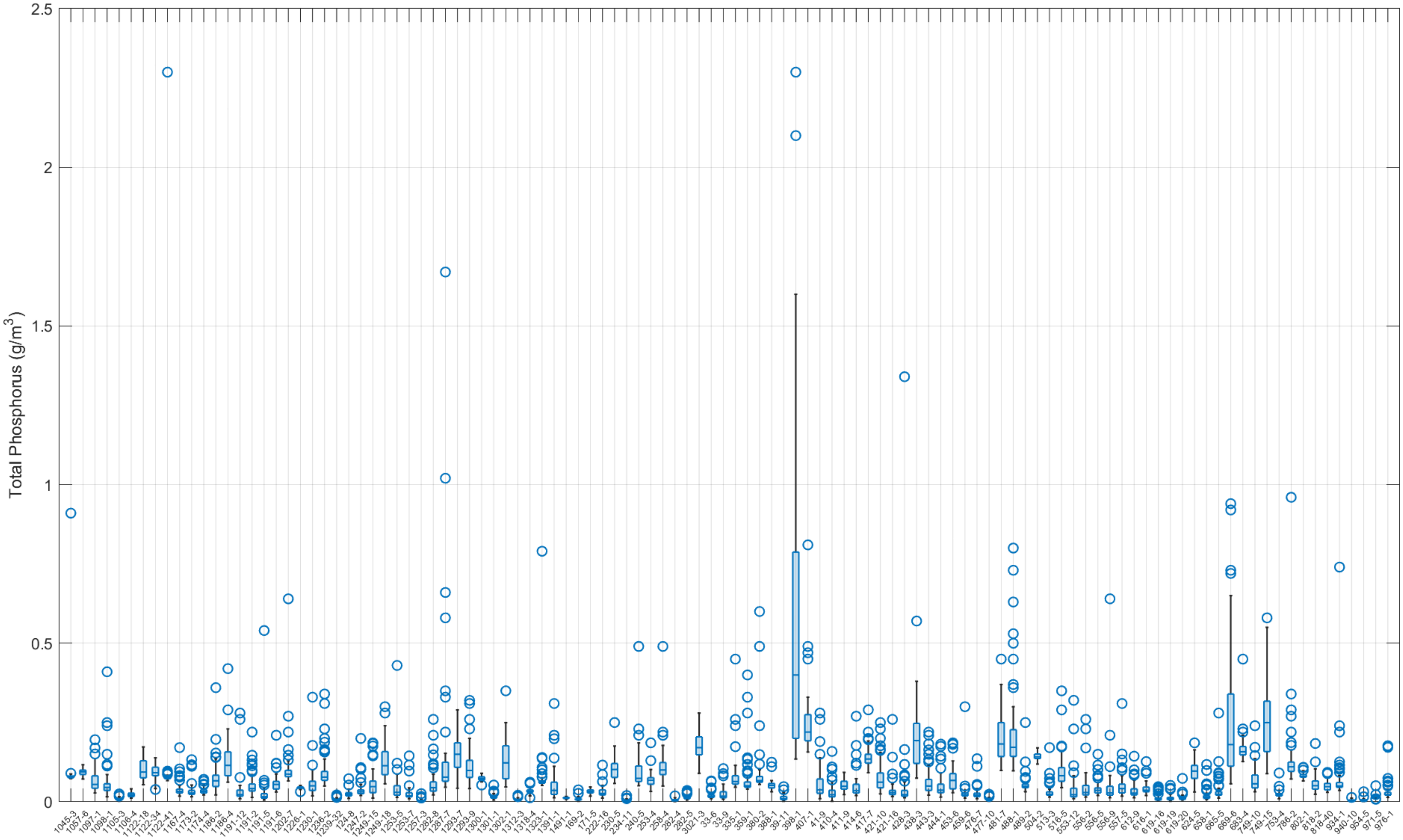

Figure 37 Boxplots of total phosphorus (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years.

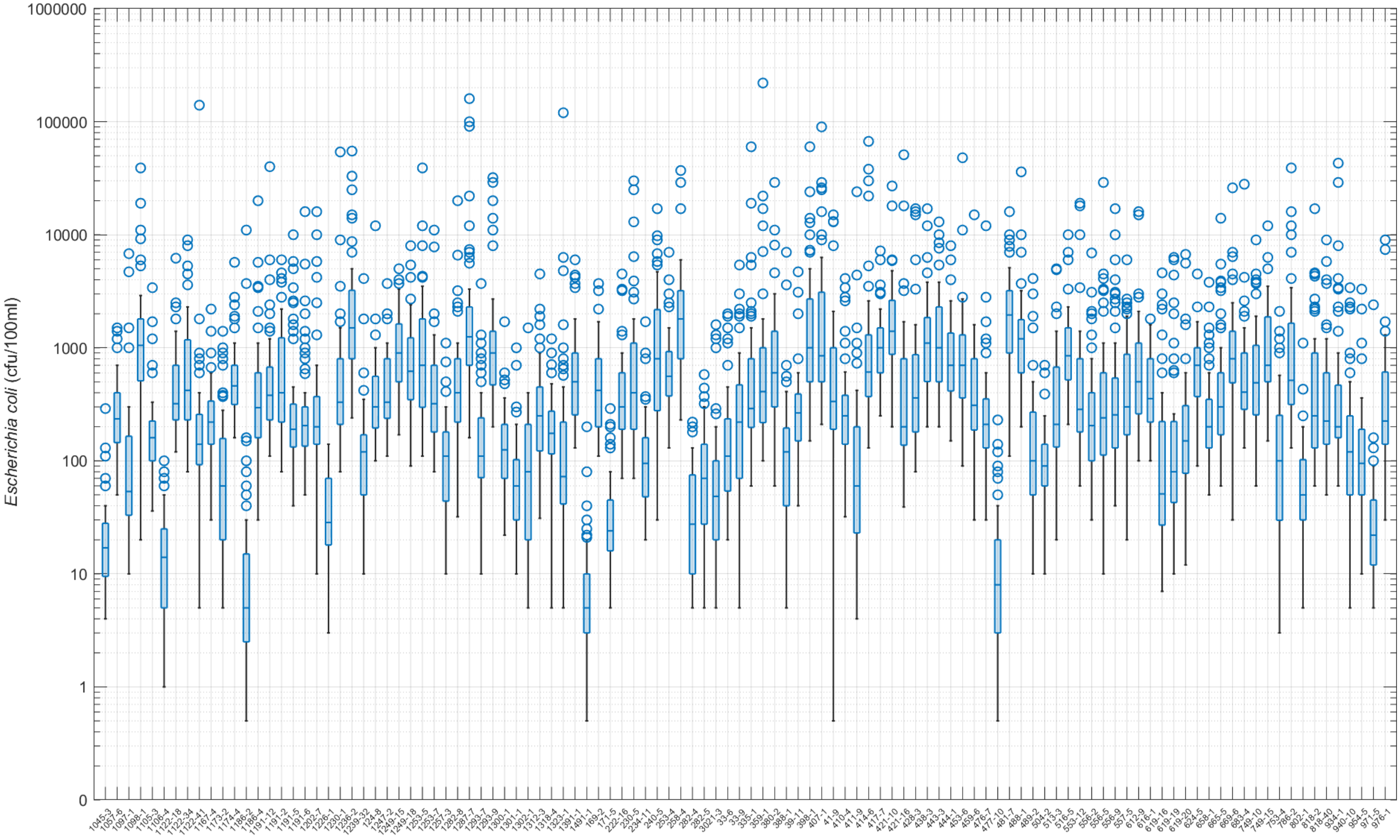

Figure 38 Boxplots of *Escherichia coli* (cfu/100mL) from ReRiMP sites (n=110) over the last five hydrological years.

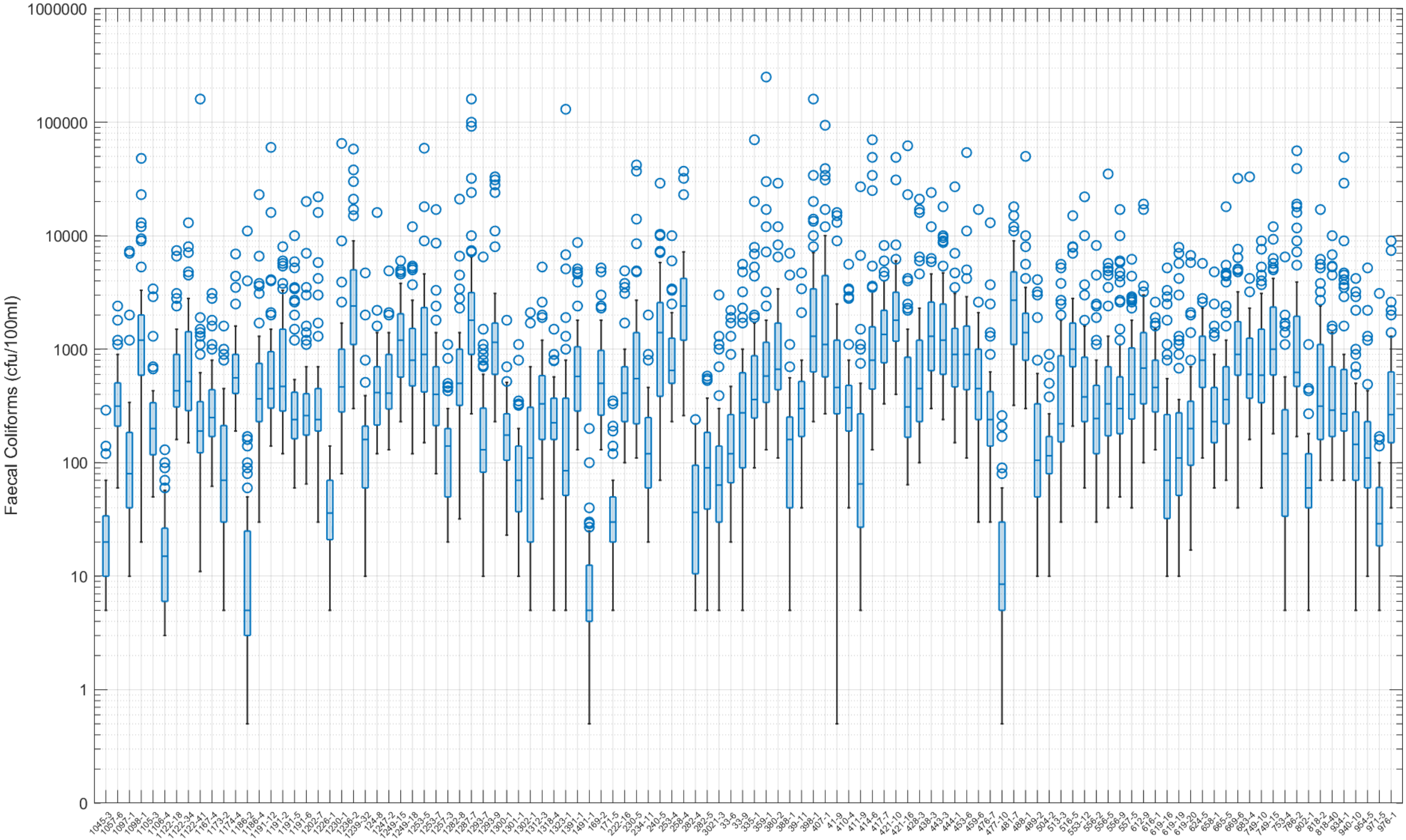

Figure 39 Boxplots of faecal coliforms (cfu/100mL) from ReRiMP sites (n=110) over the last five hydrological years.

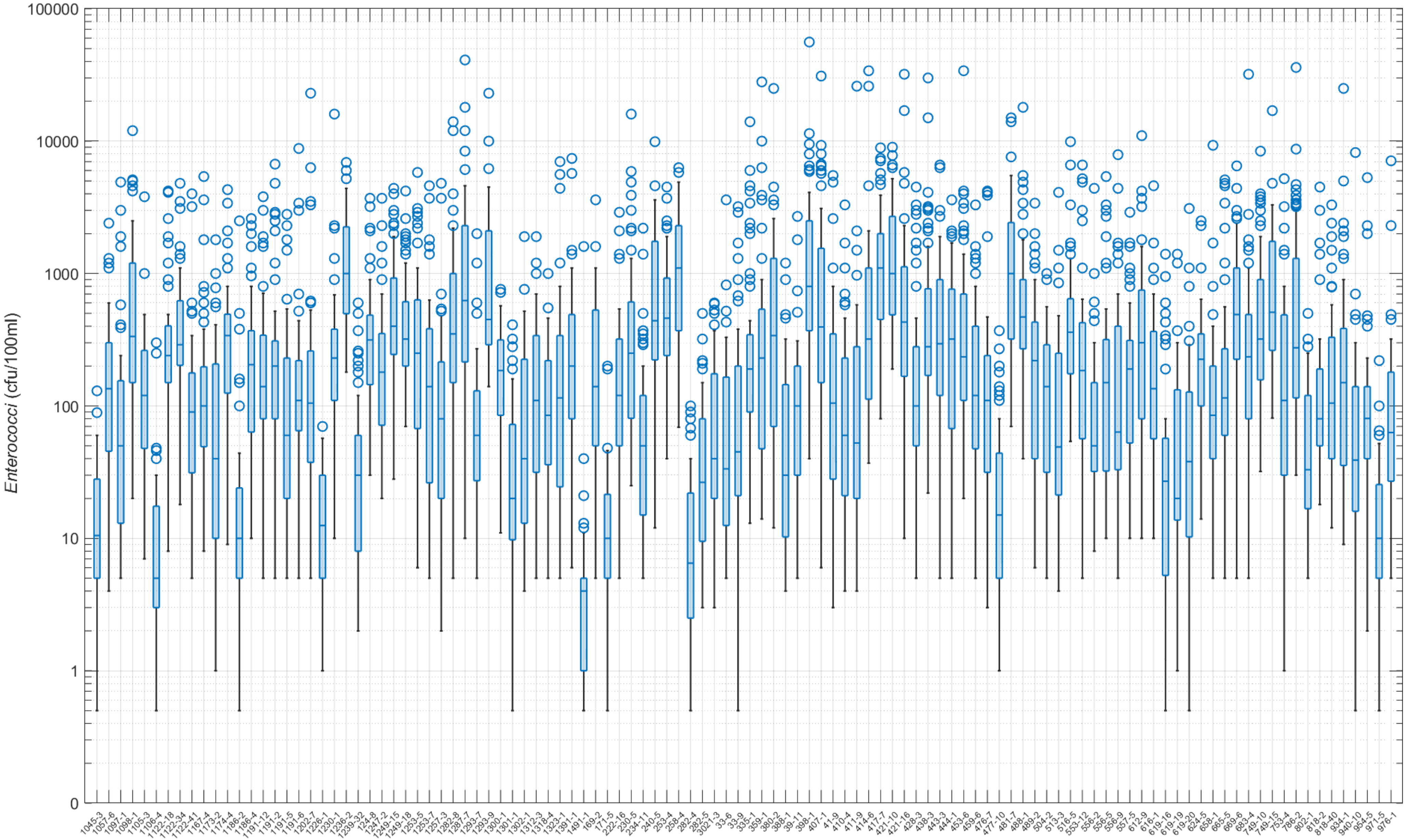

Figure 40 Boxplots of *Enterococci* (cfu/100mL) from ReRiMP sites (n=110) over the last five hydrological years.

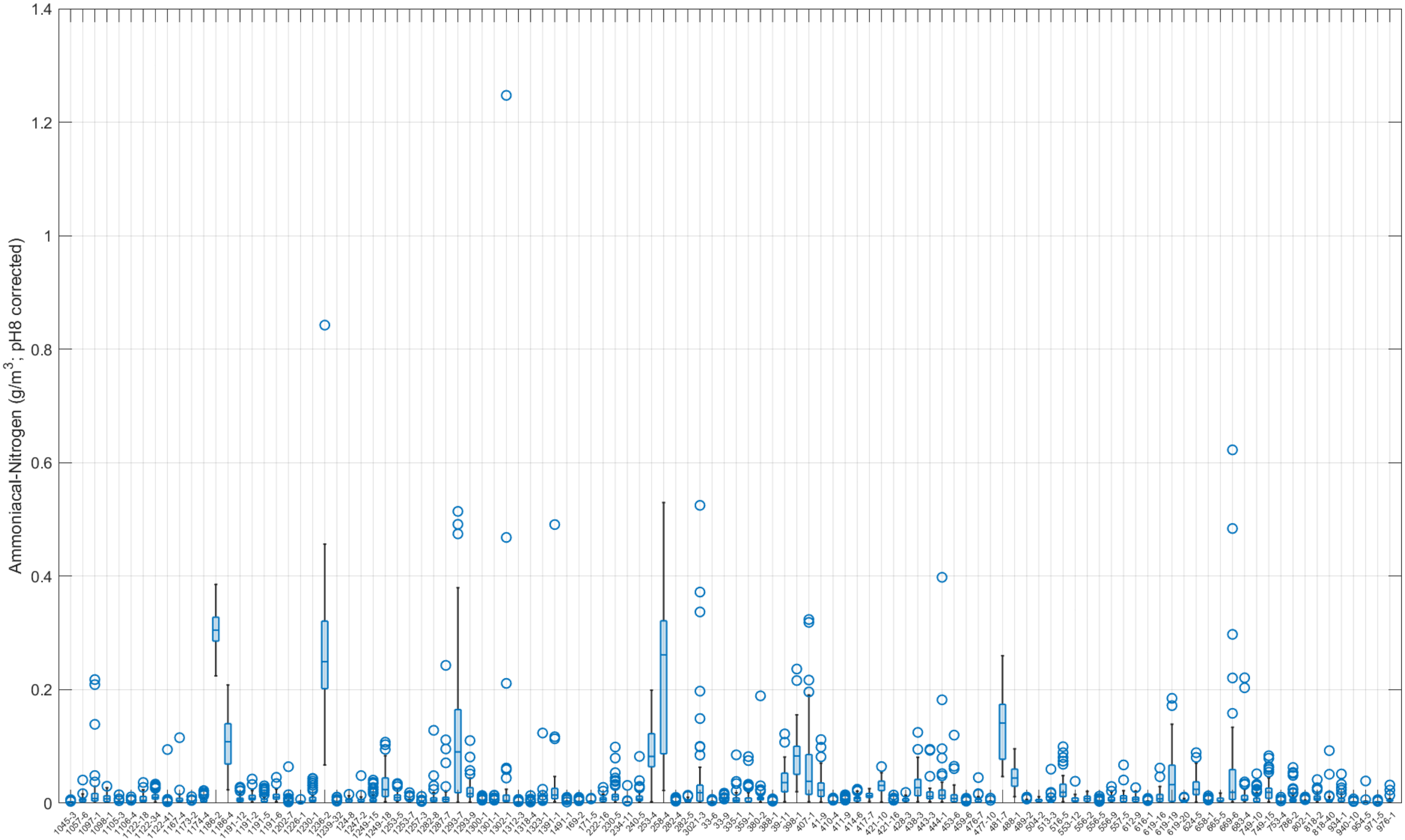

Figure 41 Boxplots of ammoniacal-nitrogen standardised to pH 8 (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years.

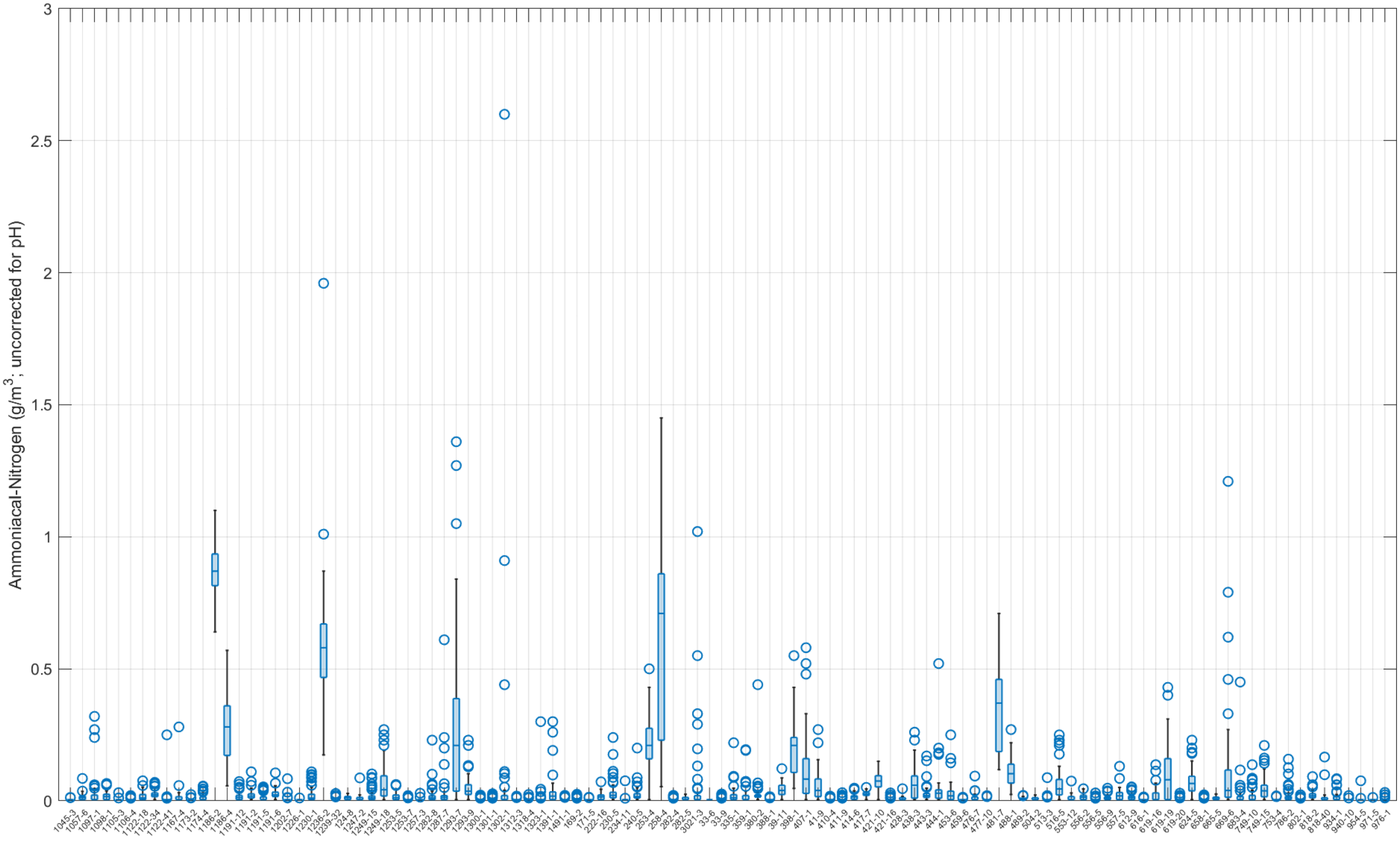

Figure 42 Boxplots of uncorrected ammoniacal-nitrogen (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years.

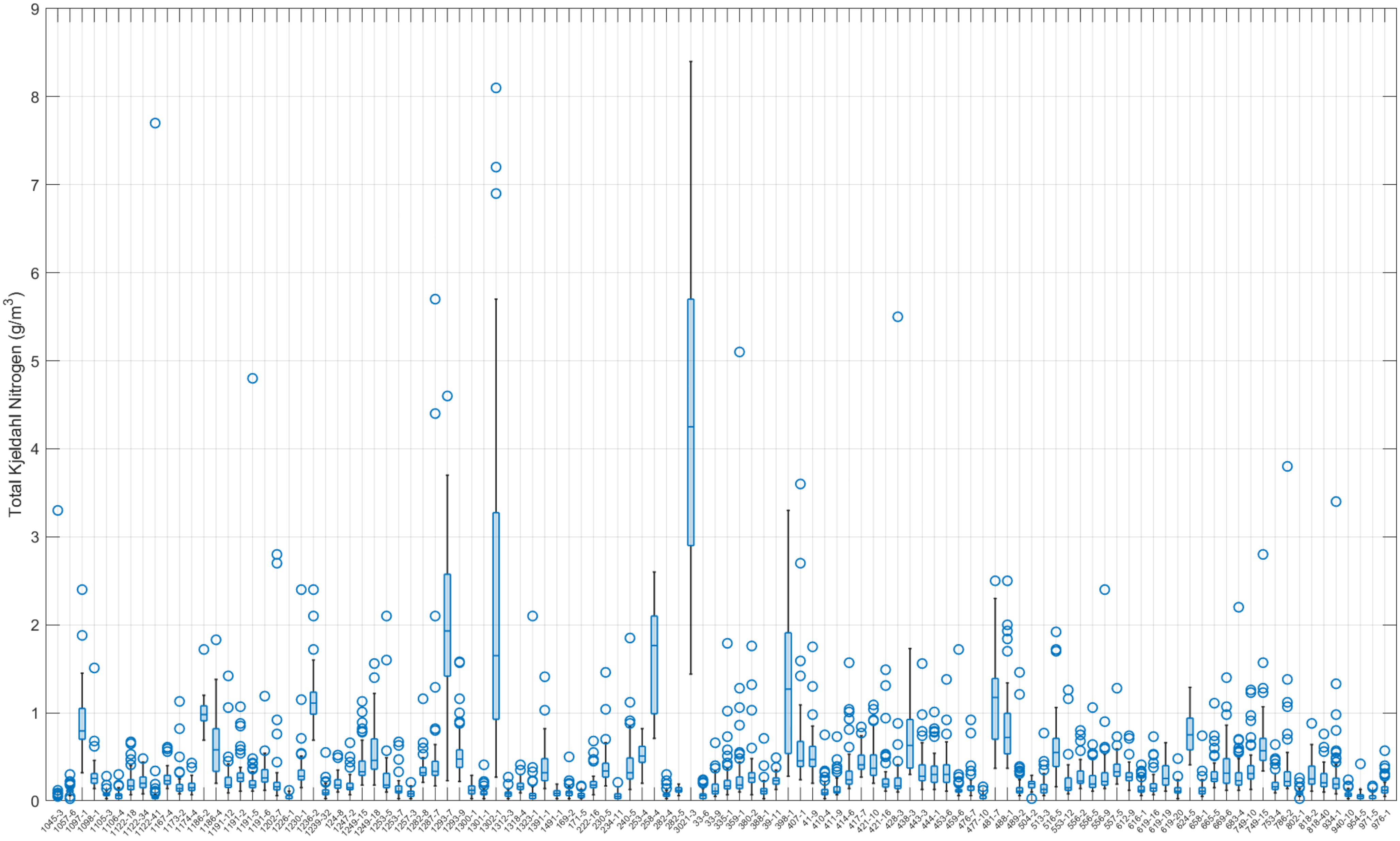

Figure 43 Boxplots total kjeldahl nitrogen (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years.

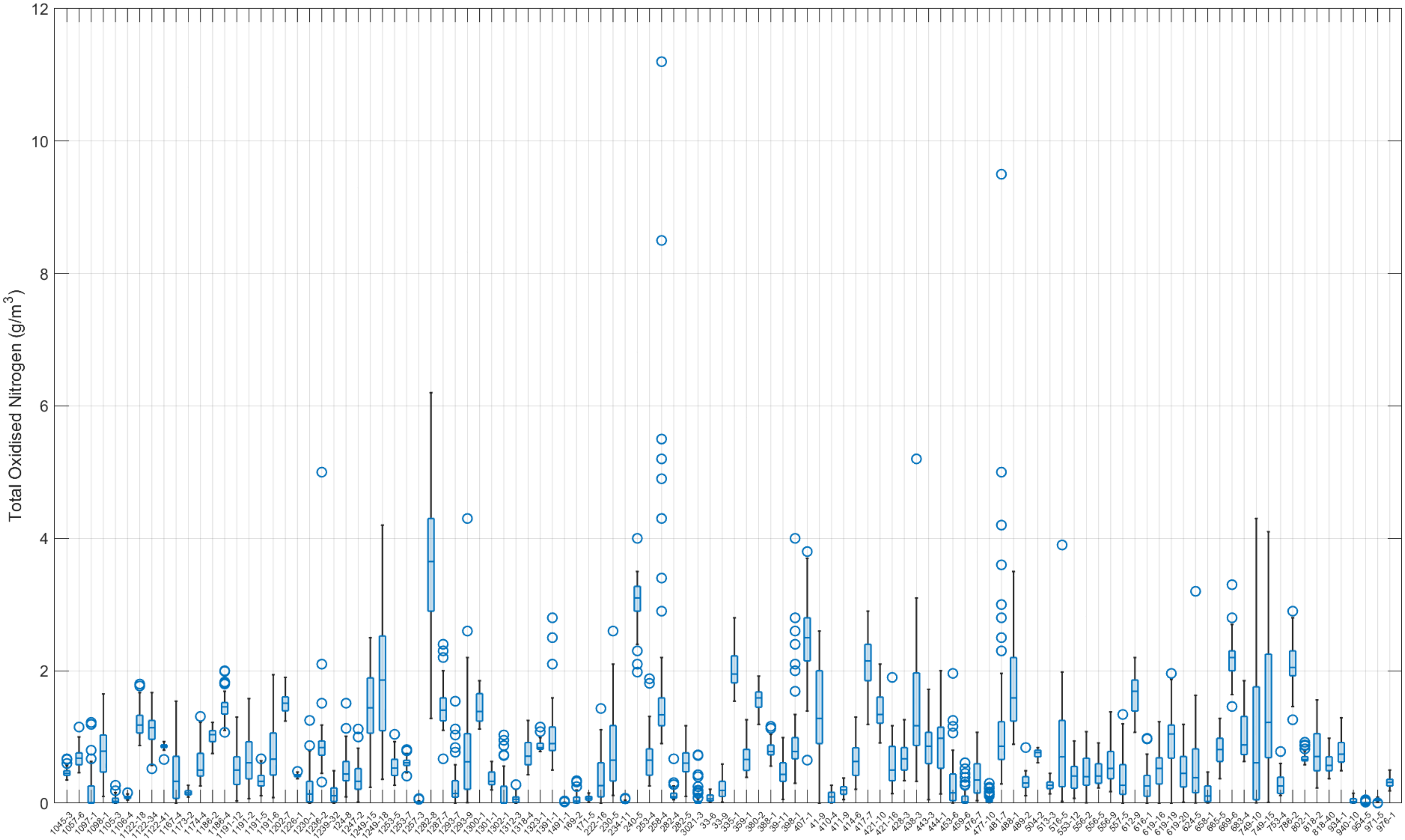

Figure 44 Boxplots total oxidised nitrogen (g/m^3) from ReRiMP sites (n=110) over the last five hydrological years.

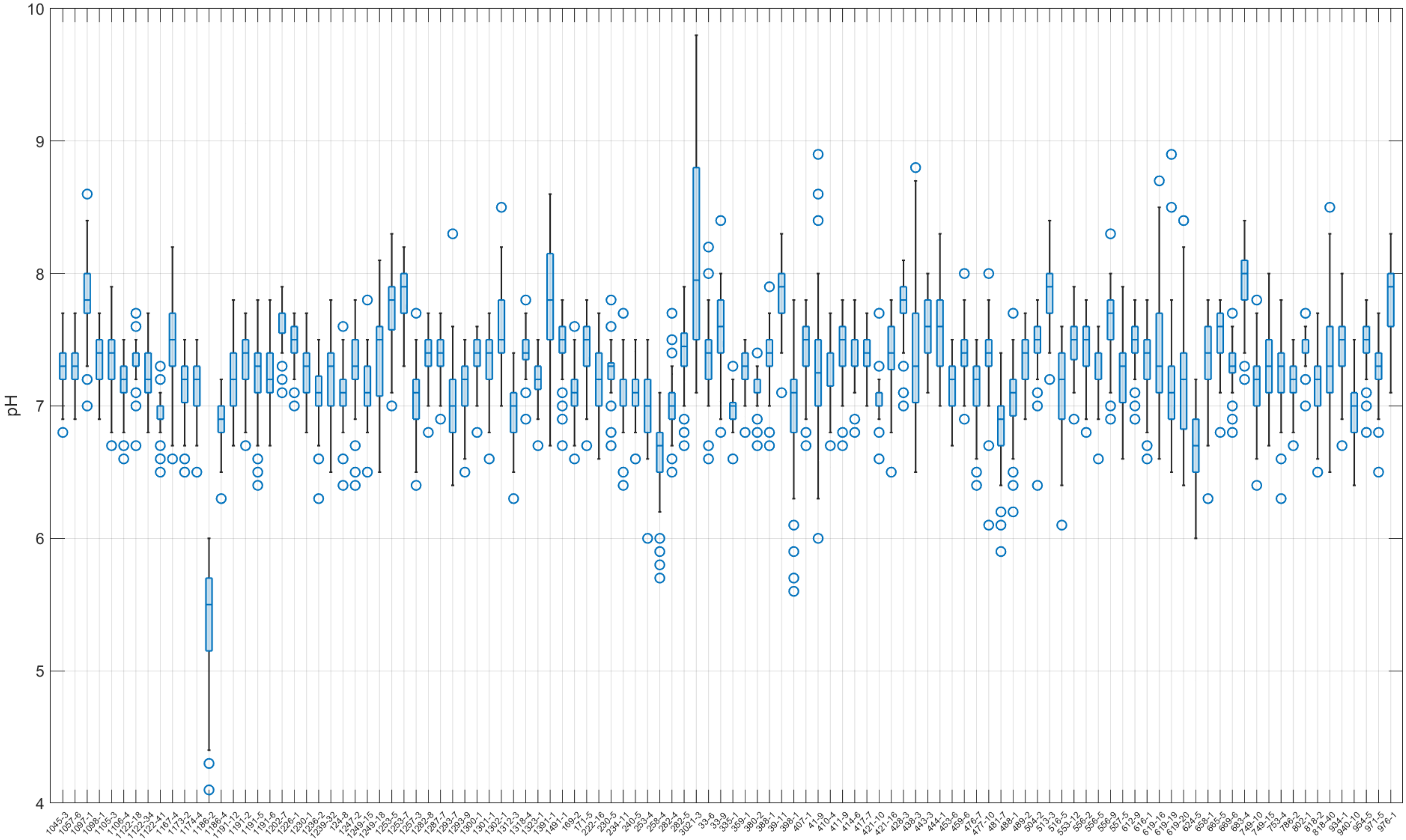

Figure 45 Boxplots of pH (-log$_{10}$[H$^+$]) from ReRiMP sites (n=110) over the last five hydrological years.

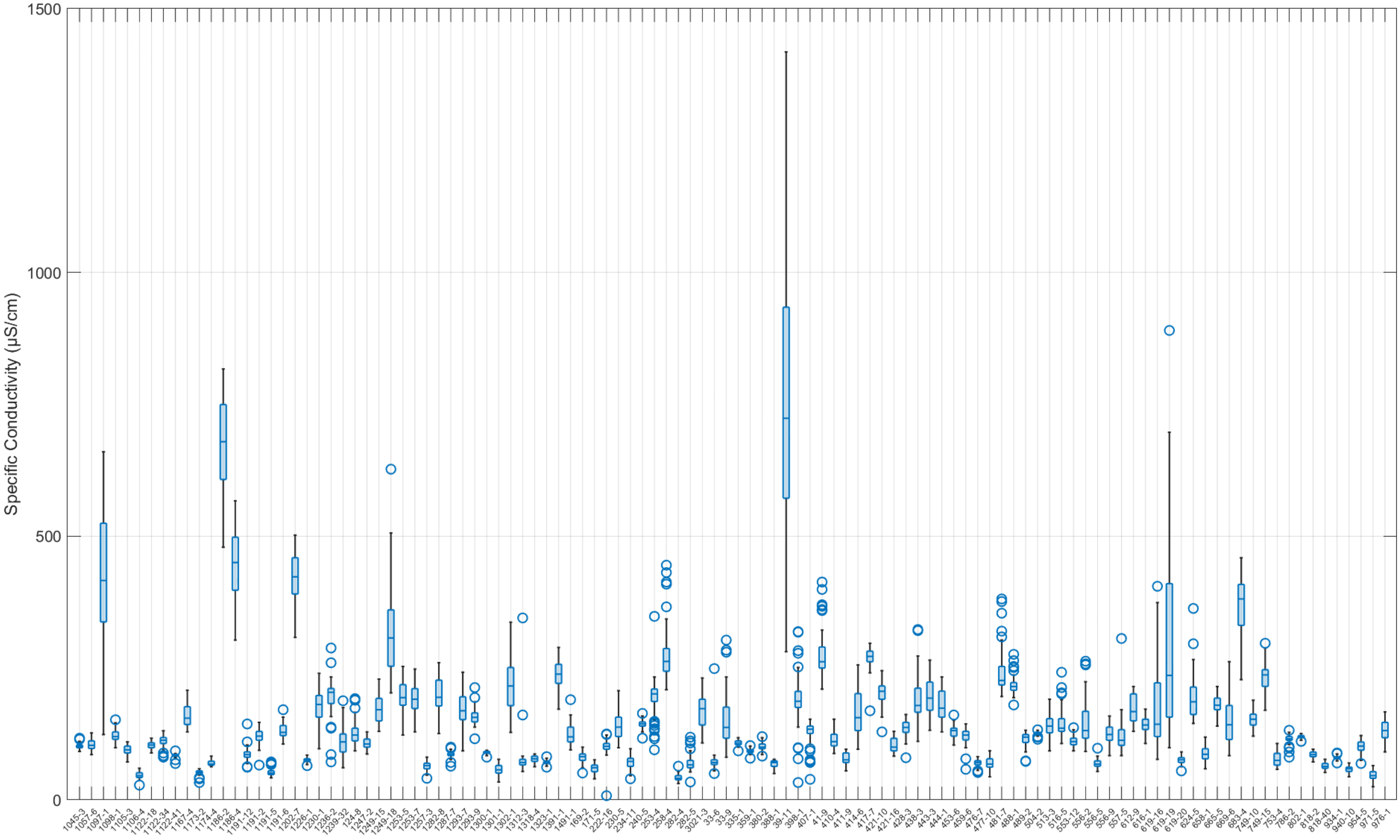

Figure 46 Boxplots of specific conductivity (µS/cm) from ReRiMP sites (n=110) over the last five hydrological years.

Appendix E

Table 11 Median time at site for ReRiMP sites (n=110) over the last five hydrological years.

Site	Median time at site (hh:mm:ss)
1045_3 - Tokaanu Stm	10:01:00
1057_6 - Torepatutahi Stm	12:48:00
1097_1 - Waahi Stm	09:44:30
1098_1 - Waerenga Stm	08:06:00
1105_3 - Waiau River	10:11:30
1106_4 - Waihaha River	13:08:30
1122_18 - Waihou River	09:53:00
1122_34 - Waihou River	09:14:00
1122_41 - Waihou River	08:53:00
1167_4 - Waingaro River (Pukemiro)	10:28:00
1173_2 - Waiohotu Stm	08:33:00
1174_4 - Waiomou Stm	10:10:00
1186_2 - Waiotapu Stm	12:09:30
1186_4 - Waiotapu Stm	12:40:00
1191_12 - Waipa River	13:34:00
1191_2 - Waipa River	08:16:00
1191_5 - Waipa River	13:11:00
1191_6 - Waipa River	08:09:30
1202_7 - Waipapa Stm (Mokai)	10:42:00
1226_1 - Waitahanui River	08:41:00
1230_1 - Waitakaruru River (Hauraki Plains)	13:28:00
1236_2 - Waitawhiriwhiri Stm	12:18:00
1239_32 - Waitekauri River	13:49:00
1247_2 - Waitetuna River	10:56:00
1249_15 - Waitoa River	10:43:00
1249_18 - Waitoa River	08:51:00
124_8 - Firewood Creek	07:49:00
1253_5 - Waitomo Stm	14:06:00
1253_7 - Waitomo Stm	12:07:00
1257_3 - Waiwawa River	11:02:00
1282_8 - Whakapipi Stm	10:51:30
1287_7 - Whakauru Stm	10:03:30
1293_7 - Whangamarino River	12:17:00
1293_9 - Whangamarino River	08:27:00
1300_1 - Whangamata Stm (Kinloch)	07:06:00
1301_1 - Whanganui Stm	12:32:00
1302_1 - Whangape Stm	09:22:00
1312_3 - Wharekawa River	12:17:00
1318_4 - Whareroa Stm (Taupo)	11:39:30
1323_1 - Whirinaki Stm	11:41:30
1391_1 - Mangarama Stm	12:43:00
1491_1 - Tokaanu Power Station Tailrace Canal	10:18:00
169_2 - Hikutaia River	08:04:30
171_5 - Hinemaiaia River	09:00:00
222_16 - Kaniwhaniwha Stm	11:27:30

Site	Median time at site (hh:mm:ss)
230_5 - Karapiro Stm	12:38:00
234_11 - Kauaeranga River	08:43:00
240_5 - Kawaunui Stm	12:17:00
253_4 - Kirikiriroa Stm	12:32:00
258_4 - Komakorau Stm	08:33:00
282_4 - Kuratau River	11:16:30
282_5 - Kuratau River	10:49:00
3021_3 - Northern Outlet Canal (a.k.a.Pungarehu Canal)	08:47:30
335_1 - Little Waipa Stm	09:26:00
33_6 - Awakino River	11:08:00
33_9 - Awakino River	10:36:00
359_1 - Mangaharakeke Stm (Atiamuri)	11:01:00
380_2 - Mangakara Stm (Reporoa)	12:32:30
388_1 - Mangakino Stm (Whakamaru)	12:35:00
398_1 - Mangakotukutuku Stm (Rukuhia)	13:26:00
39_11 - Awaroa Stm (Rotowaro)	09:56:00
407_1 - Mangamingi Stm (Tokoroa)	09:51:30
410_4 - Manganui River	10:00:00
411_9 - Mangaohoi Stm	13:01:30
414_6 - Mangaokewa Stm	08:26:00
417_7 - Mangaone Stm (Waikato)	07:22:30
41_9 - Awaroa River (Waiuku)	11:22:30
421_10 - Mangaonua Stm	07:41:00
421_16 - Mangaonua Stm	12:09:00
428_3 - Mangaotaki River	09:13:30
438_3 - Mangapiko Stm (Pirongia/Te Awamutu)	14:12:00
443_3 - Mangapu River	13:25:30
444_1 - Mangarapa Stm	13:11:00
453_6 - Mangatangi River	13:06:00
459_6 - Mangatawhiri River	12:45:00
476_7 - Mangatutu Stm (Waikeria)	13:29:00
477_10 - Mangauika Stm	08:45:30
481_7 - Mangawara Stm	08:44:00
488_1 - Mangawhero Stm (Cambridge)	13:00:00
489_2 - Mangawhero Stm (Kaihere)	13:52:30
504_2 - Mapara Stm (Lake Taupo)	07:30:00
513_3 - Marokopa River	11:05:00
516_5 - Matahuru Stm	09:00:30
553_12 - Moakurarua Stm	09:10:30
556_2 - Mokau River	10:22:00
556_5 - Mokau River	13:37:00
556_9 - Mokau River	11:34:30
557_5 - Mokauiti Stm	11:46:00
612_9 - Ohaeroa Stm	10:31:30
616_1 - Ohautira Stm	10:40:30
619_16 - Ohinemuri River	14:07:00
619_19 - Ohinemuri River	13:32:30
619_20 - Ohinemuri River	13:11:00
624_5 - Ohote Stm	11:53:00
658_1 - Oparau River	10:01:30

Site	Median time at site (hh:mm:ss)
665_5 - Opuatia Stm	10:03:00
669_6 - Oraka Stm	07:59:30
683_4 - Otamakokore Stm	11:47:30
749_10 - Piako River	11:38:00
749_15 - Piako River	08:25:00
753_4 - Piakonui Stm	11:10:00
786_2 - Pokaiwhenua Stm	09:12:30
802_1 - Pueto Stm	13:10:00
818_2 - Puniu River	13:53:00
818_40 - Puniu River	13:38:30
934_1 - Tahunaatara Stm	11:14:00
940_10 - Tairua River	11:51:00
954_5 - Tapu River	09:24:00
971_5 - Tauranga-Taupo River	09:19:00
976_1 - Tawarau River	11:17:00

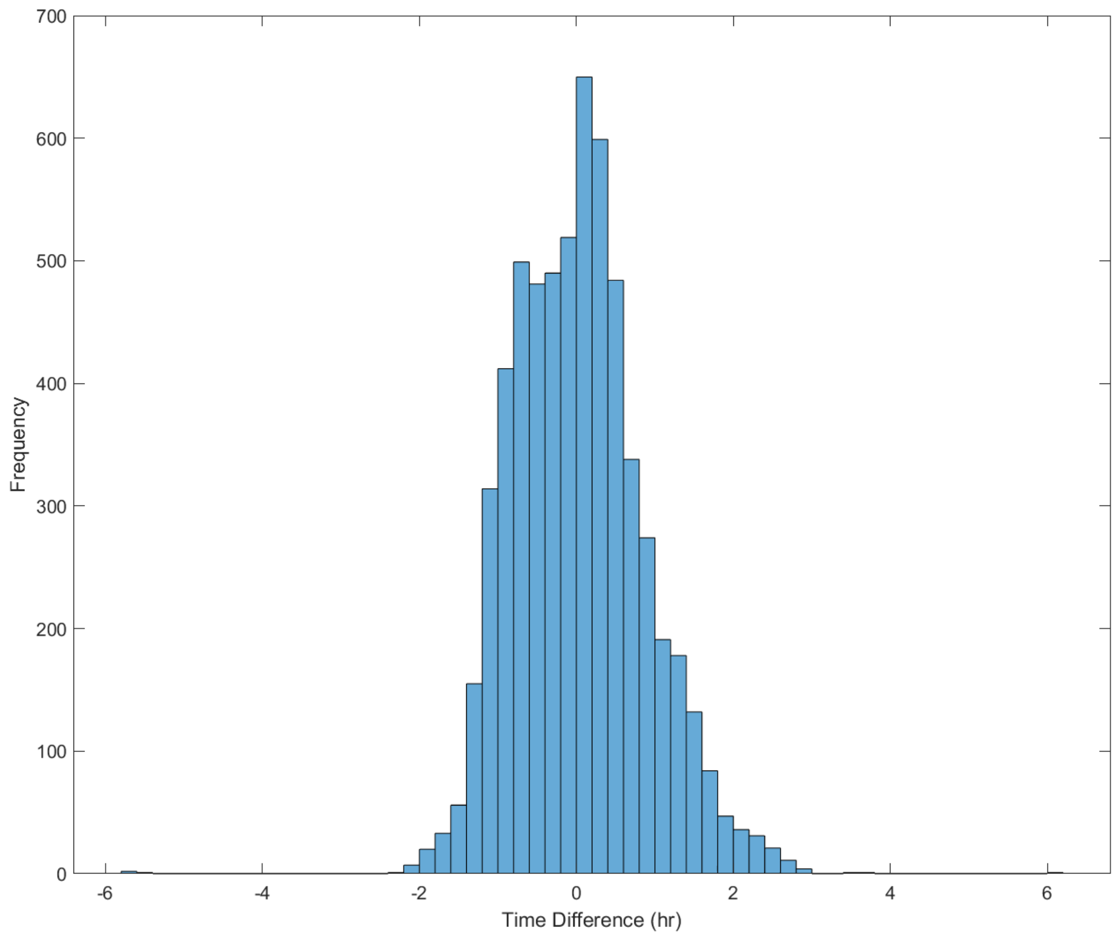

Figure 47 Time difference from median time at site for ReRiMP sites (n=110) over the last five hydrological years.

Appendix F

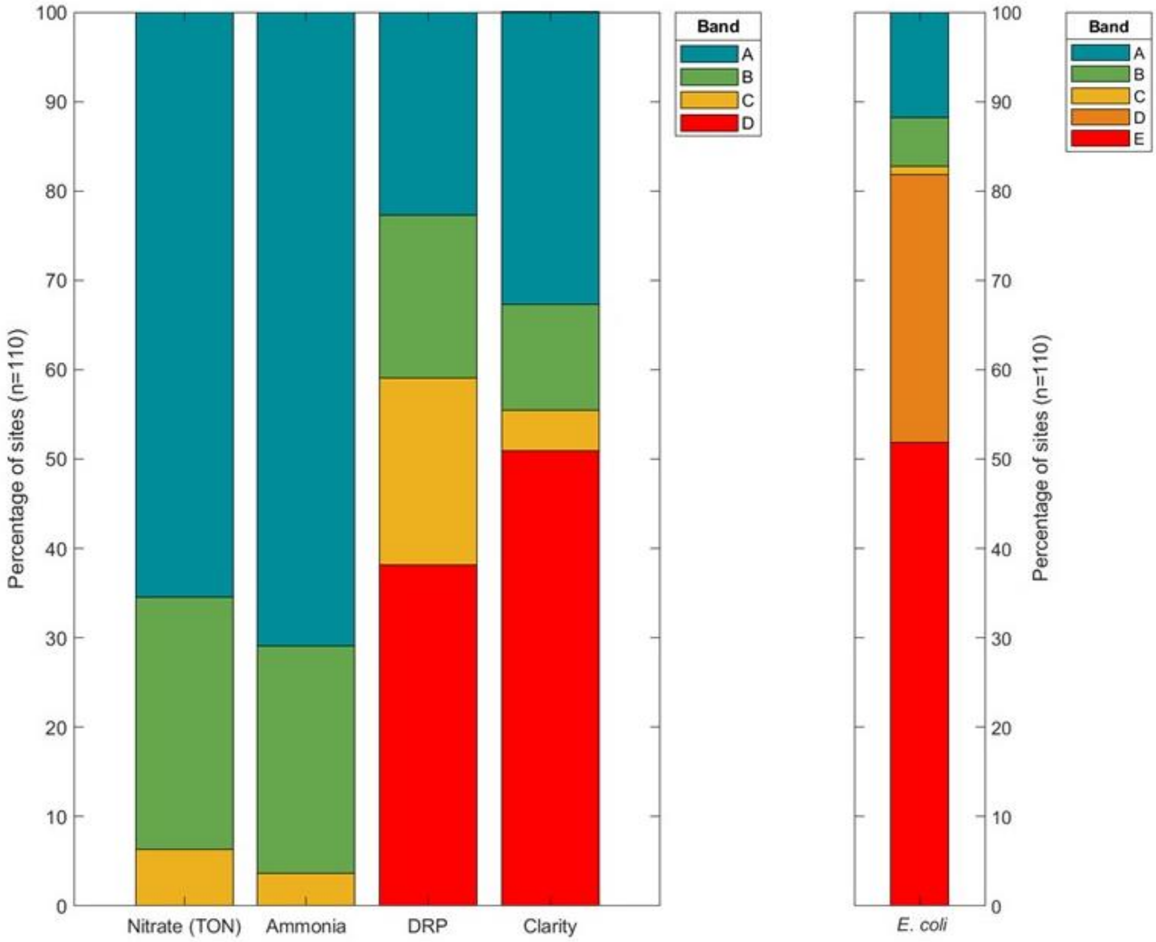

Figure 48 NPS-FM (2020) ecosystem water quality and human health values for ReRiMP sites (n=110) over the last five hydrological years.

Table 12 Percentage of ReRiMP sites (n=110) within applicable water quality NPS-FM (2020) attribute bands for baseline state (2017) and current reporting period. Values at or below national bottom lines are indicated in bold red font.

	Ammonia		Nitrate		DRP		Clarity		*E. coli*	
	2017	**2023**	**2017**	**2023**	**2017**	**2023**	**2017**	**2023**	**2017**	**2023**
A band	65.2	70.9	71.3	65.5	21.7	22.7	33.3	32.7	25.2	11.8
B band	30.4	25.5	22.6	28.2	12.2	18.2	24.3	11.8	6.1	5.5
C band	**4.3**	**3.6**	**6.1**	**6.4**	22.6	20.9	27.0	4.6	1.7	0.9
D band	**0**	**0**	**0**	**0**	43.5	38.2	**26.1**	**50.9**	3.5	30.0
E band									63.5	51.8