State of Stream Temperature in Auckland

An NPS-FM Assessment Using High-Frequency Monitoring Data, 2020-2024

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January 2026

Technical Report 2026/1

aucklandcouncil.govt.nz

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ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-991415-57-8 (PDF)

The Peer Review Panel reviewed this report
Review completed on 30 January 2026 Reviewed by two reviewers
Approved for Auckland Council publication by: Name: Paul Klinac Position: General Manager, Engineering, Assets and Technical Advisory
Recommended for approval/publication by:
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Date: 30 January 2026

Recommended citation
Dikareva, N. (2026). State of stream temperature in Auckland: an NPS-FM assessment using high-frequency monitoring data, 2020-2024. Auckland Council technical report, TR2026/1

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Acknowledgement
Feedback on initial draft provided by J. Gadd

Executive summary

Water temperature is a critical driver of stream ecosystem health, influencing dissolved oxygen levels, chemical processes, and the physiological responses of aquatic organisms. Elevated temperatures can cause thermal stress, disrupt species composition, and alter ecological function. In Auckland, thermal pollution has emerged as an important management concern, particularly in urban and unshaded rural streams, where ongoing land development and catchment modification increase the risk of exceedance of ecological temperature thresholds.

This report presents a regional assessment of stream water temperature across 39 sites in the Auckland region, using automated high-frequency records (maximum 15-minute logging interval) to evaluate both acute (daily maximum) and chronic (5-day Cox-Rutherford Index, CRI) thermal attributes. Temperature bands were assigned following the framework proposed by Clapcott et al. (2015), adapted to align with the National Policy Statement for Freshwater Management 2020 – Amended October 2024 (NPS-FM) additional attribute requirements. Data were analysed for two 5-year periods representing baseline (2013-2017) and current state (2020-2024) conditions.

Overall, the analysis found that most Auckland streams fall within B and C bands, indicating moderate thermal stress on aquatic ecosystems. Native forest streams were the coolest, while urban streams – particularly those with limited riparian shading and modified or concrete-lined channels – were consistently the warmest. Four urban sites exceeded the proposed regional bottom line (Band D), representing conditions of significant ecological stress. Of the 39 sites assessed, eight changed bands between baseline and current states, with the majority at a worse band for current state, representing warmer temperatures.

Long-term 5-year rolling medians showed that most streams have relatively stable temperature regimes, remaining within one band over the observation period. However, increasing trends in both daily maxima and CRI were observed in several rural (Wairoa, Rangitōpuni, Hōteo, Alexandra) and urban streams (Awaruku and Lucas). In contrast, Vaughan Stream exhibited decreasing temperature trends coinciding with improvements in turbidity and metal concentrations, likely reflecting the effectiveness of integrated Water Sensitive Design (WSD) and riparian restoration implemented as part of the Long Bay urban development.

Multiple linear regression analyses confirmed that reach-scale riparian shading and channel modification are significant predictors of stream temperature, together explaining up to half of the observed variation across sites. Streams with high (>90%) shading and natural channels exhibited significantly lower daily maxima and CRI values compared with modified or unshaded reaches.

A comparison between continuous and discrete temperature datasets revealed that discrete monthly measurements underestimate the hottest day of the year by an average of 3°C, particularly missing short-term heat extremes. As a result, discrete data tended to overestimate stream condition, with

more sites classified in higher (better) NPS-FM bands compared with continuous datasets. These findings support the use of continuous (or high-frequency) monitoring of temperature for robust thermal attribute assessment in Auckland’s rivers and streams.

In summary, this assessment demonstrates that stream thermal regimes in the Auckland region are closely linked to land use, shading, and channel condition. Maintaining and restoring riparian vegetation, reducing channel modification, and embedding Wate Sensitive Design (WSD) are essential for mitigating thermal pollution and protecting freshwater ecosystem health under ongoing urban growth and rural production and climate warming.

This report builds on the 2023 baseline state assessment (Auckland Council, 2023) by expanding data coverage and improving confidence in state evaluations. Additional years of monitoring data have enabled more sites to meet minimum data requirements and reduced key data gaps identified in the previous assessment, allowing longer-term changes in in-stream temperature to be evaluated. The analysis is further extended by examining potential drivers of in-stream temperature, including shade cover and channel modification, and by comparing discrete measurements with high-frequency monitoring data. Together, these improvements deliver a stronger and more comprehensive baseline for evaluating future change, while ensuring consistency with previous assessments.

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1. Introduction

1.1 Effects of temperature on stream health

Stream temperature management is critical because many freshwater species tolerate only small increases above their optimal growth range. Water temperature regulates key physical and chemical processes, such as oxygen solubility, and directly influences aquatic organisms. Elevated temperatures can alter their metabolic rates, behaviour, growth, reproduction, and abundance, and in extreme cases can cause mortality (Bonacina et al., 2023; Smith, 2006). Sustained temperature increases can also lead to shifts in species composition and changes in overall ecosystem structure and function (Nelson and Palmer, 2007).

The effects of elevated stream temperatures depend on the magnitude, frequency, duration, timing and spatial extent of exposure (Arseneau, 2010; Arismendi et al., 2013; Steel et al., 2017). During summer, temperatures can approach lethal levels for sensitive species (Olsen et al., 2011). Stream temperature maxima and aquatic temperature guidelines distinguish between acute and chronic thresholds: acute thresholds refer to short-term temperature spikes that cause immediate mortality, while chronic thresholds relate to prolonged exposure to elevated but sub-lethal temperatures that affect growth, reproduction, and behaviour (Olsen et al., 2011). Both thresholds are critical for maintaining ecological integrity, as even small deviations from natural temperature regimes can disrupt key biological processes such as migration and spawning.

Thermal tolerance of stream animals in New Zealand is relatively well studied (Quinn et al., 1994; Richardson et al., 1994). For example, laboratory tests on 12 New Zealand freshwater invertebrate taxa showed that their upper thermal tolerance, expressed as the temperature lethal to 50% of individuals (LT_{50}), decreased over four days of exposure. After 48 and 96 hours, LT_{50} values ranged from 24.5°C to >34°C and 22.6°C to 32.6°C, respectively, suggesting that summer temperatures in many New Zealand streams may limit the distribution and abundance of some species (Quinn et al., 1994). Stream temperature also affects macroinvertebrate community composition, with mayflies, stoneflies, and caddisflies preferring cooler sites, while snails, crustaceans, chironomids, and worms are more abundant in warmer streams (Quinn and Hickey, 1990).

1.2 Factors affecting stream temperature

Water temperature naturally changes with daily and seasonal cycles, mostly due to incoming solar radiation. However, it can also be affected by water inputs that are warmer – like industrial cooling water or stormwater – or cooler, such as water released from the bottom of dams (Clapcott et al., 2015).

The extent of thermal heating in streams is influenced by land use type and the degree of catchment modification (Pluhowski 1970; Le Blanc et al., 1997). In Auckland, streams are experiencing thermal impacts from stormwater discharges (Young et al., 2013). Stream temperatures typically increase with greater levels of urbanisation and catchment imperviousness (Roa-Espinosa et al., 2003; Arrington, 2003; Herb et al., 2009). Maximum temperatures tend to be higher in urban streams than in rural or forested streams, and urban streams also exhibit wider temperature ranges (Mills and Williamson, 2008).

Stream shading plays an important role in regulating water temperature, but its influence can vary depending on the specific temperature metric being considered. Shading can significantly reduce maximum stream temperatures and help buffer extreme thermal conditions, although it has limited effect on minimum or mean temperatures (Johnson, 2004). The influence of shading on instream temperatures depends on the extent of contiguous shading and shade can fluctuate greatly between reaches. While the extent of existing shading is difficult to measure, and the potential benefits of restoring shade can be difficult to predict, riparian margins and buffer zones between land use activities and streams are widely recognised as key management tools for mitigating shading loss and thermal impacts on stream ecosystems (Davies-Colley et al., 2013). However, the measurement of shade is highly variable and does not solely reflect vegetation cover (e.g. topographic features), so it is difficult to measure in a standardised manner (Rutherford et al., 1997). In addition, shading may depend on combination of factors, such as stream orientation and tree shape (Rutherford et al., 2021).

Substrate type of the stream channel can also influence water temperature. Differences in substrate affect how much solar radiation is absorbed and retained, influencing heat exchange between the streambed and the overlying water. Maximum temperatures are typically higher in stream reaches lined with bedrock compared with those underlain by alluvial substrate (Johnson, 2004). Extreme temperature values have also been recorded in shallow, unshaded, concrete-lined channels in some parts of Auckland (Mills and Williamson, 2008).

1.3 Regional attribute framework

Thermal pollution – defined as the degradation of water quality due to changes in ambient water temperature – is a significant environmental issue affecting both rural and urban areas in Auckland (Young et al., 2013). Unshaded rural streams and streams receiving urban stormwater are particularly prone to high temperatures. Temperature has been included as an additional attribute for Auckland due to the high proportion of unshaded urban and rural streams in the region and the ongoing and future urban development planned. Importantly, stream water temperature directly influences other water quality parameters – such as periphyton growth, dissolved oxygen, and ammonia toxicity – that are already compulsory attributes under the NPS-FM; therefore, temperature is an important attribute to include in assessments.

Instream temperature current state grading in this report is in accordance with proposed criteria for a water temperature attribute for the Auckland region developed by Clapcott et. al., (2015). This was adapted from Davies-Colley et al. (2013) who proposed nationally applicable NPS-FM temperature attribute states based on the Cox-Rutherford Index (CRI) and the annual maximum instream temperature (Table 1). The CRI is a metric used to account for diel temperature variation by representing an ecologically relevant temperature that lies between the daily mean and the daily maximum. It was developed to improve the ecological relevance of laboratory-derived thermal limits by better matching them to fluctuating temperatures experienced by organisms in natural streams (Cox & Rutherford, 2000). The CRI from the five hottest days of summer provides a more robust statistic that reduces the effect of erroneous or anomalous data. The use of the CRI and maximum temperature metrics is intended to respectively represent chronic and acute temperature effects on instream aquatic life.

Table 1. Temperature attribute table for rivers and streams as outlined in table 1 of Clapcott et al., 2015. CRI equals Cox Rutherford Index.

Band	Description	CRI °C	Maximum °C
A	No thermal stress on any aquatic organism that is present at matched reference (near-pristine) sites.	≤18	≤19
B	Minor thermal stress on occasion (clear days in summer) on particularly sensitive organisms such as certain insects and fish.	≤20	≤22
C	Some thermal stress on occasion, with elimination of certain sensitive insects and absence of certain sensitive fish.	≤24	≤25
Regional bottom line			
D	Significant thermal stress on a range of aquatic organisms. Risk of local elimination of keystone species with loss of ecological integrity	>24	>25

2. Methods

2.1 Monitoring network and site categorisation

Auckland Council's network of high-frequency temperature monitoring was initially implemented at existing river hydrology monitoring stations (around 2003). Additional sites were added to the network from 2021 onward at selected discrete water quality and river ecology monitoring sites. Therefore, sites differ in the length of high-frequency temperature time-series available for the analysis, starting between 2003 and 2021 and varying from 20+ to 4 years in length. The current monitoring network includes 46 sites. After all sites were reviewed in relation to site quality and data limitations that may influence continuous temperature evaluation with consideration of National Environmental Monitoring Standards (NEMS) as described in section 2.2, 39 sites were included in the analysis in this report (Figure 1). Seven sites were excluded from the temperature analysis due to poor data quality and site condition concerns, including the risk of sensors being buried or exposed in extremely shallow, sun-exposed concrete channels or strong tidal influence (and therefore potential coastal temperature influence).

To preliminarily assess whether discrete measurements are adequate for assigning temperature attributes, we used long-term monthly discrete stream temperature measurements collected at the same locations as continuous temperature records, taken at variable times of day but within the period between 8 am and 2 pm. Discrete temperature is measured monthly as part of the routine water quality monitoring programme. Measurements are collected using a YSI EXO sonde equipped with a thermistor sensor (calibrated against a laboratory reference thermometer that's had a 10 point water bath calibration as per NEMS) which is placed on the streambed and allowed to stabilise for 3-5 minutes before two consecutive readings are recorded. These readings are subsequently reviewed by an environmental monitoring specialist, and provided the values do not differ substantially, one measurement is retained in the database while the duplicate is removed.

The dominant land cover classes in the upstream catchment of the river monitoring sites are shown in Table 2. The colours in this table are used throughout the report to represent the different dominant land cover groups. Dominant land cover groups were assigned based on Auckland Council's internal process, as described by Ingley et al., (2025). Climate, underlying geology and stream order for each monitoring site were assigned according to River Environmental Classification New Zealand (2004, Snelder et al., 2004).

The NPS-FM requires councils to divide regions into Freshwater Management Units (FMUs) at a scale that supports integrated, whole-catchment freshwater management and surface water accounting. FMUs must collectively encompass all waterbodies and their catchments. Auckland Council has defined three FMUs – Kaipara, Hauraki, and Manukau (Table 2) – which align with the river systems draining to the region's three major coastal receiving environments and reflect shared management issues within each area.

Many stream sites are subject to some degree of channel modification including widening, deepening (either anthropogenically or through erosion), or may include short sections of pervious or impervious bank or channel lining and are not necessarily ‘natural’ but are categorised as ‘unmodified’ where these features are not prevalent in the upstream reach of the monitoring site. Sites with extensive channel modification at the monitoring site reach or immediately upstream were identified based on high level site observations. The categories included: piped – where the stream was enclosed in a pipe upstream of the sampling location; concrete – where the streambed was lined with concrete; and modified – where visible alterations to the channel were observed, such as straightening, netting, or lining with pervious materials (Table 2). The purpose of this assessment was to investigate where modifications may impact thermal regimes directly.

Overhead stream reach shading was calculated by densitometer readings at each of the continuous temperature monitoring sites in 2024. Overhead shading includes both riparian vegetation and topographic features at the reach scale. The evaluation of shading was confined to conditions at the monitoring site and did not include an assessment of shading extent upstream. The overhead shading data was grouped into six categories (Table 2) based on the scoring for the ‘Water temperature control’ variable (Vshade) of the Stream Ecological Valuation methodology (Storey et al. 2011).

Figure 1. Site location of continuous temperature sensors on the 39 streams analysed in this report. Colours indicate the dominant land-use category for each catchment (see Table 2).

Stream name	Land cover	Climate	Geology	Stream order	Channel Modification	Reach Shading	FMU
Cascades	Native forest	WW	VA	4	Natural	Moderate	Manukau
Wairoa trib	Native forest	WW	HS	2	Natural	Very high	Hauraki
West Hoe	Native forest	WW	SS	2	Natural	High	Hauraki
Mahurangi	Exotic forest	WW	SS	2	Natural	None	Hauraki
Waiwhiu	Exotic forest	WW	SS	2	Natural	Low	Kaipara
Matakana	Rural - Low	WW	SS	4	Natural	Low	Hauraki
Wairoa	Rural - Low	WW	HS	5	Natural	Very low	Hauraki
Waiwera	Rural - Low	WW	SS	4	Natural	Very low	Hauraki
Ōpanuku Upper	Rural - Low	WW	SS	3	Natural	Moderate	Hauraki
Hōteo	Rural - High	WW	SS	5	Natural	Moderate	Kaipara
Kaipara	Rural - High	WW	SS	5	Natural	Very low	Kaipara
Kaukapakapa	Rural - High	WW	SS	5	Natural	Low	Kaipara
Makarau	Rural - High	WW	SS	5	Natural	Very low	Kaipara
Mangemangeroa	Rural - High	WD	SS	3	Natural	Very high	Hauraki
Ngākōroa	Rural - High	WW	VA	3	Natural	Moderate	Manukau
Rangitōpuni	Rural - High	WW	SS	1	Natural	Very low	Hauraki
Te Muri	Rural - High	WD	SS	1	Natural	Moderate	Hauraki
Waitangi	Rural - High	WW	VA	3	Natural	Very high	Manukau
Whangamaire	Rural - High	WW	VA	2	Natural	High	Manukau
Alexandra	Urban	WD	SS	2	Natural	Very high	Hauraki
Awaruku	Urban	WD	SS	2	Modified	Moderate	Hauraki
Eskdale	Urban	WW	SS	3	Natural	Moderate	Hauraki
Kaipatiki	Urban	WD	SS	2	Natural	High	Hauraki
Lucas	Urban	WD	SS	3	Natural	Very low	Hauraki
Mairangi Bay	Urban	WD	SS	2	Piped	High	Hauraki
Newmarket	Urban	WW	SS	3	Concrete	High	Hauraki
Onetangi	Urban	WD	HS	1	Natural	Very high	Hauraki
Oratia	Urban	WW	SS	4	Natural	High	Hauraki
Oteha	Urban	WD	SS	3	Natural	Very low	Hauraki
Papakura	Urban	WW	HS	4	Modified	Very low	Manukau
Paramuka	Urban	WW	SS	2	Natural	High	Hauraki
Puhinui	Urban	WW	HS	3	Natural	Low	Manukau
Swanson	Urban	WW	SS	4	Natural	Low	Hauraki
Tāmaki	Urban	WD	SS	3	Piped	Very low	Hauraki
Vaughan	Urban	WD	SS	2	Natural	None	Hauraki
Wairau Upper	Urban	WD	SS	3	Concrete	None	Hauraki
Whau	Urban	WW	SS	2	Natural	High	Hauraki
Ōpanuku Lower	Urban	WW	SS	3	Natural	Moderate	Hauraki
Ōtara	Urban	WD	SS	3	Concrete	High	Hauraki

Table 2. Stream names, including upstream catchment's dominant land cover groups used throughout this report. Climate[1]: WD – warm-dry, WW – warm-wet. Geology[1]: HS – hard sedimentary rocks, VA – volcanic acidic, SS – soft sedimentary.

[1] Geology and climate classes for the sites are based on the River Environment Classification New Zealand (2010) (https://data.mfe.govt.nz/layer/51845-river-environment-classification-new-zealand-2010).

2.2 Data preparation and analysis

Temperature was measured at each site using either Seametrics T1 or PT12 submersible digital temperature (and pressure/temperature) sensors, or Zebratech D-Opto optical dissolved oxygen sensors equipped with integrated digital temperature sensors. Sensors were positioned to ensure continuous contact with the water and to provide representative temperature measurements. The placement within the water column and distance from the bank were selected to ensure the sensor remained submerged based on the long-term minimum water-level stage, that water mixing was sufficient to provide unbiased measurements, and that substrate movement or bed mobility did not affect the readings.

The initial dataset for this report comprised time-series records of continuous temperature measurements from 39 sites across the Auckland region. At most sites and during most years, temperature was recorded at 15-minute intervals. However, in some cases, measurements were taken at 5-minute or even 2-minute intervals during certain years at selected sites. Specifically, temperature was measured every 2 minutes at Te Muri and Tāmaki for the majority of the monitoring period, and every 5 minutes at the West Hoe and Mangemangeroa sites.

All time-series datasets had undergone quality control procedures prior to retrieval from the Auckland Council database. Each site's data had been quality coded in accordance with the National Environmental Monitoring Standards (NEMS, 2019) and Auckland Council's internal quality assurance protocols. To calculate summary statistics, only quality controlled data with associated quality codes (QC) of 10 and 20 were used. These correspond to NEMS codes 600 (good quality) and 500 (fair quality), respectively.

We extracted data for the summer period and calculated the total number of days with data meeting quality criteria available for each hydrological year. In addition, we determined the number of days with data meeting quality criteria during the two hottest months – January and February. Hydrological years that had more than 90 days of data per summer season (i.e. more than 50% of the maximum possible days) and more than 30 days of data in January-February, sustained over more than five years, were assigned a 'Final' grade. When the requirement of more than 90 days of data per summer season and more than 30 days of data in January-February was met, but had 3 to 4 years of data that meets these requirements an 'Interim' grade was assigned. Hydrological years with fewer than 90 days of data over the 'summer season' were excluded from the calculation of 5-year median values for the baseline and current state. Median values based on less than 3 years of data should be treated with caution.

Following Clapcott et al. (2015) recommendations on temperature attribute assessment in Auckland streams, we extracted maximum daily temperatures and calculated mean CRI of the 5 hottest days per each summer period (1 November to 30 April)[2] for each stream. The CRI was calculated as the average of daily mean temperature and daily maximum temperatures over the five hottest days in the summer period from inspection of a continuous temperature record (CRI = (Tmax + Tmean)/2). The CRI was calculated for each day before calculating a 5 day moving mean. The maximum 5-day moving mean was selected to represent each year from 1 November to 30 April (i.e. the hottest 5 consecutive days of summer). The annual period was extended by two months from the December to March period recommended by Clapcott et al. 2015, to align with the 'summer season' NPS-FM attribute for the dissolved oxygen in rivers. This assumes that maximum temperatures most likely occur in summer when air temperatures are higher and stream flows are generally lower.

Calculations and statistical analysis were conducted using R Core and R Studio version 2025.9.1.401 (R Core Team, 2025; Posit Team, 2025). For each monitoring site, water temperature data were analysed separately for each summer year. Daily mean temperatures were first calculated and then summed over consecutive five-day periods using a rolling window. The five-day period with the highest cumulative temperature was identified for each summer year and site. The individual dates comprising this hottest five-day period were then extracted, and the temperature data were filtered to include only observations from these five days. For each of these days, the daily mean and daily maximum temperatures were calculated. A daily CRI was derived as the average of the daily mean and daily maximum temperature. The final summer-year CRI was calculated as the mean of the daily CRI values across the hottest five-day period. Five-year rolling medians were then calculated for both the CRI and annual maximum temperature, along with counts of the number of years contributing data within each five-year window and the number of years classified as having insufficient data.

The baseline state for the temperature attribute was calculated using data over the 5-year period from the 2013-17 hydrological years for those sites with available data during this period. If no data were available for that time period, the stream was not graded for the baseline state. This baseline state period is based on the definition given in the NPS-FM 2020 (MfE 2024, section 1.4). The current state was calculated using data over the 5-year period from the 2020-24 hydrological years. The use of statistics calculated over a 5-year period provides a robust snapshot of the state of the environment and helps avoid changes in bands (due to state switching) that might occur with annual statistics (McBride 2016).

To help with visualisation of long-term trends in temperature, a 5-year rolling median was calculated for both maximum CRI and annual maximum series. The rolling median was calculated as a right-aligned 5-year median, which uses the median of the previous 4 years of the time-series plus the current year for each value. For sites with less than 5 years of data, rolling median were not calculated. Hydrological years with less than 90 days of data during the summer season were

[2] The hydrological year is used to identify the year of a given summer, with the name of the hydrological year applying to the year in which the dataset ends. For example, the summer from 1 November 2004 to 30 April 2005 is described as the summer of the hydrological year 2005.

included in the calculation of the 5-year rolling median for completeness. Annual values that were calculated with less than 90 days of data are displayed as hollow dots in Figure 3 and 4 and these results should be treated with caution.

Statistical analyses were undertaken to assess the relationship between stream shading, channel type, and temperature metrics. Differences in the 5-day CRI current state between channel types were tested using Welch's two-sample *t*-test, which does not assume equal variances between groups. Bivariate relationships between shading cover and temperature metrics were initially explored using scatterplots and Pearson correlation analysis. Linear regression was then applied to quantify these relationships, including simple linear regression between shading value and CRI metrics, and a multiple linear regression model in which 1-day maximum temperature and 5-day CRI were modelled as a function of shading value (continuous predictor) and channel type (categorical predictor). This multiple linear regression framework allowed the effect of shading on stream temperature to be assessed while accounting for differences between channel types.

Multiple linear regression model equation:

$$T_{max}/CRI=\beta_0+\beta_1(Shading)+\beta_2(Channel)+\varepsilon$$

T_{max} = 1-day maximum temperature (current state); CRI – 5-day CRI (current state); Shading = shading value (percent coverage) at the monitoring site; Channel = categorical variable describing channel type; β_0 = intercept; β_1, β_2 = regression coefficients; ε = random error term.

3. Results and Discussion

3.1 Temperature in Auckland rivers as assessed against an NPS-FM regional attribute framework

The annual maximum daily temperature and CRI at each site are presented in Table 3. The regional map of the overall current state (2020-2024 hydrological years) across monitored sites is presented in Figure 2. Of the 39 sites assessed, 11 lacked data during the baseline period and thus could not be compared with the current state. Further, the current state grades for two sites (Waiwhiu and Tāmaki streams) were based on only two years of data and should therefore be interpreted with caution (indicated with diagonal shading in Table 3).

Daily maximum temperatures for the baseline period ranged from 18.3 °C at West Hoe stream (native forest) to 32.2 °C at Wairau Upper Creek (urban concrete lined). The current state ranged from 19 °C to 31.8 °C at the same sites. CRI for the baseline period ranged from 17.6 at West Hoe to 27.1 at Wairau Upper Creek, while over the current period it ranged from 18.4 at the Wairoa Tributary (native forest) stream to 26.1 at Wairau Upper Creek.

Within assigned landcover groups, the current state of temperatures varied the most in urban streams, with daily maxima ranging from 19.9 °C at Onetangi Stream (very high shading) to 31.8 °C at Wairau Upper Creek (no shading). Among rural streams, Mangemangeroa Creek (very high shading) was the coolest, with a daily maximum of 20.3 °C and a CRI of 19.4, while the Wairoa Tributary (very low shading) had the highest daily maximum (24.7 °C) and the Waiwera River (very low shading) the highest CRI (22.8). Among the two exotic forest sites, Waiwhiu Stream (low shading) was cooler (daily maximum = 19.7 °C, CRI = 19.2) than the Mahurangi River (no shading) (daily maximum = 23.3 °C, CRI = 22.3). Daily maxima in the native forest sites ranged from 19 °C at West Hoe (high shading) to 22.6 °C at Cascades Stream (moderate shading), while CRI ranged from 18.4 at the Wairoa Tributary (very high shading) to 21.2 at Cascades Stream (moderate shading).

Eight of the 28 sites where both baseline and current states were assessed changed bands, out of a total of 39 sites across all land cover groups. Of these, only one site – the Hōteo River – moved to an improved band (from D to C), while seven shifted to more degraded bands, with the current state consistently indicating warmer instream temperatures. Within the native forest catchment group, West Hoe was the only site where both baseline and current states were assessed, and current state water temperatures were higher than the baseline for both metrics: daily maxima and CRI. In rural catchments, most streams remained in the same band, with two exceptions: Ngākōroa Stream declined from band B to C, while the Hōteo River improved from band D to C. Among urban streams, four declined from band B to C, and one stream (Awaruku) declined from band C to D, crossing the proposed regional bottom line (Clapcott et al., 2015).

When looking at the baseline and current state overall band picture, most streams were graded in band C (16 and 28 respectively) for both periods (Figure 3). There were the same number of streams graded in bands B and D (5 and 6 respectively) for both periods. There was only one site graded in band A at the baseline state period, while no sites were graded in band A at the current state period of assessment. These results partly reflect limitations of the monitoring network, particularly the small number of sites draining native forest catchments (three sites). However, the presence of a band A site in the baseline assessment indicates that this condition is achievable for Auckland streams draining native forest catchments. In addition, most newly assessed sites, for which baseline assessments were not possible, were graded in band C across all land cover groups, including native forest. This indicates scope for temperature improvement, although appropriate target bands should be determined in relation to upstream land cover and realistic management potential.

For the current state, of the three native forest sites, Wairoa and West Hoe were graded in band B, while Cascades Stream was placed in band C. Two exotic forest sites were graded in bands B and C, but these results should be interpreted with caution as they are based on only two to three years of qualifying data. All but one rural site was graded in band C for the current overall state, with Mangemangeroa being the only rural site graded in band B. In urban catchments, current state gradings ranged from band B (Onetangi Stream) to band D (six sites), placing the latter below the proposed regional bottom line (Clapcott et al., 2015).

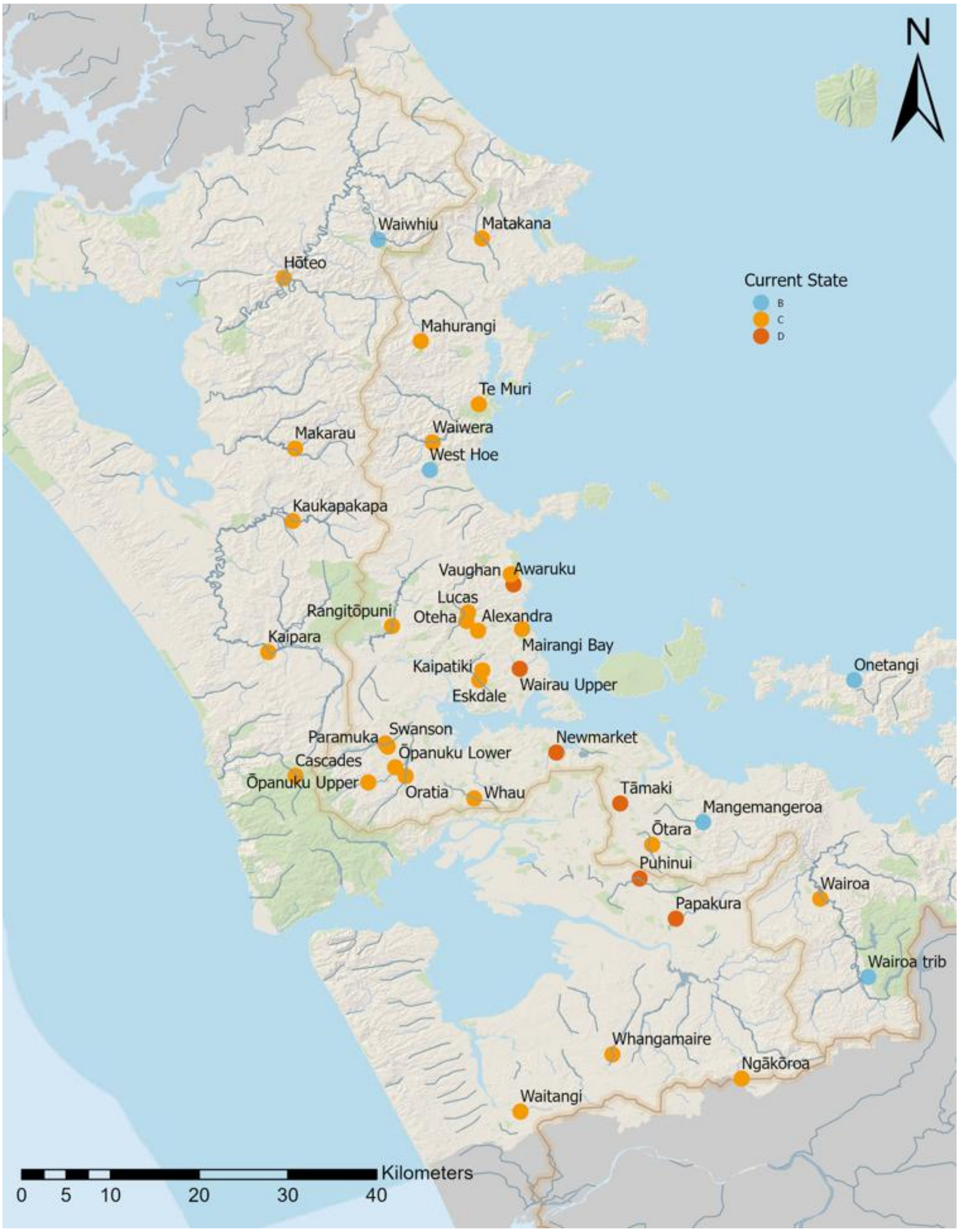


Figure 2. Overall NPS-FM current state (2020-2024 hydrological years) grades for the temperature attribute across monitored streams.

Table 3. Temperature attribute statistics (1-day maximum and annual CRI) and NPS-FM regional attribute bands for the baseline state (2013-2017 hydrological years) and current state (2020-2024 hydrological years) periods. Bands are assigned using the median value for the period, which is shown after the attribute band. The number of years used to calculate the median are within parentheses where <5 years data was utilized (only summers with more than 90 days of data were included). Band assessments based on 3-4 year data are shown with dotted patterns, and those based on 2 yr data with a diagonal line pattern (these results should be treated with caution). Overall bands were based on the worst band assessment for the 1-day maxima and CRI.

Stream name	1-day Maxima Baseline State	5-day CRI Baseline State	Overall Baseline Band	1-day Maxima Current State	5-day CRI Current State	Overall Current Band
Cascades	NA	NA	NA	C 22.6 (3)	C 21.2 (3)	C
Wairoa trib	NA	NA	NA	B 19.1 (3)	B 18.4 (3)	B
West Hoe	A 18.3	A 17.6	A	B 19 (4)	B 18.4 (4)	B
Mahurangi	NA	NA	NA	C 23.3 (3)	C 22.3 (3)	C
Waiwhiu	NA	NA	NA	B 19.7 (2)	B 19.2 (2)	B
Matakana	NA	NA	NA	C 23.5 (3)	C 22.6 (3)	C
Wairoa	C 23.8	C 22	C	C 24.7 (4)	C 22.8 (4)	C
Waiwera	NA	NA	NA	C 23.6 (3)	C 22.8 (3)	C
Ōpanuku Upper	C 22.1	C 20.3	C	C 22.2 (3)	C 20.4 (3)	C
Hōteo	D 25.2	C 23.2	D	C 23.9 (4)	C 22.6 (4)	C
Kaipara	C 22.3	B 19.9	C	C 23.4	C 22.7	C
Kaukapakapa	C 22.4	C 20.6	C	B 21.6 (4)	C 21.4 (4)	C
Makarau	NA	NA	NA	C 23.2 (3)	C 21.5 (3)	C
Mangemangeroa	NA	NA	NA	B 20.3	B 19.4	B
Ngākōroa	B 21.6	B 19.4	B	C 22.1	C 21.1	C
Rangitōpuni	B 21.2	C 20.1	C	B 21.4(4)	C 20.5 (4)	C
Te Muri	C 24.3 (3)	C 21.9 (3)	C	C 23.6	C 21.9	C
Waitangi	B 21.4	C 20.2	C	B 21.6 (4)	C 21.1	C
Whangamaire	NA	NA	NA	C 23.8 (3)	C 22.5 (3)	C
Alexandra	B 21.1	B 19.8	B	C 22.4	C 21.2	C
Awaruku	C 23.4	C 21.3	C	D 25 (4)	C 23 (4)	D
Eskdale	B 20.8	B 18.9	B	B 21.3	C 20.2	C
Kaipatiki	B 21.2	B 19.5	B	B 21.9 (4)	C 20.3	C
Lucas	C 22	C 20.6	C	C 23.3	C 21.1	C
Mairangi Bay	C 23.7	C 20.1	C	C 22.9 (4)	C 20.4	C
Newmarket	D 26.8	C 22.4	D	D 25.8 (4)	C 23.2 (4)	D
Onetangi	NA	NA	NA	B 19.9 (3)	B 19.5 (3)	B
Oratia	C 22.8	C 20.1	C	C 24.3 (4)	C 23.2 (4)	C
Oteha	B 21.6(4)	B 19.7 (4)	B	B 22 (4)	C 20.9 (4)	C
Papakura	D 25	C 22.9	D	D 25.9	D 24.7	D
Paramuka	C 22.9	C 20.4	C	C 22.8 (4)	C 21.8 (4)	C
Puhinui	D 26.9	D 25.1	D	D 26 (2)	D 24.4	D
Swanson	C 23.8	C 22.2	C	C 24.7 (4)	C 23.3	C
Tāmaki	D 27.7 (3)	D 24.3 (3)	D	D 26.9 (2)	D 24.2 (2)	D
Vaughan	C 24.1	C 21	C	C 23.1	C 21.3	C
Wairau Upper	D 32.2 (3)	D 27.1(3)	D	D 31.8 (4)	D 26.1 (4)	D
Whau	C 22.6	C 20.2	C	C 23 (4)	C 20.6 (4)	C
Ōpanuku Lower	C 23.9	C 21.9 (3)	C	C 24.6 (4)	C 23 (4)	C
Ōtara	NA	NA	NA	C 23.6	C 22.5	C

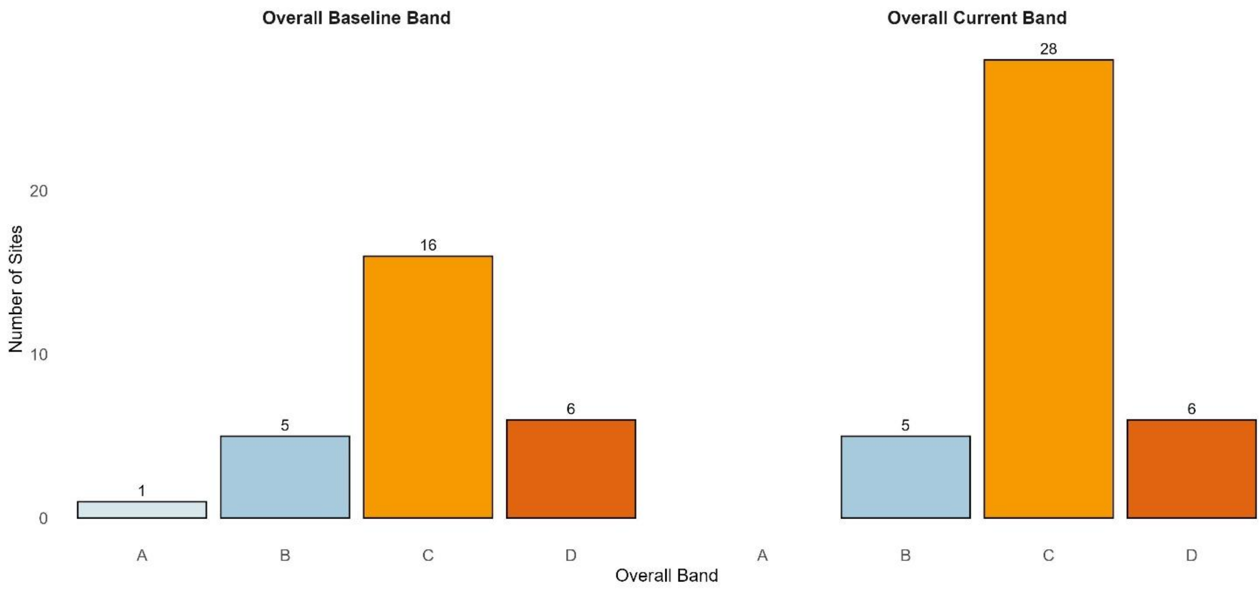


Figure 3. Number of streams assigned to each band of the regional temperature attribute framework at baseline and current state.

The 5-year rolling medians and individual annual summer medians with color-coded bands based on daily maximum metric and CRI are presented in Figures 3 and 4. The 5-year rolling median provides a useful tool for visualising long-term changes in temperature maxima attributes, but it slightly differs from the results shown in Table 3, as it includes years with fewer than 90 days of data (displayed as hollow dots). Thus, discrepancies may occur when comparing Figures 3 and 4 with Table 3. For both metrics, annual fluctuations of 1-2 bands from year to year occurred at most sites. Among sites with long-term data, these fluctuations were less pronounced at the West Hoe native forest site and at a few urban sites (e.g., Newmarket and Wairau Upper), where daily maxima and CRI remained consistently high. Ōpanuku Lower (urban) was the only stream where bands spanned A to D from year to year based on annual daily maxima, while Vaughan Stream (urban) was the only stream where bands spanned A to D based on annual CRI values.

Despite year-to-year fluctuations, the long-term values of annual maximum daily temperatures and 5-day CRI rolling medians tend to stay within one band (Figures 4 and 5). However, a few site-specific exceptions exist. Increasing 5-year rolling medians of annual daily maxima are noticeable in Wairoa, Rangitōpuni, Hōteo rivers in rural catchments as well as in the urban streams of Alexandra, Awaruku, Lucas and Ōpanuku Lower. The rolling median of the CRI metric in Rangitōpuni river also showed a consistent degradation in temperature since 2016. Interestingly, increasing summer water temperatures in Rangitōpuni river coincides with increasing DO metrics (Young et al., 2024) and increasing nutrient concentrations (Ingley et al., 2025). This pattern is unusual because increasing water temperature is typically associated with lower dissolved oxygen due to reduced oxygen solubility, rather than the concurrent increases in dissolved oxygen and nutrient concentrations observed in the Rangitōpuni River. Possible reasons for this might be an increase in primary productivity when growth of aquatic plants and algae during daytime boosts DO through photosynthesis. The CRI metric for urban rivers either showed a slight increase (i.e. Alexandra, Awaruku, Kaipatiki, Lucas) or fluctuated within a consistent range (i.e. Mairangi Bay, Oteha, Swanson). The only exception was Vaughan Stream where both rolling medians of annual maximum temperature and CRI showed consistent decline suggesting possible improvements.

The improving water temperature in Vaughan Stream also coincides with strong improving trends in turbidity and metal concentrations over the same time period (2018-2020). Water quality parameters, such as metals, ammonia, dissolved inorganic nitrogen and water clarity were lower than in most urban catchments across the region despite the large-scale urban development in the area (Ingley et al., 2025). The Long Bay residential development within the lower Vaughan catchment is an award-winning development where detailed water sensitive design was implemented (New Zealand Institute of Landscape Architects, 2019). The design focused on effective catchment management and restoration of ecological connectivity. Native forest patches from the upper to lower catchment were linked through an integrated network of vegetation and waterways. Water Sensitive Design (WSD) features, such as rain gardens and natural treatment systems, were incorporated into streetscapes and open spaces to enhance hydrological connectivity and maintain water quality. The observed decline in water temperature in Vaughan Stream is likely linked to these catchment-scale improvements, particularly the restoration and linkage of native forest patches, increased riparian shading, and the use of low-impact design features reduced thermal loading by slowing runoff, promoting infiltration, and maintaining more natural flow regimes.

Three urban streams – Oratia, Oteha, and Whau – exhibited a marked improvement in annual CRI index values in 2015, while their maximum daily temperatures remained comparable to previous years (Figures 4 and 5). This suggests that although several hot days occurred during the summer of 2014-2015, the overall summer acclimation temperature was relatively low. This pattern may reflect cooler baseflow conditions or increased groundwater inputs during that period, but in the absence of supporting data, this interpretation remains uncertain. These streams achieved band A in this summer only, based on the CRI metric. According to NIWA's Seasonal Climate Summary, rainfall was below normal and air temperatures were above average during the 2014-2015 summer, indicating that the temporary drop in CRI at these three sites was driven by site-specific factors rather than regional climate conditions.

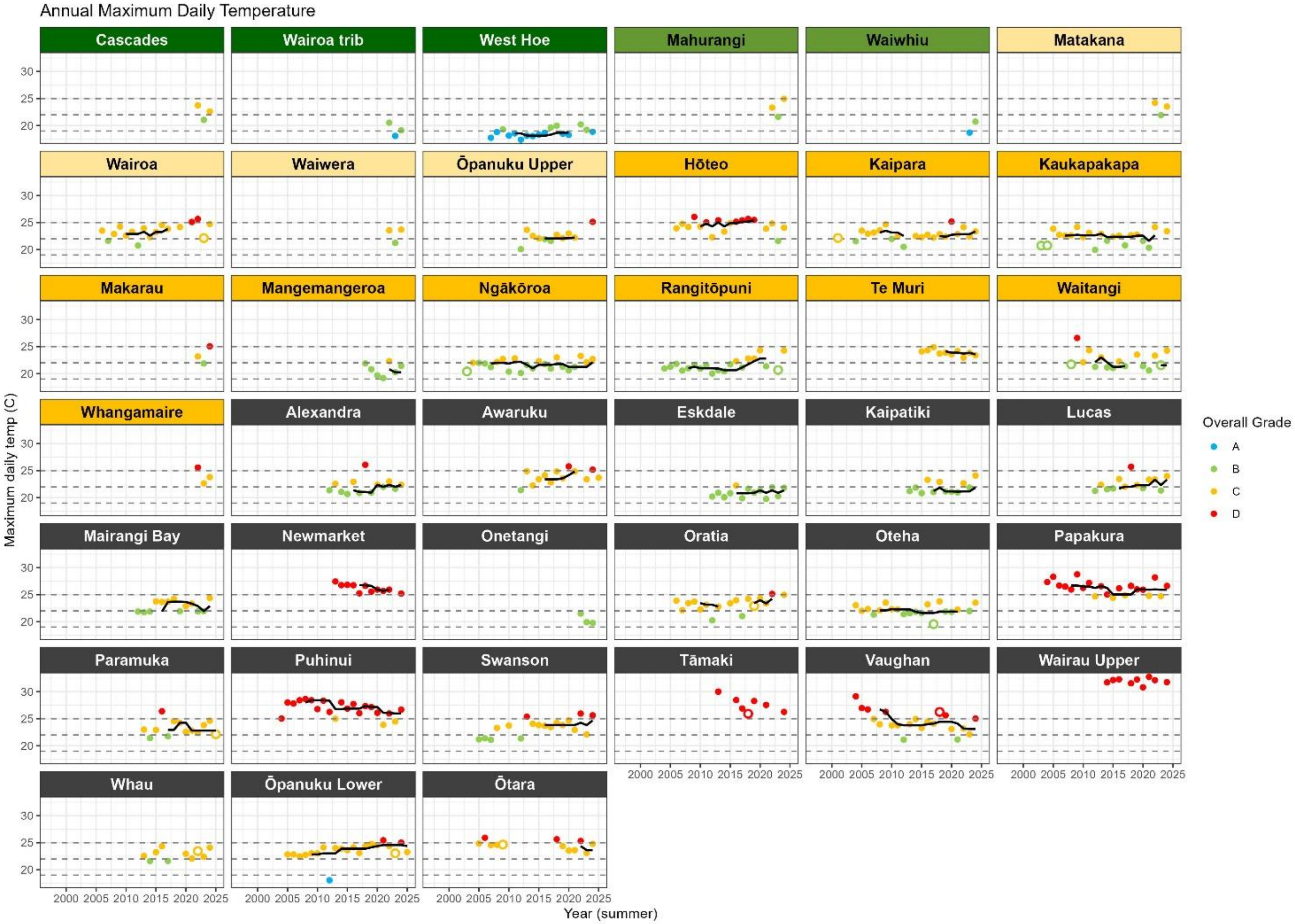


Figure 4. NPS-FM regional attribute band assessement for the daily maximum temparture. The annual values (dots) per hydrological year (summer) and the 5-year rolling median (black lines) are shown for each stream. The colours of the dots indicate the NPS-FM grade for that year based on the maximum temperature metric. Horizontal dashed lines delineate the thresholds separating the bands. Hollow dots show annual values that were calculated with less than 90 days of data and should be treated with caution.

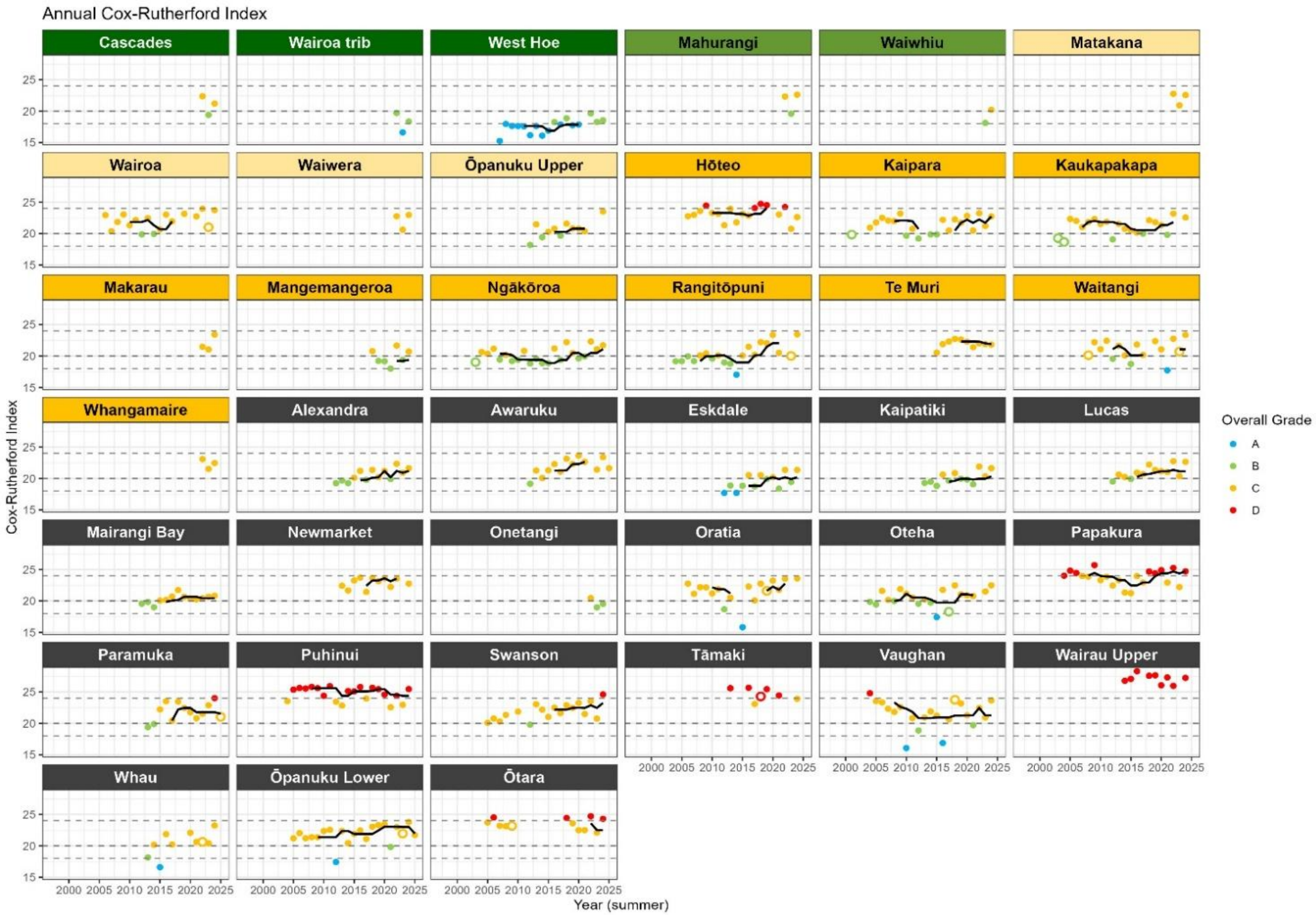


Figure 5. NPS-FM regional attribute band assessment for the annual CRI. The annual values (dots) per hydrological year (summer) and the 5-year rolling median (black lines) are shown for each stream. The colours of the dots indicate the NPS-FM grade for that year based on CRI. Horizontal dashed lines delineate the thresholds separating the bands. Hollow dots show annual values that were calculated with less than 90 days of data and should be treated with caution.

3.2 Factors affecting water temperature in Auckland streams

Land use

Streams draining forested catchments were generally cooler than those in rural or urban areas (Figure 6). However, unexpectedly the Cascades Stream (native forest) and the Mahurangi River (exotic forest) sites were both classified in band C under the regional attribute framework. No sites were currently classified in band A, although baseline data from the West Hoe (native forest) site indicates that achieving an A-band status is possible for Auckland streams with these types of catchments.

As part of an earlier previous baseline assessment (using data from 2010-2014), Clapcott (2015) reported a maximum daily temperature of 17.09 °C and a 5-day CRI of 15.92 °C for Cascades Stream, placing it in band A. In contrast, the current assessment classified this stream in band C for both metrics, with daily maximum temperature exceeding the baseline by 5.5 °C and CRI exceeding baseline by 5 °C (Table 3). Such a marked increase in maximum temperature and CRI within a decade for a native forest stream is concerning. There was a change in monitoring location of 1km downstream, which may have contributed to this change.

The annual variation in daily maximum temperature was also notably smaller in native forest streams compared with rural and urban sites (Figure 7, top to bottom).

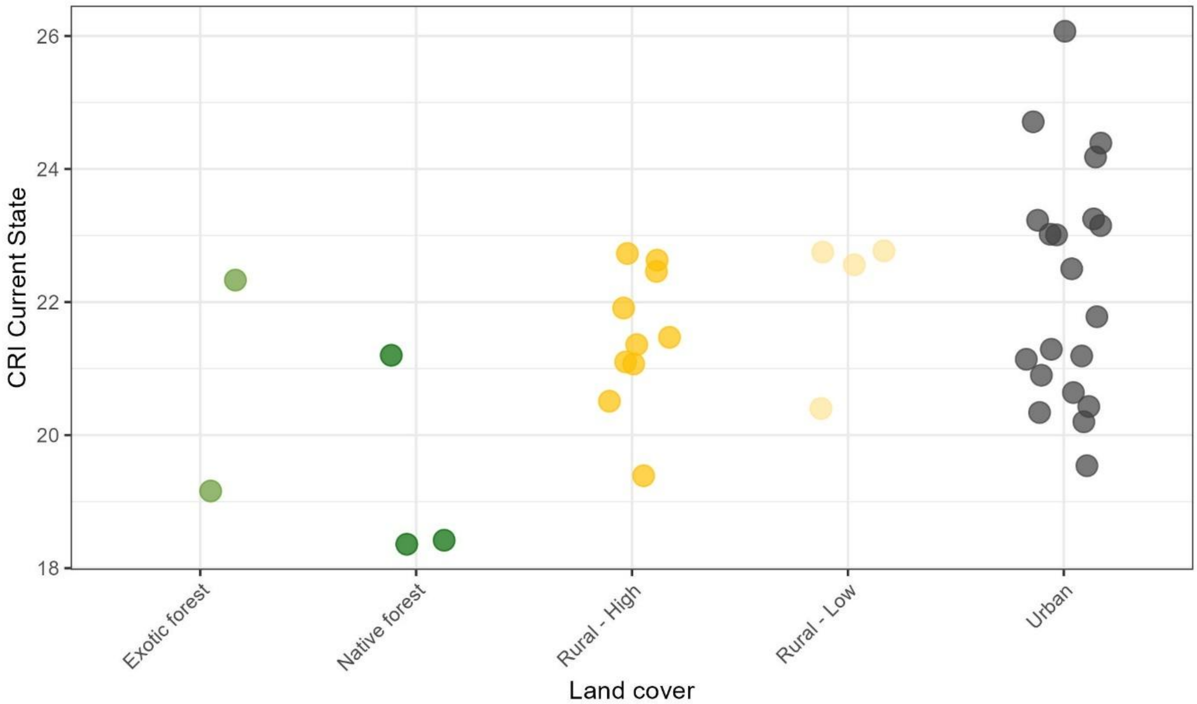


Figure 6. 5-day CRI current state for each site grouped by dominant upstream land cover.

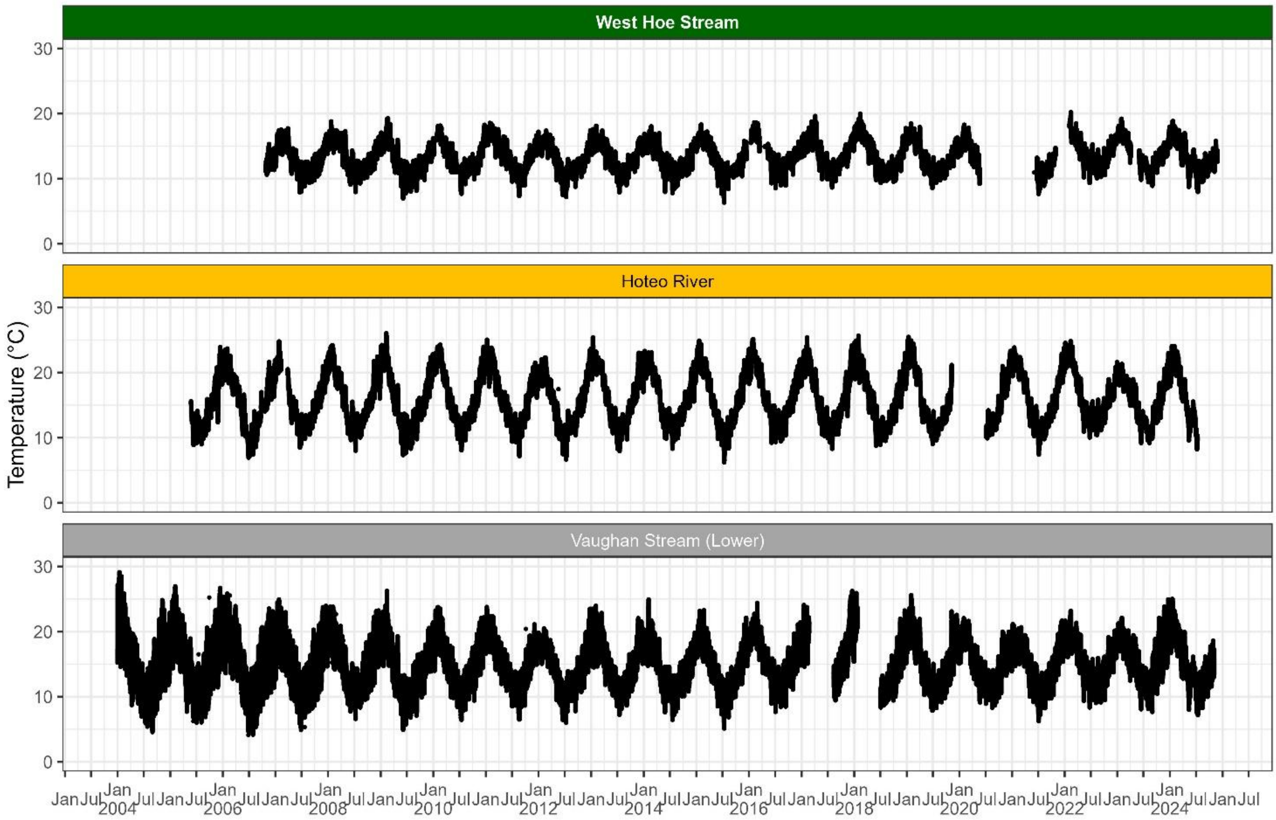


Figure 7. Time-series of daily maximum temperature over the full period of observations for three selected streams representing native forest, rural and urban catchments.

Shading and channel modification

Site shade (as percentage cover) was a significant driver of both current maximum daily temperature and CRI ($p<0.05$) (Figure 8 and 9) (Appendix 4), suggesting that streams with greater shading had lower instream temperatures. However, the explanatory power was low with shading cover explaining around 20% of the variation among sites. Shading cover likely needs to be relatively high at the reach scale (around 90-100%) to make a meaningful difference on both temperature metrics (Figure 10). Stream reaches can respond differently to direct solar radiation, meaning that the cooling benefits of shading are highly context- and site-specific; for example, studies have shown that the length of shaded reach required to achieve a given temperature reduction can vary substantially between upstream and downstream sections of the same river (Johnson and Wilby, 2015). It is worth noting that this report assessed shading cover only at the site scale, whereas shading at the catchment scale is also likely to influence stream temperature. For example, a riparian reforestation that increases stream shading has been shown to reduce stream temperatures (Quinn et al., 2009). There is currently no evidence that site-level shading cover is representative of shading conditions across the entire catchment, and this warrants further investigation.

Channel type also significantly influenced stream temperatures. Welch two-sample t-tests indicated that modified channels had higher temperatures than natural channels for both metrics: the current state 1-day maximum temperature was higher in modified channels (26 °C) than in natural channels (23°C, $p = 0.019$), and the 5-day CRI was also higher in modified channels (23 °C vs 21 °C, $p = 0.021$) (Figure 11). This indicates that streams with modified channels have generally higher daily and multi-day summer temperatures than those with natural channels.

Multiple linear regression analyses showed that, after accounting for channel modification, shading value was a significant predictor of both stream temperature metrics. For the 5-day CRI, the model explained 38% of the variation ($p < 0.001$), with shading value significantly associated with lower CRI values (Appendix 4). Similarly, for the 1-day maximum temperature, the model explained 48% of the variation ($p < 0.001$), and shading again had a significant negative effect (Appendix 4). In both models, streams with unmodified channels exhibited significantly lower temperature values than modified channels suggesting that both shading and the channel type are one of the key drivers of stream thermal regimes.

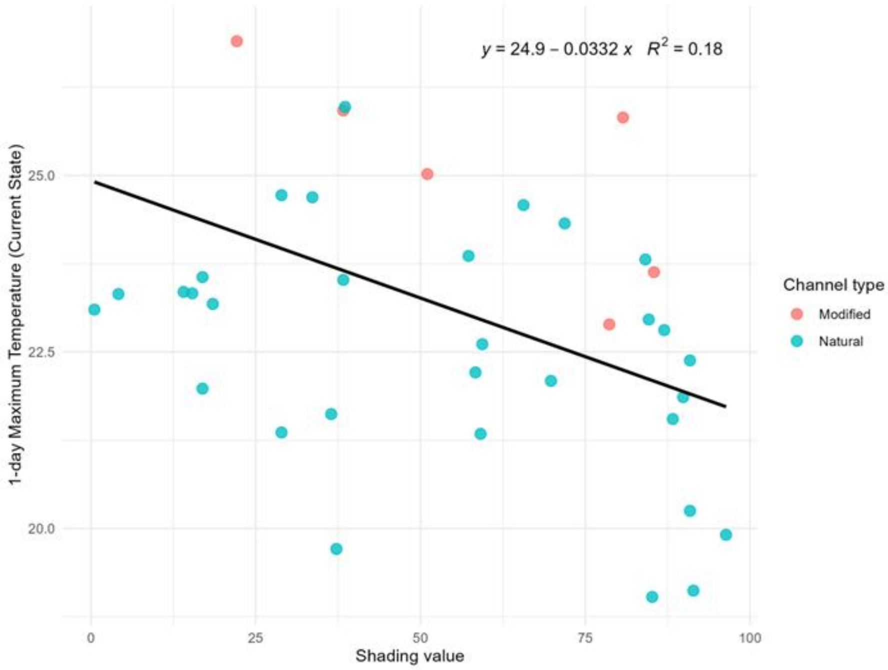


Figure 8. Relationship between 1-day maximum temperature and current state shading value at the site (percent coverage).

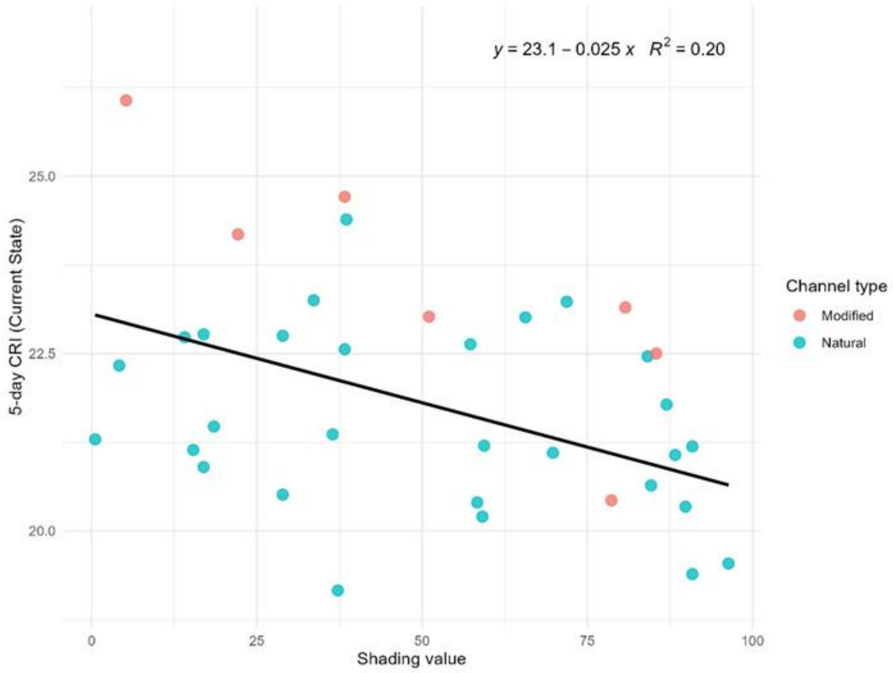


Figure 9. Relationship between current state 5-day CRI and shading value (percent coverage).

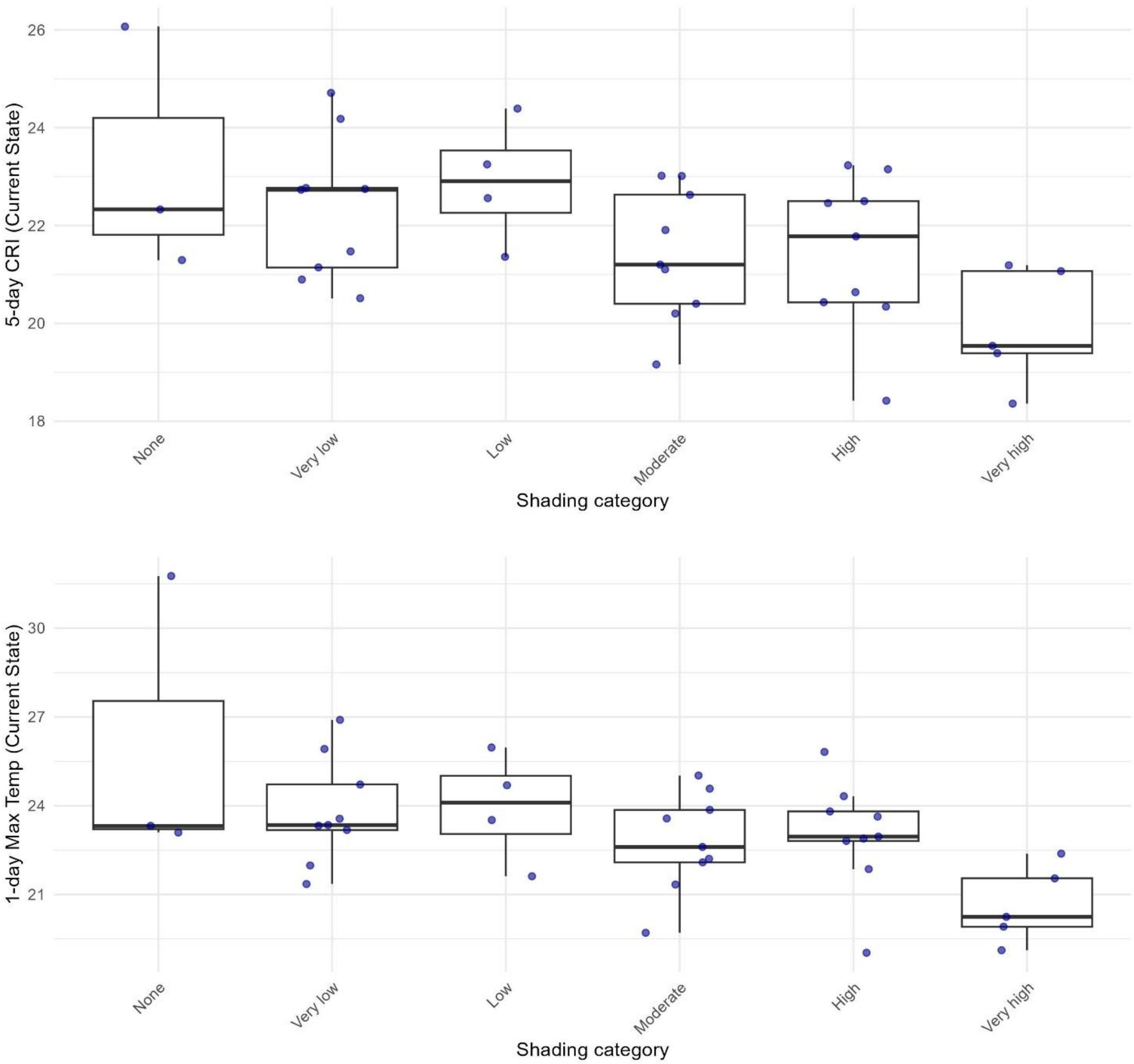


Figure 10. Box-plots of current state a) 5-day CRI and b) daily maximum temperatures by shading category of the stream.

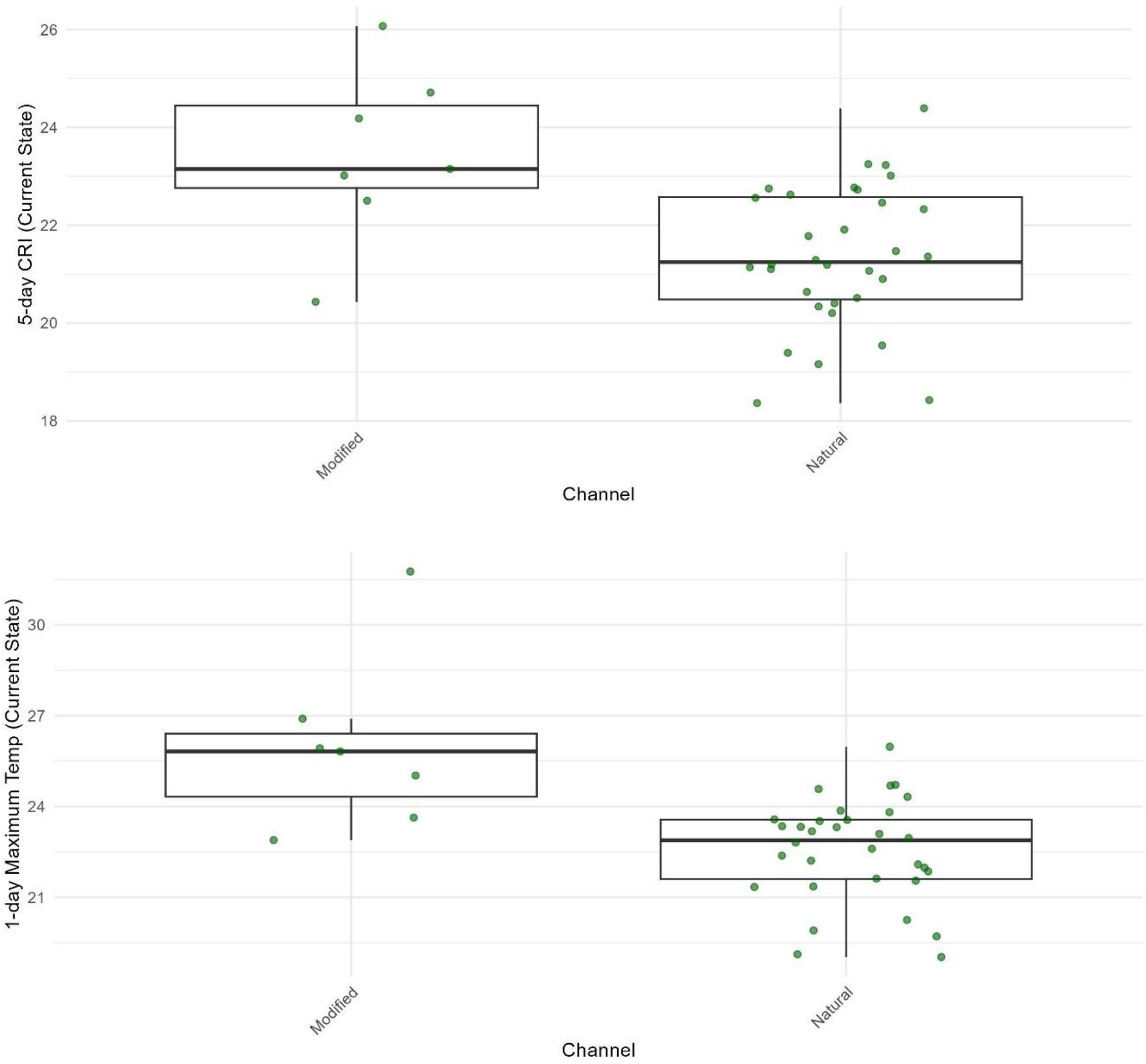


Figure 11. Box-plots of current state a) 5-day CRI and b) daily maximum temperatures by the channel type.

3.3 Comparing discrete vs continuous instream temperature assessment

There is ongoing debate about whether discrete monthly temperature measurements are sufficient for robust assessment of stream temperature attributes. Clapcott et al. (2015), based on an assessment of 36 State of the Environment monitoring sites in Auckland, concluded that discrete monthly measurements are not sufficient, as they tend to overestimate ecological health by missing the five hottest days of the year. In contrast, Wilding (2024) suggests that discrete measurements can be used to provide greater site coverage with adequate resolution to detect streams with elevated temperatures. As a preliminary assessment of the adequacy of discrete measurements for assigning temperature attributes, we analysed streams where continuous temperature data were collected at the same locations and on the same day as the long-term discrete monthly measurements.

Site by site comparison

Site-specific linear regressions showed generally strong relationships between daily maximum temperatures (derived from continuous data) and discrete monthly measurements, with R^2 values generally ranging from 0.72 at Vaughan stream to 0.97 at Waiwera Stream with Mahurangi River being an outlier (R^2 = 0.47) (Figure 12). Discrete monthly measurements were typically lower by 1 to 5 ˚C than the corresponding daily maximum temperatures recorded by continuous loggers, except at the Rangitopuni River site, where discrete values were slightly higher at the upper temperature range (Figure 12). This site anomaly may reflect slight differences in the locations and depths of the continuous logger and the spot measurement. The slope of the relationship between continuous and discrete measurements varied between sites, with some sites (e.g. Wairoa Tributary) showing closer agreement at higher temperatures, while other sites (e.g. Makaurau River) aligned better at lower temperatures.

The relationship between CRI (derived from continuous data) and discrete temperature measurements was even stronger, with R^2 values ranging from 0.65 at Mahurangi River to 0.98 at Onetangi and Waiwera streams (Figure 13). CRI could be estimated more reliably from discrete data at sites with a higher R^2 value. At several sites (e.g. Wairoa River, Oteha River, and Kaukapakapa River), CRI and discrete temperature values closely aligned along the 1:1 line, suggesting that discrete measurements provide a direct approximation of CRI on the day that temperature was measured. However, at other sites, notably Whangamaire Stream and Mahurangi River, CRI values remained more than 2 °C higher on average than the discrete measurements. .

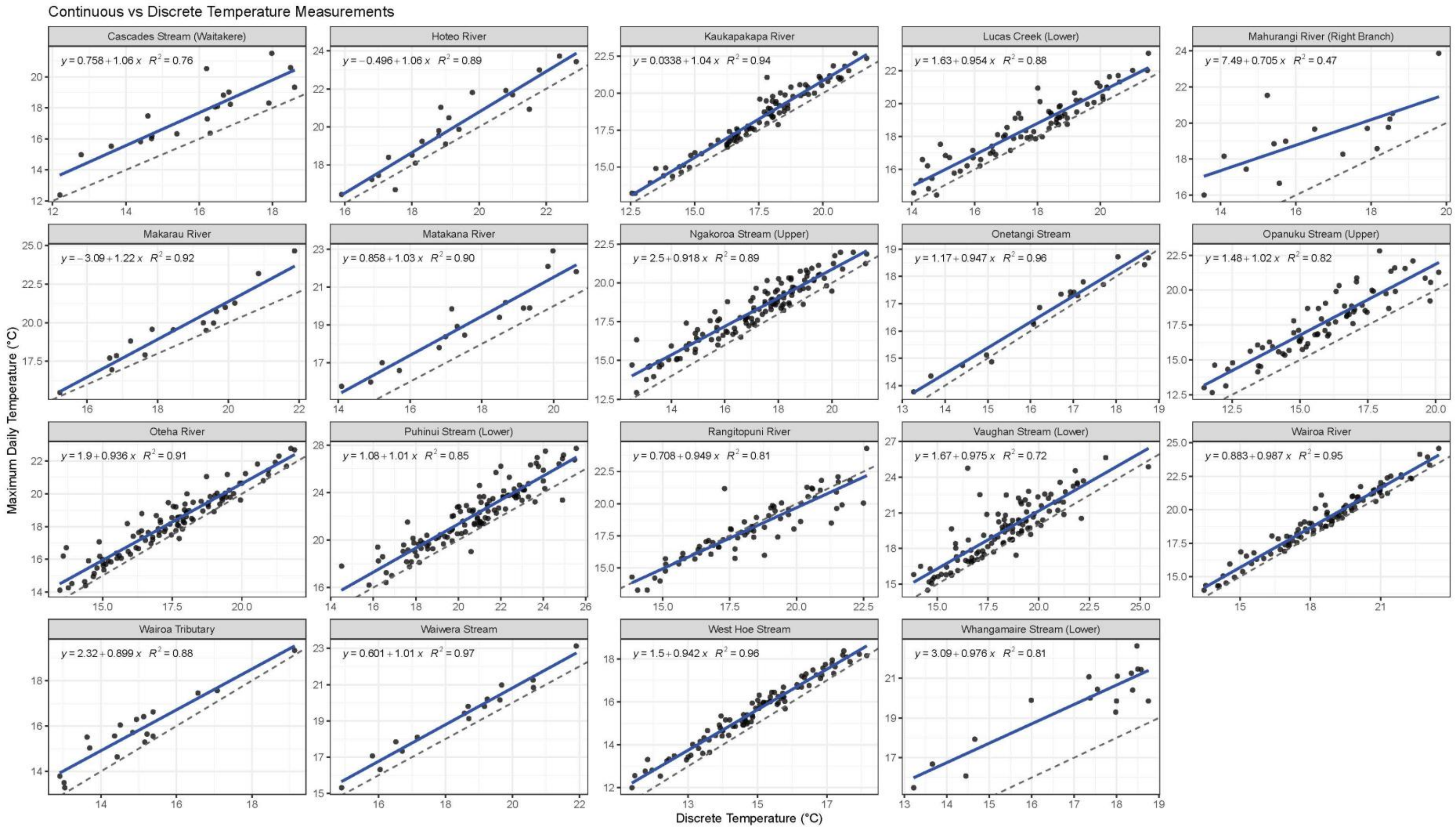


Figure 12. Site by site relationship between daily maximum temperature based on continuous records and the discrete measurements taken on the same day. Blue solid line indicates the fitted linear trend; dashed line indicates the 1:1 reference line.

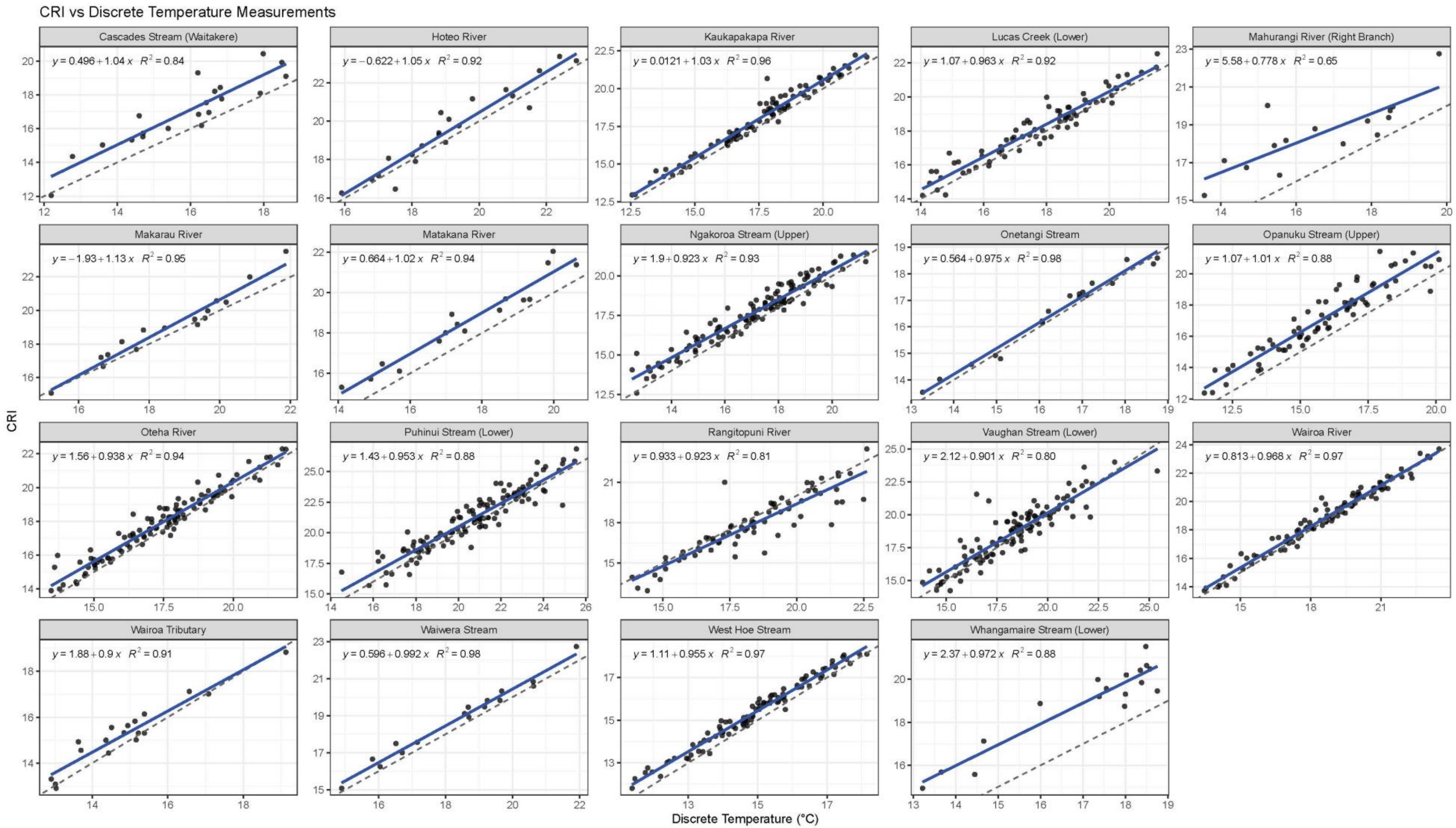


Figure 13. Site by site relationship between 5-day CRI based on continuous records and the discrete measurements taken on the same day. If the discrete data matched same-day CRI value, the points would lie on the dashed 1:1 line. A regression was fitted to the data (blue line).

Annual data comparison in relation to NPS-FM regional attribute bands

Annual maximum temperatures derived from discrete measurements were, on average, 3 °C lower than those calculated from continuous records (Figure 14a). With the maximum temp metric, there were two streams identified as failing (either once or twice) using discrete data. With the continuous data, the same two streams were identified, but these more regularly fell below the bottom line. In addition, a further three sites fell below the regional bottom line on at least one occasion. A similar pattern was observed for band classification, with a significantly greater number of streams graded in band C based on continuous data than on discrete measurements. Notably, only one stream (West Hoe) was graded in band A in multiple years based on continuous data, whereas several streams were graded as band A in multiple years using discrete measurements. The variability in the grading between the two datasets was considerable, with the rural Hoteo River and the native forest Cascades Stream graded in band D according to continuous data yet graded in band A based on discrete measurements. The largest difference between annual maximum temperatures from the continuous and discrete datasets exceeded 7 °C for the Hoteo River (Figure 14a).

When comparing CRI band grades derived from continuous data against discrete maximum temperature measurements (Figure 14b), a similar overall pattern was observed. More streams were placed in lower (poorer) bands when using continuous CRI values than when using discrete temperature measurements.

This preliminary assessment highlights the potential misclassification of grades for the temperature attribute when relying solely on discrete monthly measurements. Although it may be possible to apply a correction factor to discrete data to enable grading of the temperature attribute based on discrete measurements, as suggested by Wilding (2024), further statistical analysis and model development would be required to provide a robust approach for temperature attribute implementation.

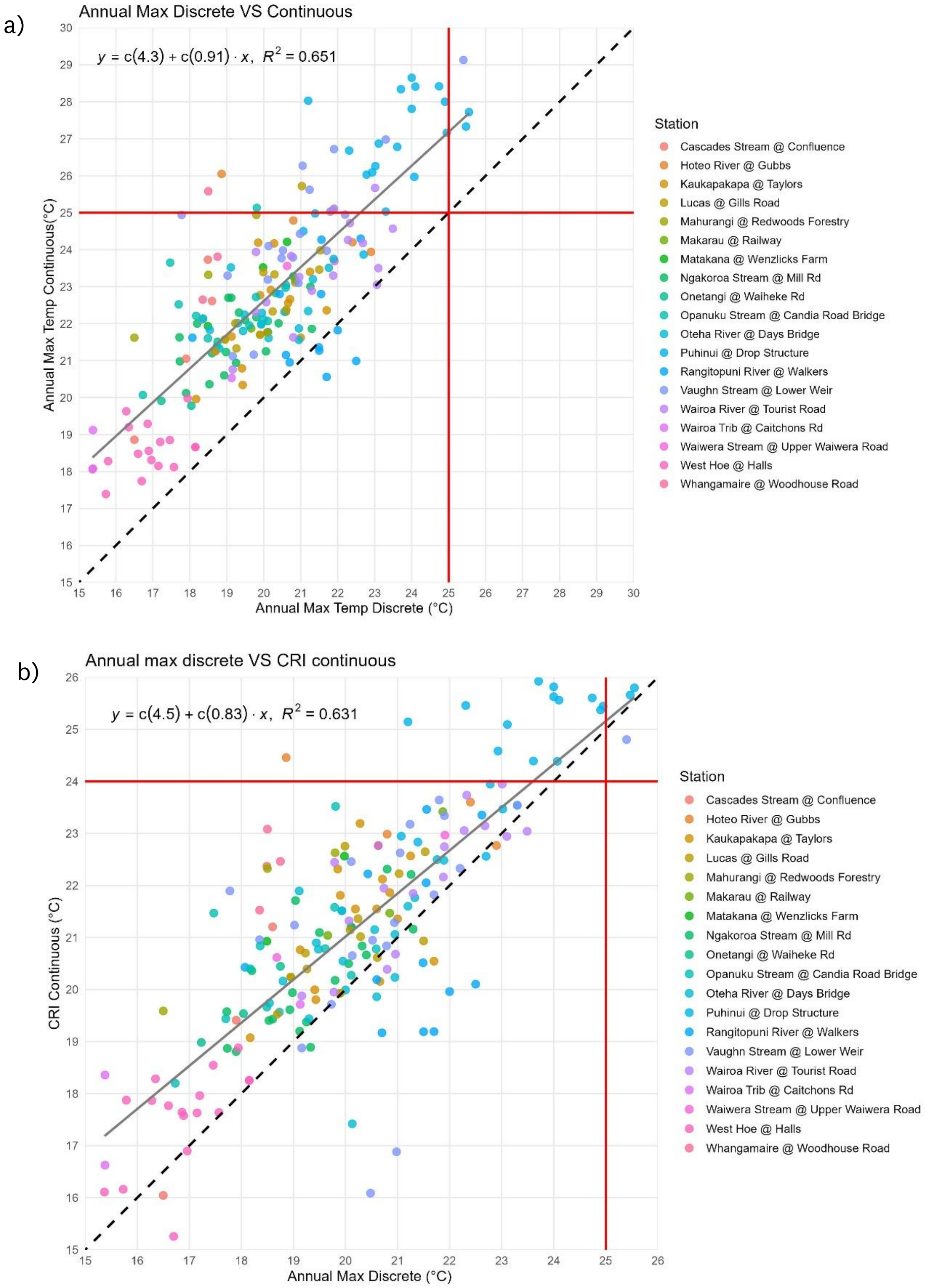


Figure 14: Annual maximum temperature (a) and CRI (b) based on continuous data vs discrete annual maximum temperatures. The red lines indicate regional bottom line (band D).

4. Conclusions and Future Directions

This report builds on the 2023 baseline state assessment by expanding both data coverage and analytical confidence (Auckland Council, 2023). Since the previous assessment, additional years of monitoring data have been incorporated, allowing a greater proportion of sites to meet minimum data requirements for robust state evaluation. Several FMUs and land-cover categories that were previously data-limited are now better represented, reducing spatial and thematic gaps identified in the 2023 assessment. In particular, the previous baseline assessment included no representation from exotic forest land cover and only a single native forest site used as a reference, whereas the current assessment incorporates a broader range of forest land-cover types. As a result, this report provides a more comprehensive and reliable baseline against which future change can be assessed, while maintaining methodological consistency with the previous assessment to ensure comparability over time.

This regional assessment highlights that most Auckland streams currently experience moderate to high levels of thermal stress, with few sites maintaining conditions suitable for the most temperature-sensitive species (e.g. sensitive insects and fish) year-round. The predominance of B and C bands, and several sites falling below the proposed regional bottom line, indicate that urbanisation and/or loss of riparian shading may already be negatively influencing stream communities through increased thermal stress. Continued warming driven by land development and climate change will likely intensify these pressures, reducing habitat suitability for native fish and invertebrates and further altering stream community composition.

Given these findings, maintaining continuous high-frequency temperature monitoring should remain a priority. The comparison with discrete data confirms that monthly sampling cannot capture short-term heat extremes. Future work could focus on developing correction models to enable use of discrete temperature data where continuous records are unavailable, ensuring consistency across monitoring programmes. The development of robust models would enable the inclusion of a further 30 streams in the regional assessment of temperature regimes, helping to identify areas where thermal stress may currently be overlooked.

To mitigate future warming, management actions should focus on riparian restoration of stream and the avoidance of channel hardening in both rural and urban settings. Urban design must increasingly integrate WSD principles and expand riparian buffers to counteract the heat-retaining effects of impervious surfaces within connected catchments.

Looking forward, predictive modelling of stream temperature under future land-use and climate scenarios could help identify catchments most at risk and guide targeted restoration and policy interventions. Incorporating projected increases in greenhouse gases, shading potential, and hydrological change into such models would support proactive management and adaptation planning.

Ultimately, improving the region's stream temperature grades will require sustained commitment across local government, urban planning and development, infrastructure and stormwater management, and catchment restoration, alongside long-term monitoring to track the effectiveness of mitigation measures as Auckland continues to grow and the climate continues to warm.

5. References

Arismendi, I., Johnson, S. L., Dunham, J. B., and Haggerty, R. O. Y. (2013). Descriptors of natural thermal regimes in streams and their responsiveness to change in the Pacific Northwest of North America. *Freshwater Biology*, *58*(5), 880-894.

Arrington KE (2003). Tools to support the protection of cold water streams from the thermal impact of development in Dane County, Wisconsin. M.S. Thesis. University of Wisconsin, Madison

Arseneau D, Weber S, Scheidel AE, Walker RR, Tufgar RH, Cartwright PJ (2010). Evaluating Temperature Impacts of Stormwater Management Ponds: A Case Study of the Hanlon Creek Business Park. *4th International Conference on Natural Channel Systems*

Auckland Council (2023). Baseline state evaluation: ecosystem health and human contact values. NPS-FM 2020 plan change implementation, October 2023.

Bonacina, L., Fasano, F., Mezzanotte, V., and Fornaroli, R. (2023). Effects of water temperature on freshwater macroinvertebrates: a systematic review. *Biological Reviews*, *98*(1), 191-221.

Clapcott JE, Afoa E, Young D (2015). Towards a temperature attribute for Auckland streams. Prepared for Auckland Council. Cawthron Report No. 2751. 27 p. plus appendices.

Cox, T. J., and Rutherford, J. C. (2000). Thermal tolerances of two stream invertebrates exposed to diurnally varying temperature. *New Zealand Journal of Marine and Freshwater Research*, *34*(2), 203-208.

Davies-Colley R, Franklin P, Wilcock B, Clearwater S, Hickey C (2013). National Objectives Framework - Temperature, Dissolved Oxygen & pH, Proposed thresholds for discussion. Prepared for Ministry for the Environment. NIWA Client Report No: HAM2013-056.

Herb WR, Janke B, Mohensi O, Stefan HG (2009). Runoff Temperature Model for Paved Surfaces. *Journal of Hydrologic Engineering*, 14(10): 1146-1155

Ingley, R., Dikareva, N. and Gadd, J. (2025). River water quality current state and trends in Tāmaki Makaurau / Auckland to 2024. State of the environment reporting. Auckland Council technical report, TR2025/20

Johnson, S. L. (2004). Factors influencing stream temperatures in small streams: substrate effects and a shading experiment. *Canadian Journal of Fisheries and Aquatic Sciences*, *61*(6), 913-923.

Johnson, M. F., and Wilby, R. L. (2015). Seeing the landscape for the trees: Metrics to guide riparian shade management in river catchments. *Water Resources Research*, *51*(5), 3754-3769.

Le Blanc RT, Brown RD, FitzGibbon JE (1997). Modeling the Effects of Land Use Change on the Water Temperature in Unregulated Urban Streams. *Journal of Environmental Management,* 49: 445-469

McBride G. 2016. National Objectives Framework – Statistical considerations for design and assessment. Hamilton: National Institute of Water and Atmospheric Research. NIWA Client Report No. HAM16022. Prepared for Ministry for the Environment.

Mills, G.N., and Williamson, R.B. (2008). The Impacts of Urban Stormwater in Auckland's Aquatic Receiving Environment: a review of Information 1995 to 20005. Prepared by Diffuse Sources Ltd and Geosyntec Consultants for Auckland Regional Council. Auckland Regional Council Technical Report 2008/029.

Ministry for the Environment (2024). Guidance on the National Objectives Framework of the NPS-FM. Identifying attributes and their baseline states, or other criteria for assessing achievement of environmental outcomes under clause 3.10 of the National Policy Statement for Freshwater Management 2020. https://environment.govt.nz/publications/guidance-on-the-national-objectives-framework-of-the-nps-fm/clause-3-10

National Environmental Monitoring Standards (NEMS) (2019). NEMS Water Quality Part 2 Sampling Measuring Processing and Archiving of Discrete River Water Quality Data v1.0.0

Nelson, K. C., and Palmer, M. A. (2007). Stream temperature surges under urbanization and climate change: data, models, and responses 1. *JAWRA journal of the American water resources association*, *43*(2), 440-452.

New Zealand Institute of Landscape Architects (2019). https://www.nzila.co.nz/showcase/vaughans-stream-corridor-long-bay

Olsen DA, Tremblay L, Clapcott J, Holmes R (2011). Water Temperature Criteria for Native Aquatic Biota. Prepared for Auckland Council, Environment Waikato and Hawkes Bay Regional Council. Cawthron Report No. 2024

Pluhowski EJ (1970). Urbanization and Its Effect on the Temperature of the Streams on Long Island, New York. *Geological Survey Professional Paper,* 627-D

Posit team (2025). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. URL http://www.posit.co/

Quinn, J. M., Croker, G. F., Smith, B. J., and Bellingham, M. A. (2009). Integrated catchment management effects on flow, habitat, instream vegetation and macroinvertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research*, *43*(3), 775-802.

Quinn, J. M., and Hickey, C. W. (1990). Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand journal of marine and freshwater research*, *24*(3), 387-409.

Quinn, J. M., Steele, G. L., Hickey, C. W., and Vickers, M. L. (1994). Upper thermal tolerances of twelve New Zealand stream invertebrate species. *New Zealand Journal of Marine and Freshwater Research*, *28*(4), 391-397. https://doi.org/10.1080/00288330.1994.9516629

R Core Team (2025). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>

Richardson, J., Boubée, J. A. T., and West, D. W. (1994). Thermal tolerance and preference of some native New Zealand freshwater fish. *New Zealand Journal of Marine and Freshwater Research*, *28*(4), 399-407. https://doi.org/10.1080/00288330.1994.9516630

Roa-Espinosa, A., Wilson, T.B., Norman, J.M., Johnson, K. (2003). Predicting the impact of urban development on stream temperature using a thermal urban runoff model (TURM). *Proceedings of the US EPA National Conference on Urban Stormwater: Enhancing Programs at the Local Level, Chicago, IL*, 369-389. National Risk Management Research Laboratory, Cincinnati, OH

Rutherford, J.C., Davies-Colley R.J., Quinn J.M., Stroud N.J., Cooper A.B. (1997). Stream Shade: Towards a Restoration Strategy, DoC report.

Rutherford, J.C., Haidekker, S., Matheson, F. E., and Hicks, A. (2023). Modelled effects of channel orientation and tree canopy shape on average shade in streams. *New Zealand Journal of Marine and Freshwater Research*, *57*(1), 22-46.

Smith, D. (2006). Stormwater Temperature Monitoring in Federal Way, WA. Published online by Stormwater: The Journal for Surface Water Quality Professionals, http://www.erosioncontrol.biz/SW/Articles/Stormwater_Temperature_Monitoring_in_Federal_Way_W_133.aspx

Snelder, T., Biggs, B., Weatherhead, M. (2004). *New Zealand River Environment Classification User Guide*. Ministry for the Environment, Auckland.

Storey, R.G., Neale, M.W., Rowe, D.K., Collier, K.J., Hatton, C., Joy, M.K., Maxted, J. R., Moore, S., Parkyn, S.M., Phillips, N. and Quinn, J.M. (2011) Stream Ecological Valuation (SEV): a method for assessing the ecological function of Auckland streams. Auckland Council Technical Report 2011/009.

Steel, E. A., Beechie, T. J., Torgersen, C. E., and Fullerton, A. H. (2017). Envisioning, quantifying, and managing thermal regimes on river networks. *BioScience*, *67*(6), 506-522.

Wilding T. (2024). Developing monitoring attributes for oxygen and temperature in rivers. Waikato Regional Council Internal Series 2023/28.

Young, D., Afoa, E., Meijer, K., Wagenhoff, A., Utech, C. (2013). Temperature as a contaminant in streams in the Auckland region, stormwater issues and management options. Prepared by Morphum Environmental Ltd for Auckland Council. Auckland Council technical report, TR2013/044

Young R, Casanovas P, Cervantes Loreto A, Kamke J, Fraser S. (2025). Dissolved oxygen and ecosystem metabolism in Auckland rivers: 2020-24. Nelson: Cawthron Institute. Cawthron Report 4111. Prepared for Auckland Council.

Appendix 1: Standard operating procedure for temperature data processing

Standard Operating Procedure

Environmental Evaluation and Monitoring Unit - Hydrology

Subject	Processing Temperature Data
Version	1
Category	Data Processing
Date	19/03/2025
Person responsible	Matt Wright

Scope

This SOP is designed to explain the procedure for processing temperature data collected at water-level monitoring sites.

Applicable Standards

NEMS for Water Temperature Recording Version 2.0 – we adopted NEMS in 2023. Data has been back processed from the start of 2021 to comply with NEMS.

Inspections are completed at least every two months. To meet the requirements for QC10 (QC600 NEMS) the data must be recorded at a maximum of 15-minute intervals and be within 0.8 degrees of the manual temperature reading taken on-site during inspection. If the sensor is between 0.8 and 1.2 degrees different from the manual temperature reading, the data is coded as QC20, and if the difference is above 1.2 degrees the data is coded as QC42.

If the sensor is outside of tolerance for two site visits in a row, there is something wrong with the sensor placement or the sensor itself. Check for changes to the placement of the sensor or to the surrounding environment. If the location is still ok, the sensor will need to be removed from site and replaced with a new one, then bench tested and/or retired.

Resources Overview

HYDSTRA Programs

HYDMWB (Data Managers Workbench): This tool is used for processing the data in HYDSTRA.

SITE (Manage Site Related Tables): This tool is used to find information on inspections, gauging, site information, site history and instrumentation.

Hazards

n/a

Initial Setup/Preparative Work

Temperature Data Variables

450.00 – Water Temperature (degrees Celsius) *(Processed Temp)*

450.20 – Water Temperature (degrees Celsius) – Water Temp manual Deg C

450.60 – Water Temperature (degrees Celsius) – Primary Raw Temperature *(Raw Temp)*

Collecting Preliminary Information

Open *SITE (Manage Site Related Tables).*

Select *search tool* -> enter the site number -> *OK* (the site will now be opened).

Click *HISTORY* (this contains the record of site inspections, sensor validations, and surveys completed at the site, which are imported from GoCanvas forms).

Use the 'toggle tool' to open columns of records, click on the HISTORY tab to navigate to the most recent inspection.

Click on a record to highlight it, Use the 'toggle tool' again to open that specific record.

Under the ***Text*** column click to see the text from the record. Take note of the following:

The time/date at which the inspection was completed.

The time/date that the previous inspection was completed (this determines the processing 'block' between inspections).

If there are two inspections for one site visit, we process from the first inspection (of the previous site visit) to the first inspection of the next site visit.

Multiple ‘blocks’ can be processed at once during processing, but these will be split and processed independently.

The manual/reference and logger temperature values. The error (between reference and logger temperature sensors) for both inspections must be within 0.8 degrees to meet the requirements for QC10/QC600. If this site temperature sensor is out of tolerance, the quality code of the data will be decreased.

Method

Creating working files for processing

Open *HYDMWB (Data Managers Workbench)*

Use the ‘open a file’ tool  and enter the site number to open its suffixes.

The blue file with the A is the archive folder. Select the archive folder and use  to make a copy, Label this as ‘chosen suffix letter’ (this is the Archive-copy).

Create a copy of the *TELEM* (telemetry file), two options:

Select the archive folder and use  to make a copy, Label this as an ‘appropriate suffix letter’ (this is the TELEM-copy), this file used to isolate the data of interest and make any changes needed.

OR

HYFILER can be used to both create a copy of the TELEM and also split the data variables at the required time/date (this saves doing this individually).

Open *HYXPLORE* -> HYFILER

Command: SUBSET

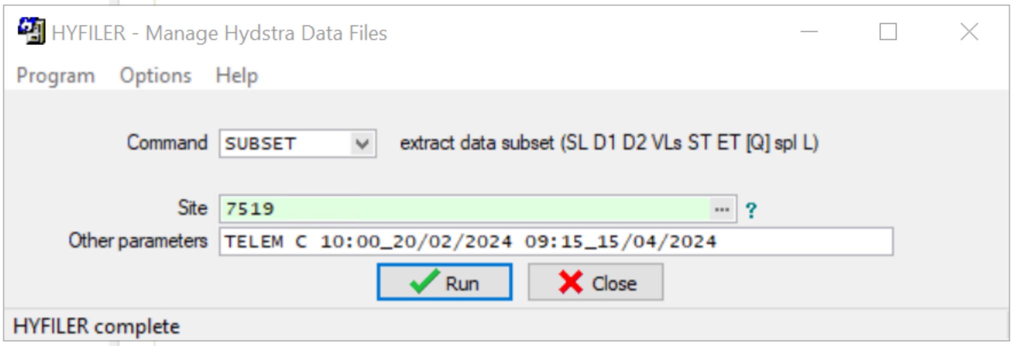
Site: Enter site number (e.g. 7519)

Other parameters: Enter *TELEM* (a copy is being created of this data), the chosen suffix letter for TELEM-copy (e.g. C), start split time/date

(e.g. 10:00_20/02/2024), end split time/date (e.g. 09:15_15/04/2024)

For date/time it is best to put a buffer of 15mins on either end of the intended split as *HYFILER* can sometimes exclude data.

The example below shows the window with the required information:



Press *Run* -> There will now be a TELEM-copy file in the data workbench which is already split at the required times. If the site workbench is already open, *Refresh Workbench* will be required for the new suffix to appear.

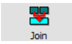
Open the 'Archive-copy' file – all the variables from this site will show up, take note of the last processed date and make sure this is the same as the spreadsheet.

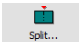
You now have a 'Archive-copy' and 'TELEM-copy' ready for processing.

450.20 – Water Temperature (degrees Celsius) – Water Temp Manual

Generally, it is best to process the manual temperature first (450.20).

Open the 'TELEM-copy' file and open 450.20 (manual measurements, these will have auto auto-transferred via GoCanvas).

Select the *Blocks* menu at the top of the page -> *Select all* (this will highlight all the blocks) -> click *Join*  (now there will be one data block remaining).

Click the top block and click *Split*  -> use the last archived-time as the first split time and use the most recent inspection being 'processed to' as the end split time.

Note: If *HYFILER* was used initially to split the data this step may not be necessary.

After splitting the blocks, delete the blocks that are not required. There should be one block remaining. Remember these are discrete measurements.

In the *Text* tab check that each manual reading has come through correctly from GoCanvas. Occasionally, points can be duplicated or don't transfer into HYDSTRA correctly. The *Edit Point*  tool to adjust the value in the *Sample* tab if it is not correct. Note: It is important to ensure the value is changed to the value from the form (*Comments/History*).

In the *Blocks* tab select the block and click *Adjust* . Tick the box *Change Qualities* and in the dropdown under '*To'* change it to QC10. Manual temperature readings are usually QC10 as these are one-off field observations in the field and should be accurate.

Note: If there is a suspected bad reading/manual sensor is out of validation the QC will be lowered to QC20.

Quit and Save.

450.60 – Water Temperature (degrees Celsius) – Primary Raw Temperature

Open the 'TELEM-copy' file and open 450.00. There is a lot more data as these are continuous temperature measurements.

Select the *Blocks* menu at the top of the page -> *Select all* (this will highlight all the blocks) -> click *Join* (This will lower the number of blocks) -> delete the blocks that are not needed.

Note: If *HYFILER* was used initially to split the data, this step may not need to be completed.

There will be a number of blocks remaining. These blocks need to be split into processing blocks between each site visit (from first inspection to first inspection). Therefore, there may be a few lines of blocks for each 'processing block'.

Click the top block and click *Split* -> use the last 'archived time' as the split time. Click the bottom block and click *Split* -> use the time of the first inspection of the next site visit. Repeat (if needed) for the following site visits (remember: first inspection to first inspection). Delete any data outside of the processing blocks.

Close and Save 450.00.

Select 450.00 and click *Copy* *,* then select *Paste* . A *Paste Options* window will appear, select *Change Sub Variable to* and enter the value 60. This will create a 450.60 file (Water Temperature (degrees Celsius) – Primary Raw Temperature).

Note: The copy-and-paste method is a bit of a cheat method for changing the variable. Another method to complete a similar process is to export the data which is described under *How to Process Rainfall Data* in Operations Help.

450.00 – Water Temperature (degrees Celsius)

Deleting points/spikes (brief gaps)

Remove spikes/abnormal values (if appropriate!).

Zero/spike values (generally caused by instrument issue/ site losing power) or anomalies (temperature sensor being removed from the stream for maintenance) can scale the data and make it difficult to visualize the data trace, therefore, it is often useful to start by removing these values.

Selecting values:

Select mode to select the points of interest.

Region select can be used to highlight multiple points by dragging over points.

The arrows to move the selection left/right.

The arrows to extend the selection (add another point) left/right.

To remove numerous points at once (e.g. daily 12:00 data spikes) -> *Points* -> *Find...* -> in the *Text to find* box, enter the time (e.g. 12:00:00) -> For *Stop after selecting* choose *All matches.*

The *clear selection* tool can be used at any time to unselect selected points.

Deleting values:

Generally, when only a few data points are being deleted (accumulating to less than an hour's worth of data), these can be deleted without needing to split or gao the data. A box will appear, put in a brief comment as the reason for the deletion (e.g. zero spike deleted during site losing power). A line will automatically be linearly interpolated over the deleted points. This is allowed by NEMS as it is defined as a 'brief gap'. The QC for this interpolated period can be retained to match the rest of the block.

Note: This is only appropriate if the points being deleted don't occur over a natural peak/diurnal cycle, otherwise, synthetic data may be required instead (refer to *Water Temperature Gaps).*

Adding reference water level and rainfall traces

Now that spikes and zero values have been removed from the data you can now check the data against reference water level and rainfall traces.

Return to SITE (Manage Site Related Tables) and go to the STNINI sub-menu. There is a *RAINSTN* row and under the *Text* column, there is a site number for nearby rainfall sites. Take note of these.

You will also add the water level for the site being processed as a trace.

Open 450.00 and the *Graphics* tab. Right click on the graph -> *Open Reference Trace ->* a window will appear. Change the following:

Site ID: The neighbouring site ID

Datasource: AT

Make sure data numbers are 100.00 (WL) and 10.00 (RF)

Under scaling select *Automatic (separate)*

Everything else stays the same, press *OK*

Note: You can right-click on the graph -> *View Reference Traces* to enable and disable traces on the graph.

There will now be multiple rainfall sites and water level sites to compare your temperature record to.

Zoom into a 7-day period and scroll through the data using this rolling 7-day period. Check for spikes and inconsistencies, delete spikes and inconsistencies as needed. Some example scenarios are provided below:

Temperature and Rainfall: Temperature can spike down straight after rainfall, but then the water temperature usually warms up. This is usually because it warms up as water from roads/stormwater enters the stream/river. Just make sure there is rainfall associated with temperature spikes.

Diurnal Temperature Cycles: Water temperature will usually follow a diurnal cycle (especially if the site is exposed to sunlight).

If there are issues with your data which are resulting in large gaps, refer to the water temperature gaps.

Processing Comment

Comment when no adjustments are required

Highlight the most recent inspection -> click *Edit Point* . A window will appear and then click *Add Standard Comment* -> *Processing Temp and DO* -> fill in the missing values and information (e.g. Data 15/04/2024 @ 13:30:00 to 13/05/2024 @ 13:00:00 checked for spikes and inconsistencies. Commented throughout as appropriate. No further adjustments made.) -> ***Add Timestamp*** -> OK.

If there are any reoccurring trends in the data, it could be worth noting this in the processing comment. This would act as a blanket comment for the block and avoid too many repetitive comments throughout the block.

Note: If any significant adjustments must be made to the block, follow the steps below. This will change the processing comment required.

QCing Temperature Data

In the *Blocks* tab select your remaining block and click *Adjust* . Tick the box *Change Qualities* and in the dropdown under *To* change it to the appropriate QC. To check the QC has changed, the line should be blue (QC10)/ red (QC20) in the *Graphics* tab.

Note: Each site has a maximum QC that the data can be coded based on NEMS conditions. The max QC of a site will usually remain the same unless some changes are made to the site (e.g. removal of trees). Refer to the most recent annual inspection performed at the site to identify the max QC.

Water Temperature Gaps

If there are an hour or more worth of data that must be removed, the resulting gap must be filled with back up data or estimated/synthetic data.

Backup temperature data

If possible, the best method for infilling temperature gaps is by retrieving temperature data from another sensor at the same site, i.e. a pressure transducer or IQ.

In 450.00, split the data either side of the area you want to gap. Delete this block. Exit this working file and save.

Check if temperature data from the backup sensor is coming into Hydstra by going back into your working file (TELEM copy) and checking for variable 450.10 – Water Temp Backup DegC.

If variable 450.10 is present:

Export it to a new working file with a different suffix. Go into the new suffix -> go into 450.10 -> split the block at the same times as the boundaries of the gap you want to fill in 450.00. Delete all data on either side of this block. Exit and save.

Select 450.10 and click *Copy* , then select *Paste* . Select *Change Sub Variable to* and enter 00. This will create a 450.00 file. Delete the 450.10 variable. You should now have only 450.00 in this working file, which contains only the short block of data required to fill the gap. Drag this suffix into your primary working file (TELEM copy) to fill the temp gap in 450.00.

You will now have a data discontinuity in 450.00. Edit the values of the boundary data points for the block you just used to fill the gap. These should match the value of the last good boundary point from the primary temp sensor.

Note: only edit the value of the boundary point, do not ramp or adjust the infilled block as it will change the value of all the points.

QC the data used to fill the gap based on the quality of the temperature data collected by the backup sensor (i.e. check the backup temp data on Hydrotel at the time of a site inspection with a reference probe check. Use the NEMS water temperature tolerances to determine the QC of the backup sensor data (remember to factor in the max QC of the site).

Add a comment at the start of the infilled section:

'Data gapped from (date & time) to (date & time) due to _. Gap infilled with backup temperature data from (sensor type). QC for the period is _ due to _.'

Add a comment at the end of the infilled section to show data has returned to normal.

If variable 450.10 is not present:

You will need to retrieve the data from Hydrotel. Open the water temperature trace from the backup sensor in Hydrotel.

Check the 'Historic Mode' tick box and enter the date range of the data you want.

Right click on the graph -> Export -> Export samples for selected trace only -> save the CSV to your files -> No identifier required -> No QC required _> OK.

Find the CSV in file explorer and open. Combine the date and time columns into one column and enter the following equation in the cell above the new date and time column:

#time=dd/mm/yyyy hh:ii

In the cell above the temperature data column, enter the following equation, but adjust the site number to the one you require:

#site=8222,var=450.00,dt=1,qual=140,blanks=ignore

Open *HYCSVIN* in Hydstra and copy the two rows of data from your spreadsheet, including the two headings you just entered. Paste the data in *HYSCVIN*, this will send the data to the *data managers' workbench* under the suffix shown on the Hydstra home screen.

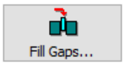
In *workbench*, drag the newly created suffix containing the Hydrotel data into the working file with the temperature gap.

Follow steps 6.5.1.3 c-f above to finish the process.

Linear interpolation of gaps

Linear interpolation can be used if the data you want to gap lie on a constantly increasing rise or decreasing fall (i.e. not spanning over a peak or trough).

Split the data on either side of the area you want to gap. Delete this block.

In the *Blocks* tab, highlight the block with the indicated gap and the block located below it. Select *Fill Gaps* 

tool, the *Fill Gaps* window will appear. Select *Fill with New Block* -> select the three dots, in the *Points Calculator* window:

Check the increment is correct (15 or 5 minutes).

Check that the start and end times are correct.

Click OK

Back in the *Fill Gaps* window, change the *Inserted Quality* to *40 (Estimated/Extrapolated Data).*

Note: This will cause a quality discontinuity as HYDSTRA will add a QC40 value at the start and end of the block (where real data is present). Change these to match the QC of the neighbouring real data point.

Add a comment: Select the point where the interpolation begins. Specify the time of the gap in the comments. '*Gap in data filled by linear interpolation from Date Time to Date Time.*'

Synthetic data

Synthetic data must be used to fill temperature gaps where backup data is unavailable and linear interpolation is not suitable (i.e. when the gap spans over an expected temperature peak or trough). If the gap is larger than 30 days, synthetic data is not suitable and the gap will remain.

Open *HYPLOTXY* in Hydstra to find the neighbouring temperature site with the best correlation.

Y-axis – Site with the gap you want to fill (Recipient)

X-axis – Site you want to check correlation with (Donor)

Data Source = A

VarFrom and VarTo = 450.0

Data Type = INST

Interval, Multiplier = 15

RUN

The correlation results will open on the Hydstra home page. Check the correlation coefficient. Rerun *HYPLOTXY* with a different donor site in the X-axis. Compare all neighbouring sites to identify the pair with the best correlation coefficient.

Open *HYCSV* in Hydstra to extract the data from the donor site.

Site number of donor site

Data Source A (Data from the donor site must be processed, checked and archived before being extracted. There can’t be any gaps or synthetic data in the during the period you are extracting from the donor site. Check this in *Data Manager's Workbench*).

VarFrom and VarTo = 450.00

Data Type = INST

Interval, Multiplier = 15 Minutes

Start of First Interval = Approx. 1 week before the start of the gap you want to fill

Start of Last Interval = Approx. 1 week after the end of the gap

Output File = Screen

Time format template = DD/MM/YYYY HH:II (Change this now to save future adjustments)

RUN

The output file will appear on the Hydstra home screen. Copy all and paste into an empty excel sheet. Highlight all the data -> Data -> Text to Columns -> Delimited -> Tick Comma -> Finish.

In the cell next to the first datapoint (C5), enter the correlation equation between the donor and recipient sites you have chosen. This will be on the Hydstra home screen. The equation in excel should look something like this:

*=0.911*B5-0.123*

Apply this equation to the rest of the data column.

In the cell above this new data column, enter the following equation, but adjust the site number to the recipient site:

#site=8222,var=450.00,dt=1,qual=140,blanks=ignore

Move the data & time column so it's adjacent to the new temperature data column and enter the following equation:

#time=dd/mm/yyyy hh:ii

Open *HYCSVIN* in Hydstra and copy the two rows of data from your spreadsheet, including the two headings you just entered. Paste the data in *HYSCV*, this will send the data to the *data managers' workbench* under the suffix shown on the Hydstra home screen.

Go back into *workbench* and open your working file -> 450.00 -> highlight the blocks that include the gap and a bit of data on either side -> Graphics -> Open Reference Trace. Make the datasource the suffix containing the donor data that was just imported -> Scaling = automatic.

Compare the reference synthetic temperature trace to the real temperature data on either side of the gap (approx. 1 week either side). Hover your mouse over the daily peaks and troughs on both traces to check values and times.

If the peaks and troughs tend to be within 0.5 °c of each other and follow a similar diurnal trend, the synthetic data is suitable to fill the gap and can be split, trimmed and dragged into this working file to fill the gap. If not, repeat steps 1-9 with an *Interval, Multiplier* = 1 hour and *Data Type* = Mean (instead of 15 minutes and INST). If the peaks and troughs still don't match up between the hourly mean synthetic data and the real data, discard all synthetic data and leave the gap.

You will likely now have a data discontinuity in 450.00. Edit the values of the boundary data points for the block you just used to fill the gap. These should match the value of the last good boundary point from the primary temp sensor.

Note: only edit the value of the boundary point, do not ramp or adjust the infilled block as it will change the value of all the points.

Add a comment. Use the synthetic temperature comment template and fill in the dates, donor site, equation R-squared value and time interval used. This comment goes before the synthetic block.

Add your working synthetic data spreadsheet to Hydstra docs so it is easier for the checker to assess.

Reference readings

Any reference temperature readings taken at inspections during the gapped period can be entered as a value using the text edit function.

Highlight the block of data on either side of the gap -> Blocks -> Text edit -> Insert -> Adjust date and time.

That point can be QC10 as it is measured with the reference probe.

Data between these real data points can be interpolated or synthesised.

Data Adjustments

Water temperature data is not to be ramped to the reference probe reading. This is because a linear adjustment would be applied to the data, when in reality, the data would drift in a non-linear way. Ramping may only be applied is if the in-situ sensor is removed from site and bench-tested against a reference probe over a range of water temperatures to identify a temperature rating curve that can be applied to the data.

Temperature data may only be adjusted if the difference between the logged temperature and the reference temperature reading is the same on both sides of the block. This way, a linear offset would be suitable.

When temperature readings from the in-situ sensor drift from the reference probe, it is evident that there is an issue with the sensor location or the sensor itself. Rather than ramping temperature data, the issue must be fixed at site. Check the placement of the sensor and its surrounding environment to ensure it is still suitable. If sensor placement is suitable, it is likely that the sensor is faulty and will need replacing, testing and servicing.

Additional Notes and References

https://www.nems.org.nz/documents/water-temperature-recording

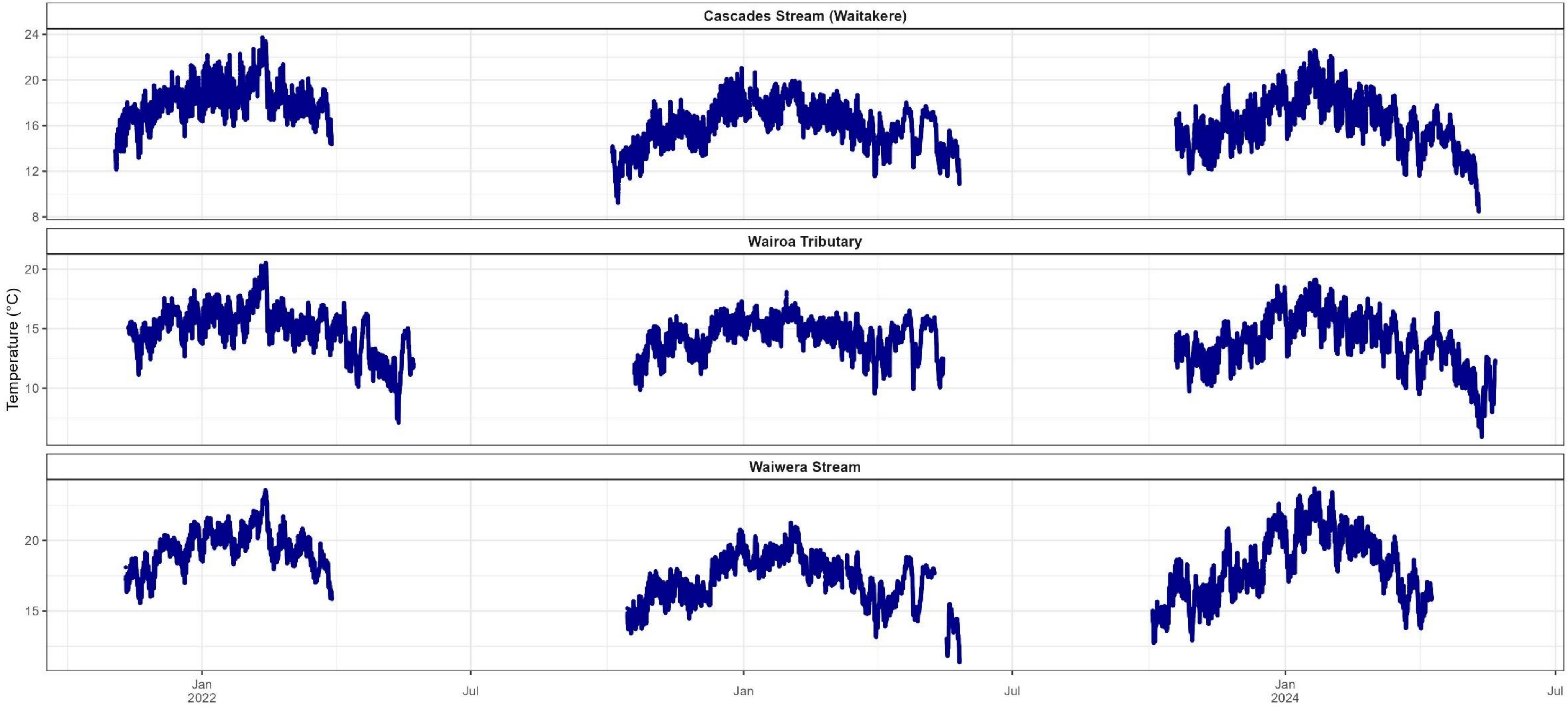
https://www.nems.org.nz/documents/data-processing

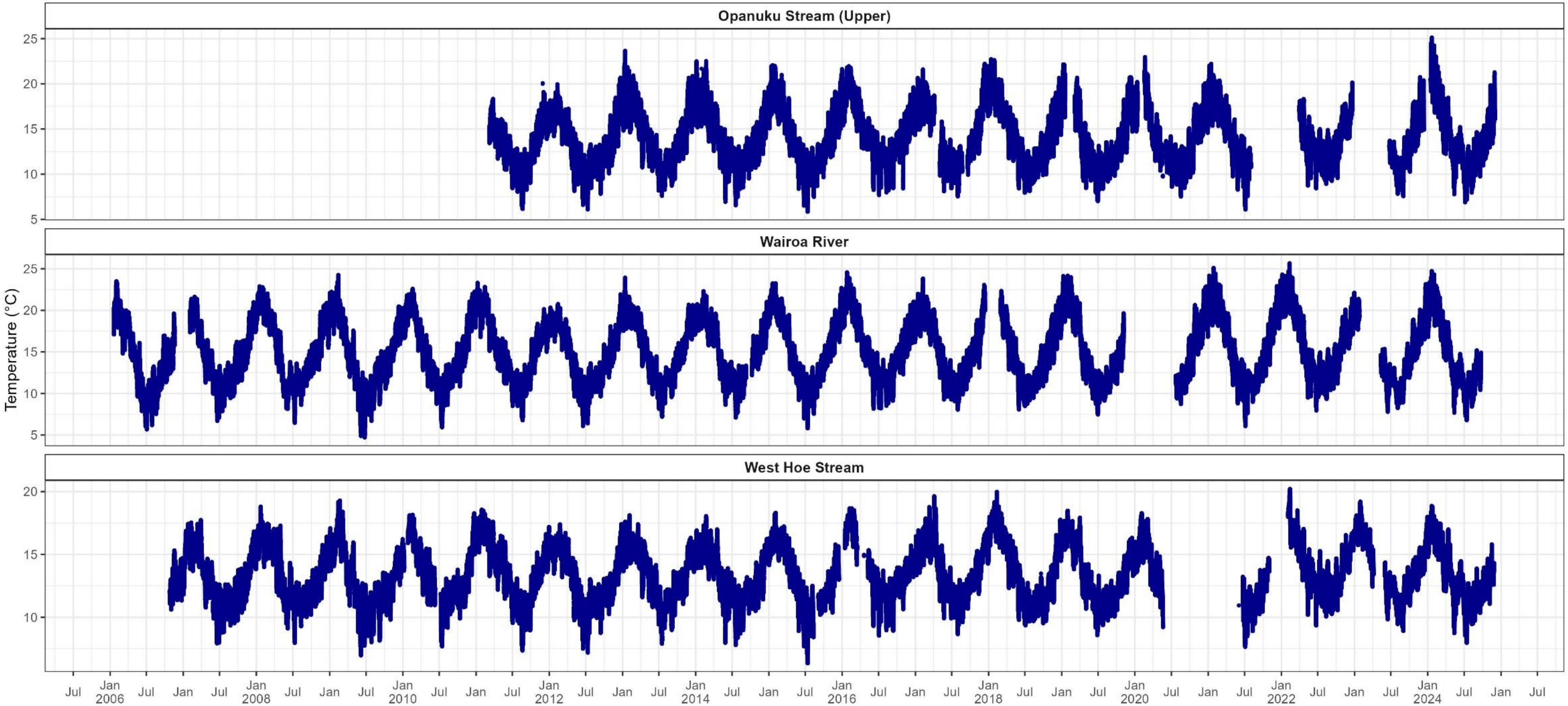
Appendix 2: Summary statistics over the full period of temperature record in Auckland streams

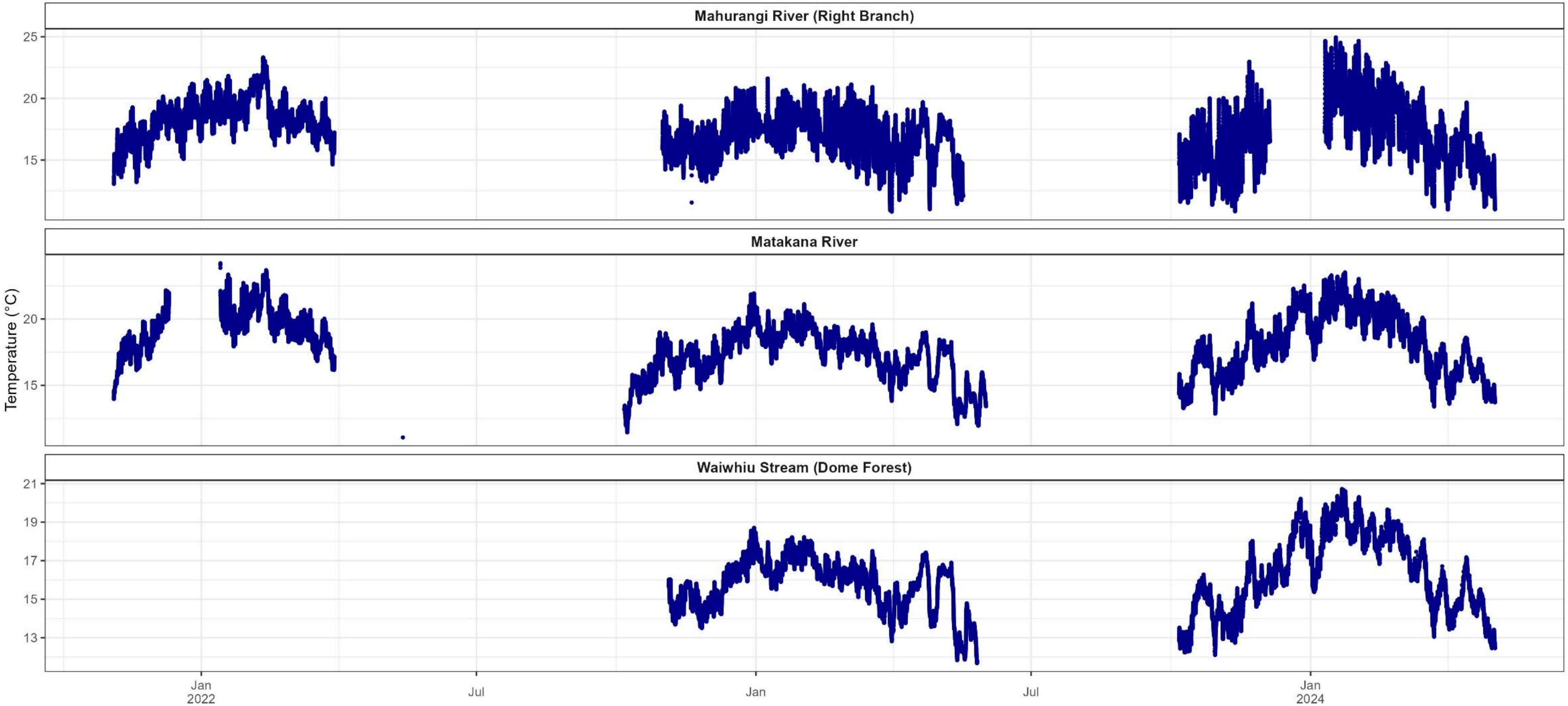
Stream name	No of observations	Max temp	Date max	Min temp	Date min	Mean temp	Median temp
Cascades	64639	23.7	10/02/2022	8.5	10/05/2024	16.2	16.3
Wairoa trib	59058	20.5	13/02/2022	5.9	12/05/2024	14.4	14.7
West Hoe	1076509	20.2	13/02/2022	6.3	13/07/2015	13.5	13.2
Mahurangi	49435	24.9	17/01/2024	10.8	31/03/2023	17.3	17.2
Waiwhiu	39447	20.7	21/01/2024	11.7	26/05/2023	16.0	16.0
Matakana	53523	24.2	13/01/2022	11.1	13/05/2022	17.9	18.0
Wairoa	556556	25.7	10/02/2022	4.7	24/06/2009	15.0	14.6
Waiwera	51806	23.7	20/01/2024	11.4	26/05/2023	18.1	18.1
Ōpanuku Upper	658130	25.1	21/01/2024	5.9	13/07/2015	14.0	13.6
Hōteo	593020	26.1	8/02/2009	6.2	13/07/2015	15.9	15.5
Kaipara	634985	25.2	18/02/2020	6.6	13/07/2015	15.1	14.8
Kaukapakapa	639308	24.2	12/02/2009	5.7	13/07/2015	14.9	14.7
Makarau	53393	25.1	21/01/2024	11.5	26/05/2023	17.8	18.0
Mangemangeroa	712103	22.3	10/02/2022	5.2	5/07/2021	13.8	13.6
Ngākōroa	802195	23.3	10/02/2022	5.6	12/07/2015	14.7	14.7
Rangitōpuni	608624	24.3	4/02/2020	5.7	13/07/2015	14.6	14.4
Te Muri	1918447	24.9	19/02/2017	5.8	13/07/2015	15.7	15.6
Waitangi	527404	26.6	14/01/2009	6.6	5/06/2009	15.5	15.3
Whangamaire	57917	25.6	10/02/2022	8.7	13/05/2022	17.9	18.0
Alexandra	454003	26.1	3/01/2018	6.3	13/07/2015	15.0	14.8
Awaruku	414717	25.8	9/03/2020	6.6	12/07/2015	15.8	15.5

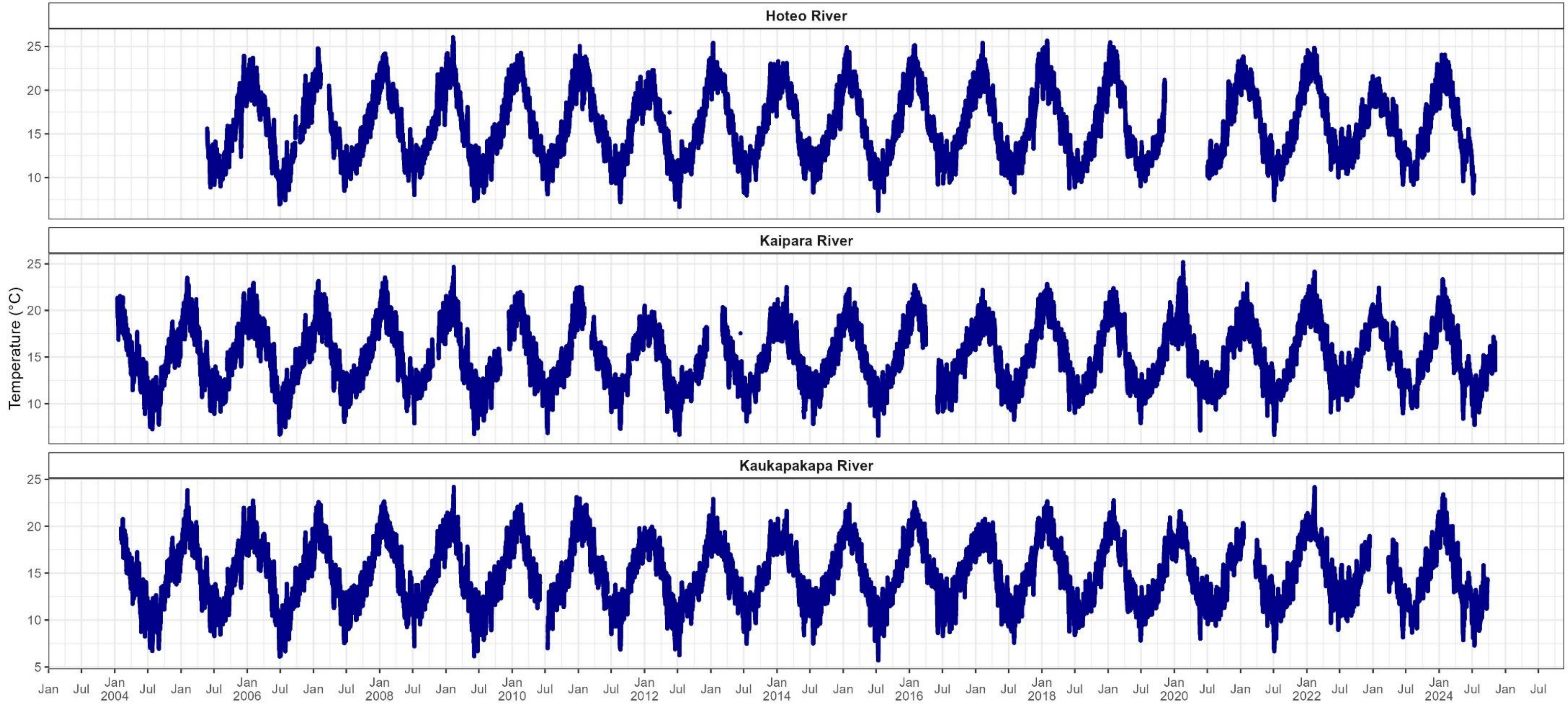
Eskdale	429084	22.2	27/02/2016	6.3	13/07/2015	14.2	13.9
Kaipatiki	387863	24.1	25/12/2023	6.9	20/06/2013	15.0	14.9
Lucas	436618	25.7	3/01/2018	5.6	13/07/2015	15.3	15.0
Mairangi Bay	461062	24.4	10/02/2024	5.1	2/08/2023	16.5	16.4
Newmarket	446561	27.4	13/01/2013	4.4	20/06/2013	16.9	16.3
Onetangi	58608	21.5	12/02/2022	9.5	12/05/2024	16.2	16.6
Oratia	930807	25.1	10/02/2022	5.6	3/07/2006	15.3	14.8
Oteha	775546	23.8	20/02/2018	7.4	15/07/2010	15.4	15.1
Papakura	680025	28.8	8/02/2009	6.4	5/06/2009	16.4	16.1
Paramuka	595036	26.4	27/01/2016	8.2	13/07/2015	16.2	16.1
Puhinui	673483	28.7	30/01/2008	6.4	5/06/2009	16.8	16.6
Swanson	853666	26.0	19/01/2022	6.4	11/07/2012	15.1	14.6
Tāmaki	994964	30.0	29/01/2013	7.0	12/09/2012	17.2	16.5
Vaughan	1042279	29.1	14/01/2004	4.1	27/06/2006	15.0	14.8
Wairau Upper	828252	32.8	15/01/2021	6.9	12/07/2015	17.2	16.3
Whau	673738	24.3	27/02/2016	6.5	10/08/2015	15.9	15.5
Ōpanuku Lower	1115447	25.5	15/01/2021	4.7	21/08/2011	15.1	14.7
Ōtara	441974	25.9	1/02/2006	6.3	27/06/2006	16.6	16.6

Appendix 3: Time Series of Continuous Temperature Data for each Site

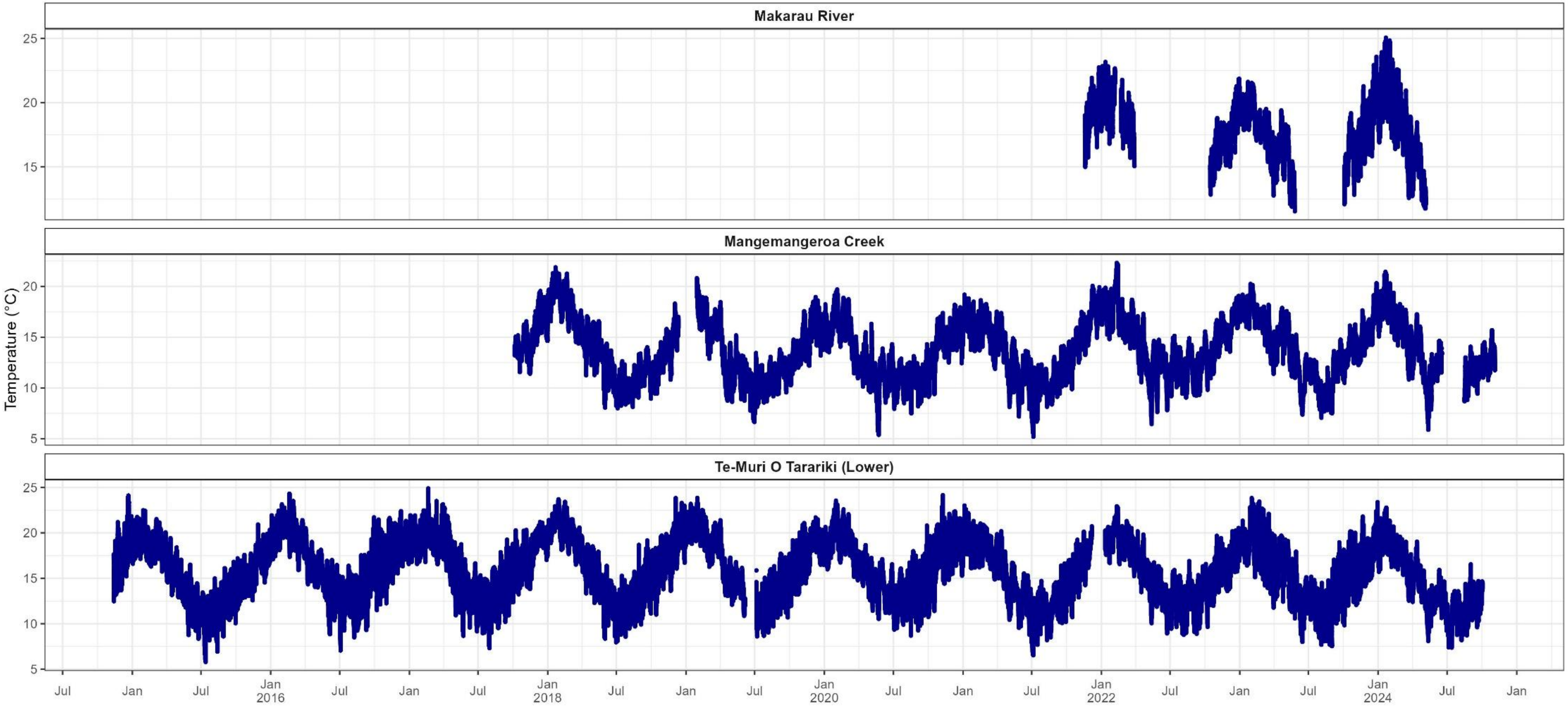


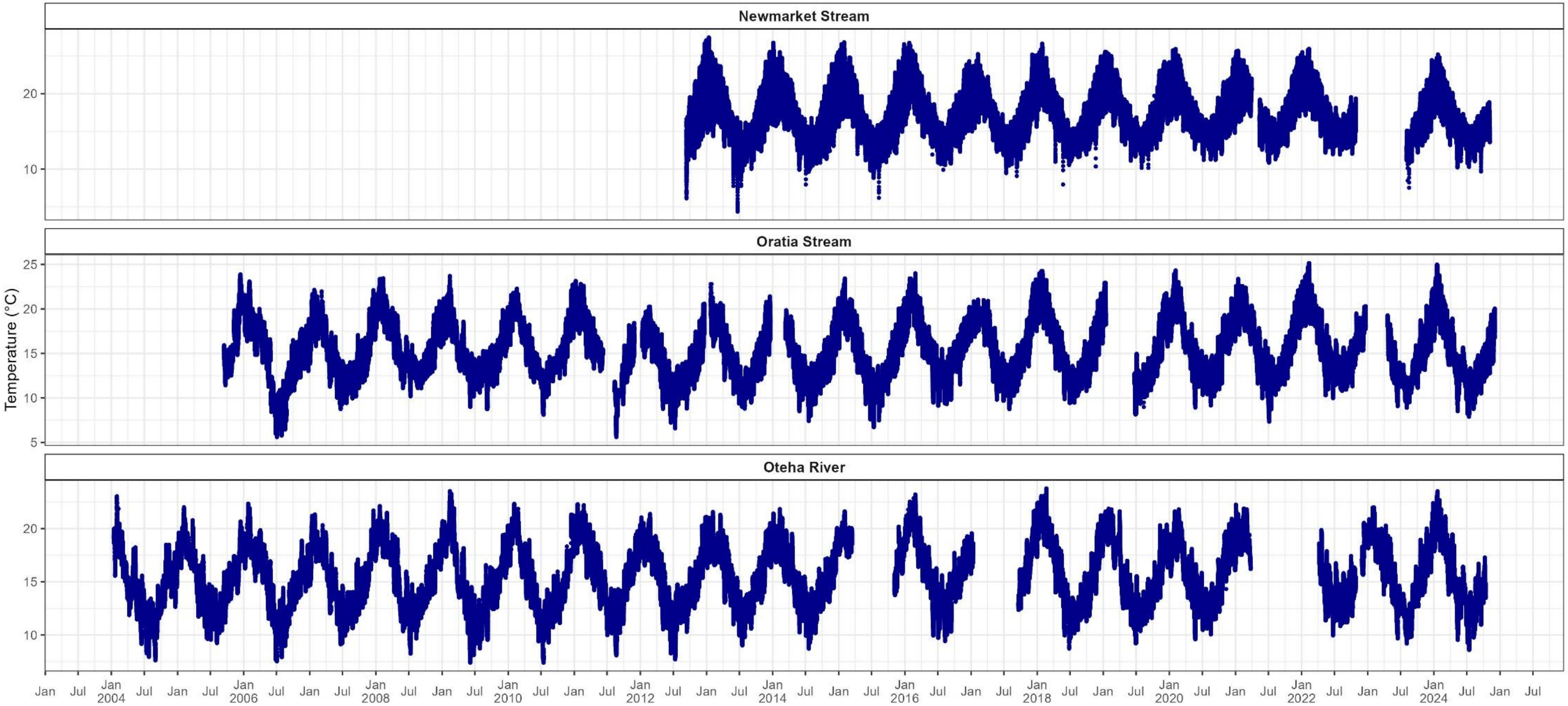

Opanuku Stream (Upper)
Wairoa River
West Hoe Stream
Temperature (°C)
25
20
15
10
5
Jul
Jan 2006
Jan 2008
Jan 2010
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024


Mahurangi River (Right Branch)
25
20
15
Matakana River
Temperature (°C)
20
15
Waiwhiu Stream (Dome Forest)
21
19
17
15
13
Jan
2022
Jul
Jan
Jul
Jan
2024



Hoteo River
Kaipara River
Kaukapakapa River
Temperature (°C)
25
20
15
10
5
Jan
Jul
Jan 2004
Jan 2006
Jan 2008
Jan 2010
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024


Makarau River
Mangemangeroa Creek
Te-Muri O Tarariki (Lower)
Temperature (°C)
25
20
15
10
5
Jul
Jan
Jul
Jan 2016
Jul
Jan
Jul
Jan 2018
Jul
Jan
Jul
Jan 2020
Jul
Jan
Jul
Jan 2022
Jul
Jan
Jul
Jan 2024
Jul
Jan


Newmarket Stream
Oratia Stream
Oteha River
Temperature (°C)
20
10
25
20
15
10
5
20
15
10
Jan
Jul
Jan 2004
Jul
Jan
Jul
Jan 2006
Jul
Jan
Jul
Jan 2008
Jul
Jan
Jul
Jan 2010
Jul
Jan
Jul
Jan 2012
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Jan 2014
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Jan 2016
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Jan 2018
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Jan 2020
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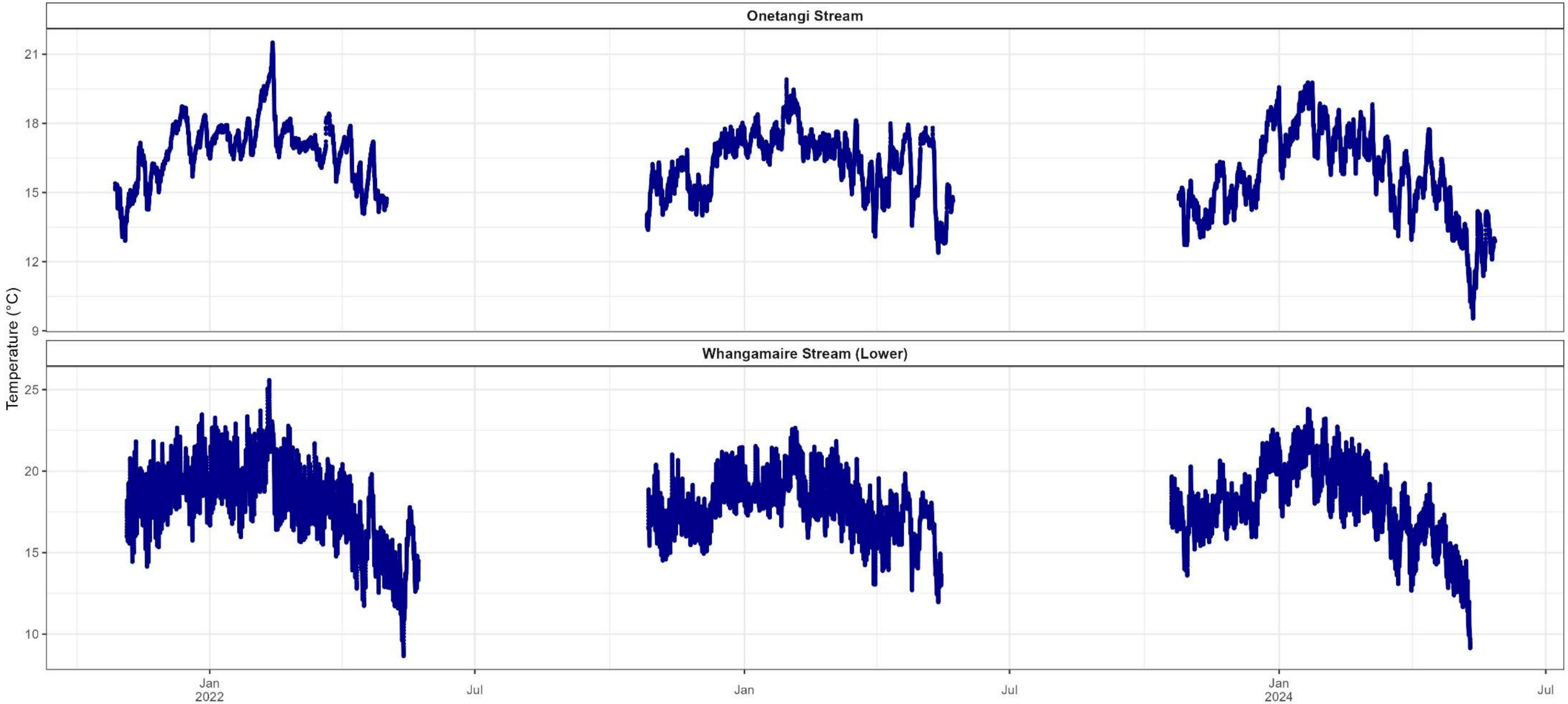
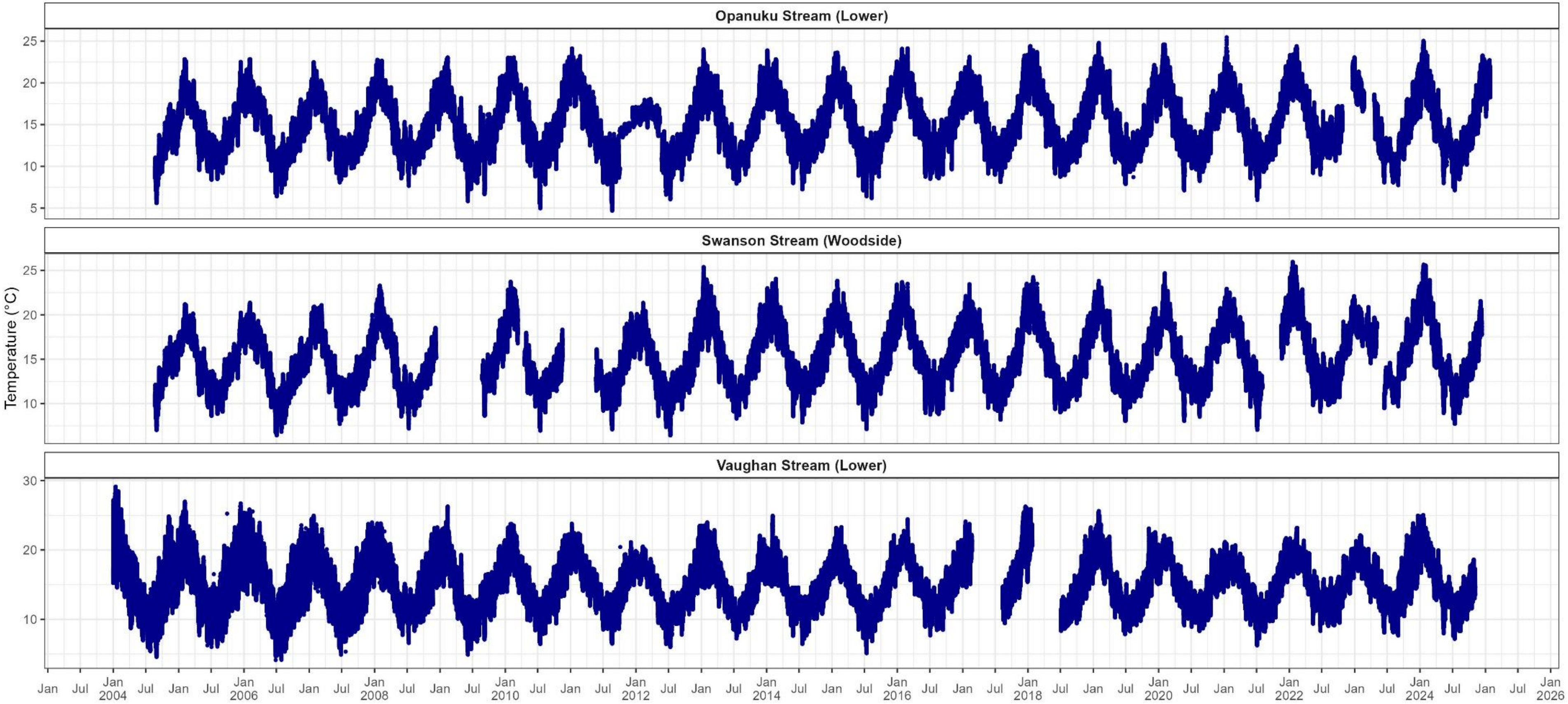
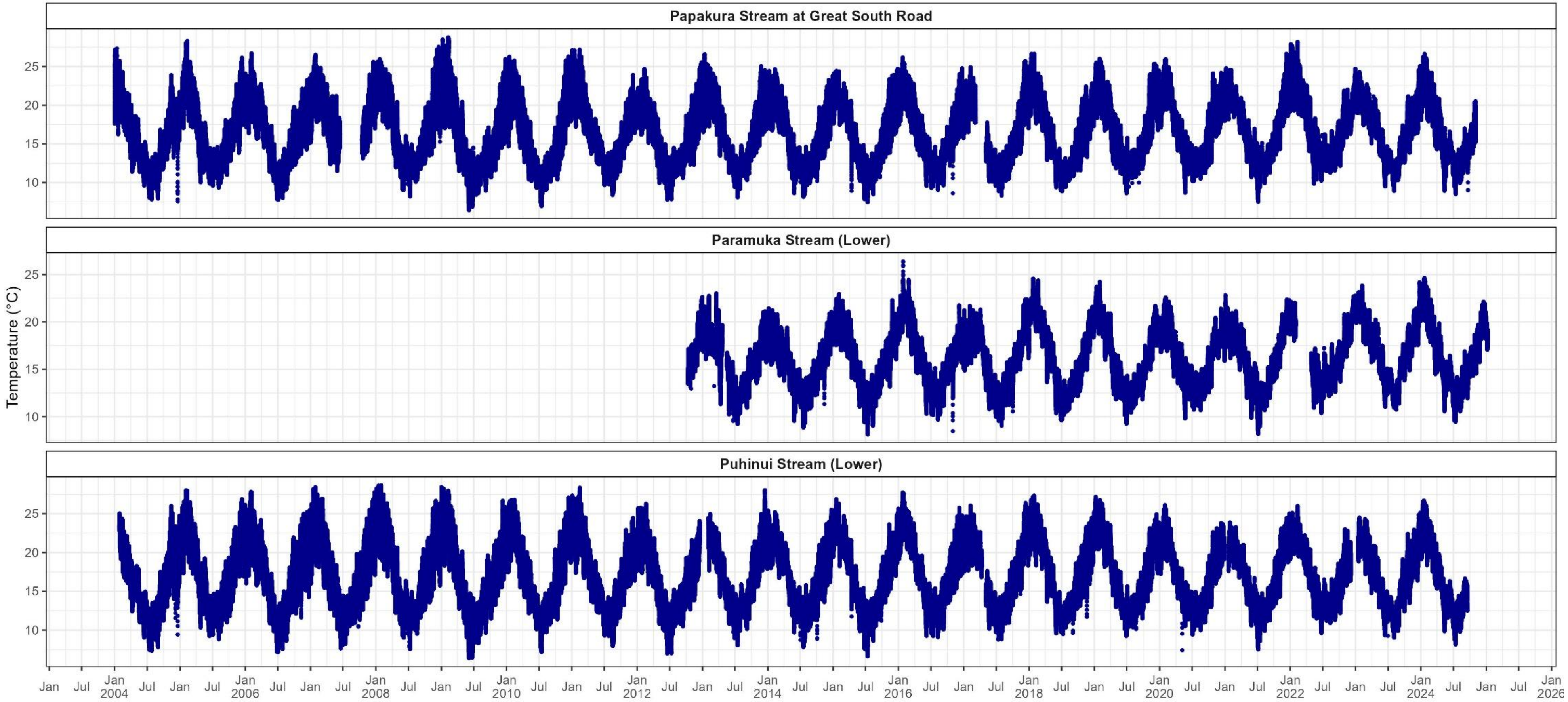
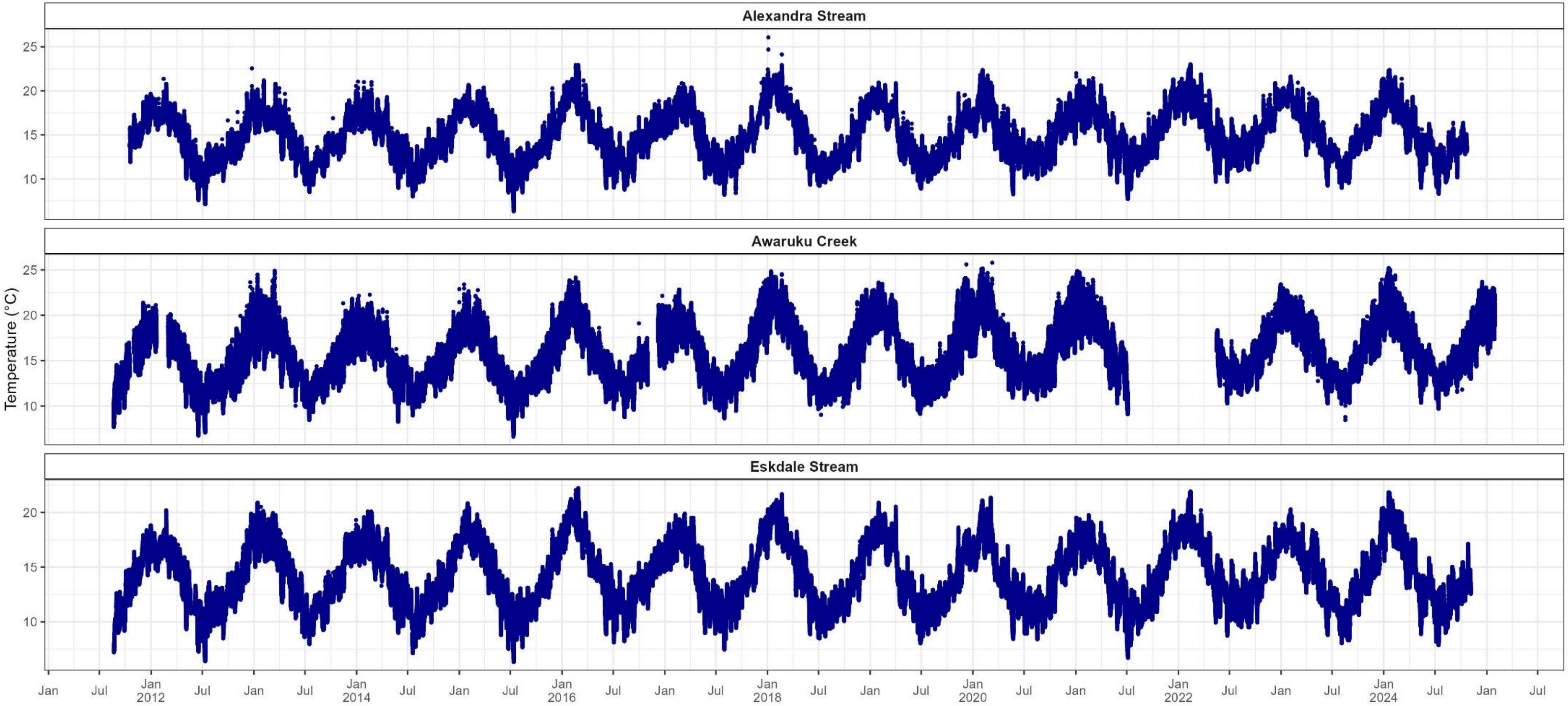
Jan
Jul
Jan 2022
Jul
Jan
Jul
Jan 2024
Jul
Jan
Jul


Onetangi Stream
Whangamaire Stream (Lower)
Temperature (°C)
21
18
15
12
9
25
20
15
10
Jan
2022
Jul
Jan
Jul
Jan
2024
Jul

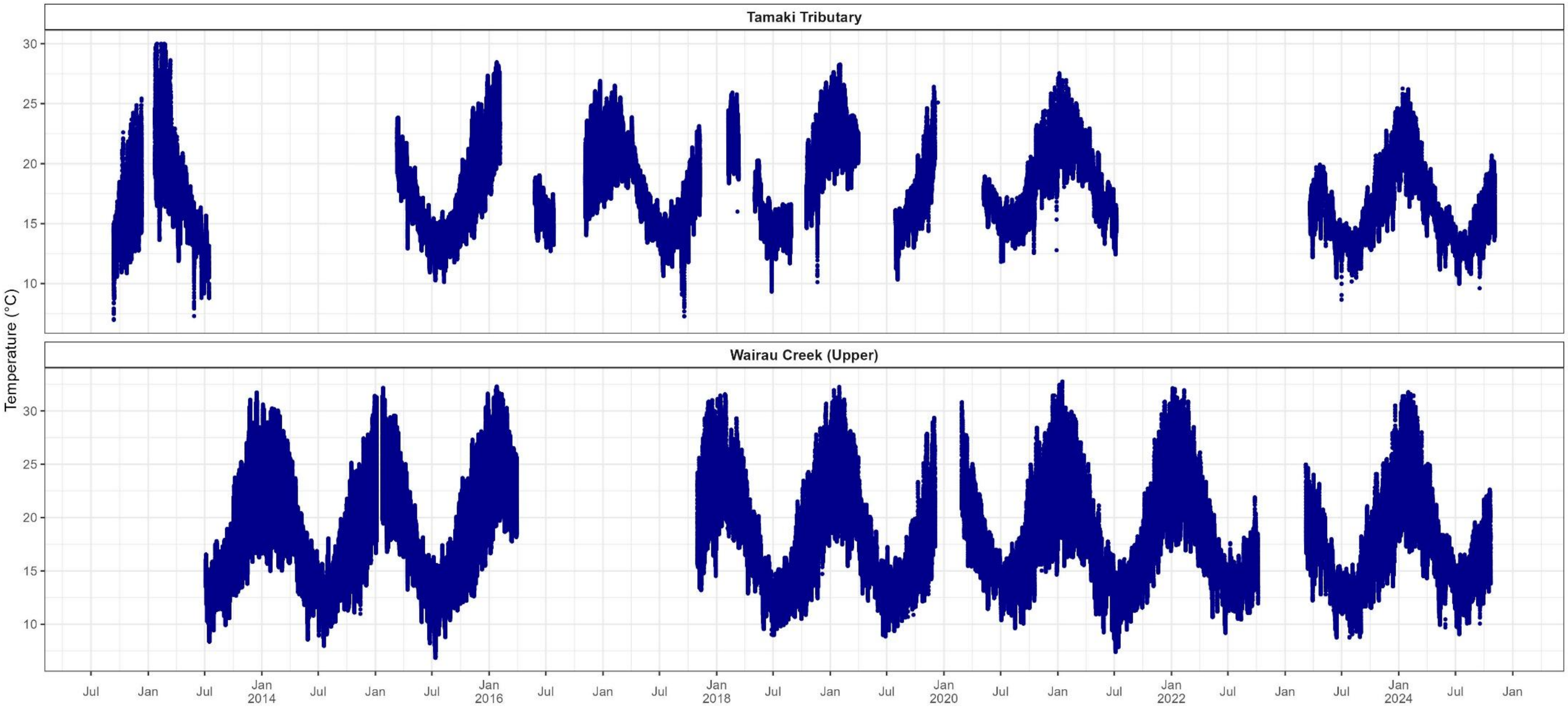

Opanuku Stream (Lower)
Swanson Stream (Woodside)
Vaughan Stream (Lower)
Temperature (°C)
25
20
15
10
5
30
Jan
Jul
Jan 2004
Jan 2006
Jan 2008
Jan 2010
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024
Jan 2026



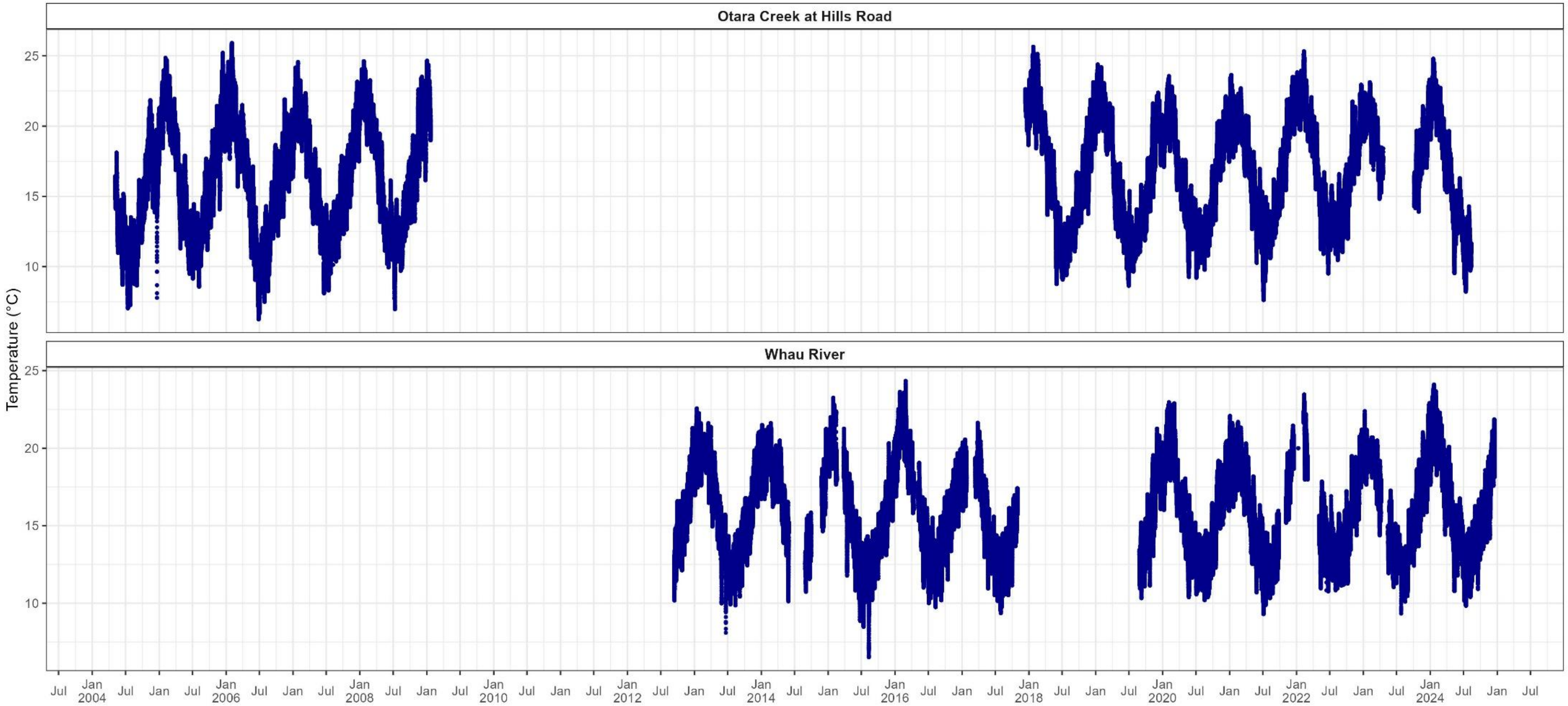
Papakura Stream at Great South Road
Paramuka Stream (Lower)
Puhinui Stream (Lower)
Temperature (°C)
25
20
15
10
Jan
Jul
Jan 2004
Jan 2006
Jan 2008
Jan 2010
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024
Jan 2026



Alexandra Stream
Awaruku Creek
Eskdale Stream
Temperature (°C)
25
20
15
10
Jan
Jul
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024



Tamaki Tributary
Wairau Creek (Upper)
Temperature (°C)
30
25
20
15
10
Jul
Jan
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024


Otara Creek at Hills Road
Whau River
Temperature (°C)
25
20
15
10
Jul
Jan 2004
Jan 2006
Jan 2008
Jan 2010
Jan 2012
Jan 2014
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Jan 2024
Jan
Jul

Appendix 4: Summary statistics of linear models assessing the influence of shading and channel modification on temperature metrics (current state)

Table A4-1. Pearson correlation between shading cover and temperature metrics

Metric	R^2	p-value	95% CI
1-day maximum temperature	−0.43	0.007	−0.66 to −0.13
5-day CRI	−0.44	0.005	−0.67 to −0.14

Table A4-2. Results of the multiple linear regression model for combined effects of shading and channel modification on temperature metrics

Metric	R^2	p-value	95% CI
1-day maximum temperature	0.48	$4.311e^{-06}$	−0.032 to 0.001
5-day CRI	0.38	$8.255e^{-05}$	−0.024 to 0.002

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