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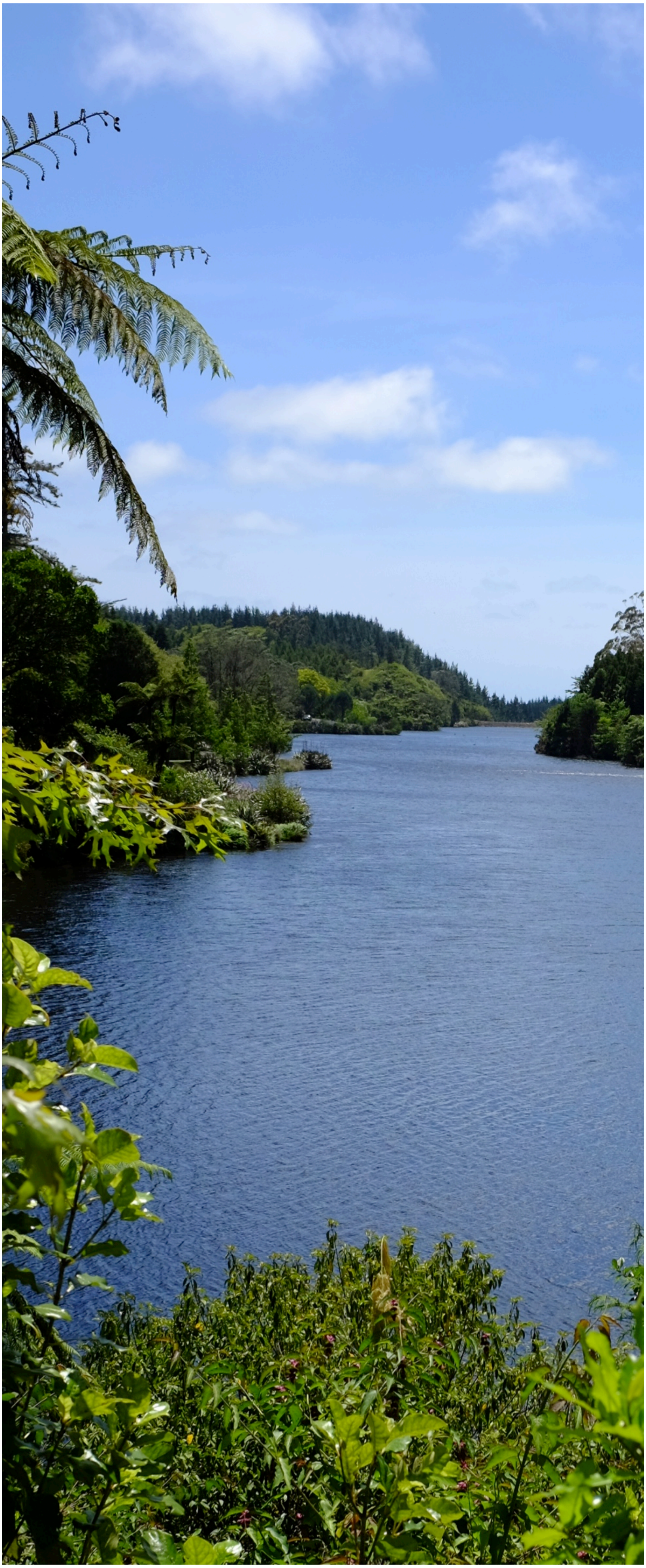
APPENDIX G

Aquatic Ecology Assessment – Ryder Environmental Limited



Trustpower

Mangorei HEPS
Aquatic Ecology AEE

November 2020

ryder

Trustpower

Mangorei HEPS
Aquatic Ecology Assessment of Effects

FINAL

November 2020

by

Ruth Goldsmith, PhD.

Reviewed by

Greg Ryder, PhD.

Ryder Environmental Limited
195 Rattray Street
PO Box 1023
DUNEDIN, 9054
New Zealand
Phone: 03 477 2119

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Cover page: Lake Mangamahoe, November 2018 (photo: G. Ryder).

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Executive Summary

The Mangorei scheme is located within the Waiwhakaiho River catchment to the south of New Plymouth. The scheme diverts water from the Waiwhakaiho River into the artificially constructed Lake Mangamahoe, from where it is directed through an intake to penstocks that carry the water through to the Mangorei Power Station. Generation water from the Mangorei Power Station is returned back to the Waiwhakaiho River, at a site known as the Meeting of the Waters, approximately 6 km downstream of the original diversion.

The Mangorei HEPS can divert up to 10 m^3/s from the Waiwhakaiho River, and must maintain a residual flow of between 0.4 m^3/s (1 May - 31 October), 0.6 m^3/s (1 November – 31 December and April) and 0.7 m^3/s (1 January - 31 March) downstream of the intake (Table 4.1)[1]. These residual flow requirements have been in place since 1996. In order to determine the effects of the water abstraction on water quality and aquatic communities downstream, existing information on aquatic communities were reviewed, and additional monitoring was undertaken in the catchment during 2019 to 2020.

The existing residual flow regime supports a diverse native fish community, with inanga, redfin bullies, longfin eels and torrentfish all present within the residual river reach. Brown trout are also present throughout, and densities of juvenile trout and redfin bullies in the residual reach are similar to or higher than that elsewhere in the river. In addition to these species, banded and shortjaw kokopu, koaro, lamprey, and shortfin eels (which are all native species with migratory life cycles) have previously been recorded upstream of the Mangorei HEPS intake weir and fish pass - confirming that fish passage through the residual reach and fish pass to the river upstream of the Mangorei HEPS intake is being maintained.

In summer water temperatures in the residual river reach can exceed thermal criteria for brown trout, however temperatures are typically within the range of thermal preferences for native fish species. Although very high water temperatures can be detrimental, warm water temperature can increase productivity in aquatic communities. Fish are also able to respond to water temperatures above their thermal preferences by temporarily moving to cooler locations (e.g. where a tributary or groundwater inflow enters). However, in order to ensure that water temperatures in the residual reach do not remain at very high temperatures for an

[1] Additionally, no water can be diverted when the flow in the Waiwhakaiho River is greater than or equal to 85 m^3/s.

extended period, it is recommended that a temporary reduction in take be implemented when temperatures are high.

Proliferations of long filamentous nuisance algae occur at times at all Waiwhakaiho River monitoring sites, although generally to a greater extent downstream of the Mangorei HEPS intake. Warm water temperatures and increased periphyton cover can result in lower macroinvertebrate community health. Macroinvertebrate community health has tended in the past to be higher upstream of the Mangorei HEPS take than downstream, although during recent summers sites communities upstream of the take and in the residual reach were both indicative of 'poor' health. Overall, macroinvertebrate community health tends to decrease downstream in the river, which is expected as it exits the national park and land-use intensity increases downstream. Ten-year trend analysis indicates degrading macroinvertebrate community health upstream of the Mangorei HEPS take, in combination with increases in nutrient (dissolved reactive phosphorus and total oxidised nitrogen) and faecal bacteria concentrations.

Nuisance growths of periphyton in the residual river are due to a combination of factors (including nutrient inputs from discharges within the residual reach), however the operation of the Mangorei HEPS is also contributing through a reduction in the magnitude of flows downstream by up to 10 m^3/s. It is therefore recommended that a flushing flow regime be implemented to allow higher flows to pass through the residual reach during 1 November to 31 March.

The damming of the lower section of Mangamahoe Stream to form Lake Mangamahoe has provided a water supply and power generation. In addition to these primary functions the lake supports a native fish community and a popular trout fishery. Flow and fish passage in the Mangamahoe Stream has been restricted for over 100 years. Despite this the water quality in the lower stream is sufficient to maintain a native fish community that includes migratory species. Provision of a residual flow at the lake dam spillway is therefore not required, and in the continued presence of the NPDC dam, would not improve habitat greatly in the stream downstream.

Varying generation outflow from the Mangorei HEPS results in daily fluctuations in water level and flow in the lower Waiwhakaiho River. This changes the habitat available for aquatic communities, most markedly on the margins of the river channel. Fish are able to move in and out of the channel margins as the habitat changes, however macroinvertebrates cannot respond quickly and therefore the species that live here have to be tolerant of these conditions. The macroinvertebrate community in the lower river is similar to that in the residual reach (and also during recent summers to that upstream of the Mangorei HEPS intake), being typically indicative of 'poor' community health. Generation discharges from the Mangorei HEPS do however also have beneficial effects on the lower Waiwhakaiho River. The discharge of water from the lake via the power station appears to have a slight cooling effect on water temperatures in the river, and increases in dissolved oxygen levels are observed due to generation. Flow increases due to generation are also effective in flushing nuisance periphyton growths.

1. Introduction

1.1. Background

Trustpower has commenced a reconsenting process for the Mangorei Hydroelectric Power Scheme (the scheme or HEPS). An Assessment of Environmental Effects (AEE), based on the assessment of the effects of the scheme on the environment, is required to support the consent application. This report, which is one of a series of technical assessment reports, addresses the water quality and aquatic ecology aspects of the scheme.

1.2. Scheme physical description

The scheme is located within the Waiwhakaiho River catchment to the south of New Plymouth (Figure 1.1). The Waiwhakaiho River catchment covers an area of approximately 136 km^2 with the upper catchment on the north-eastern slopes of Mount Taranaki into the Taranaki ring plain. From there the river flows north entering the Tasman Sea at the eastern edge of New Plymouth's urban boundary (Tonkin and Taylor 2020).

The Mangorei HEPS first supplied power to New Plymouth in 1906. The scheme diverts up to 10 m^3/s of water from the Waiwhakaiho River into the artificially constructed Lake Mangamahoe (surface area approximately 0.25 km^2), from where it is directed through an intake to penstocks that carry the water through to the Mangorei Power Station. The New Plymouth District Council (NPDC) also takes water from the lake (maximum take 740 L/s, Tonkin and Taylor (2020)) to supply drinking water. Generation water from the Mangorei Power Station is returned back to the Waiwhakaiho River, at a site known as the Meeting of the Waters, approximately 6 km downstream of the original diversion.

There is no dam on the Waiwhakaiho River, rather a low-head concrete weir is situated just downstream of an intake gate (Figure 1.2). The weir structure includes a fish pass on the true right side of the river. The bulk of the residual flow is passed down the fish pass under low flow conditions.

The scheme's Waiwhakaiho River intake is situated on the true left bank (Figure 1.3). Its location is downstream of a large rapid-run feature (Figure 1.4) that flows into a section of deeper, slower flowing water created by the weir. The bank immediately upstream of the intake has been armoured with large boulders. The fish pass (constructed in 1992) is located just downstream (below the concrete weir) on the true right side of the river. The harsh nature of the river (steep gradient, boulder substrate and frequent freshes) has meant the fish pass requires regular maintenance to remove substrate.

Tonkin and Taylor (2020) have calculated that the Waiwhakaiho River has a mean annual flow of 7.84 m^3/s at Egmont Village (approximately 2 km upstream of the scheme intake), a median flow of 3.94 m^3/s and a 7-day MALF of 2.11 m^3/s. The scheme can divert up to 10 m^3/s from the river, and must maintain a residual flow of between 0.4 m^3/s (1 May - 31 October), 0.6 m^3/s (1 November – 31 December and during April), and 0.7 m^3/s (1 January and 31 March) downstream of the intake. The existing conditions of consent require that no water be diverted when the flow in the Waiwhakaiho River is greater than or equal to 85 m^3/s.

The scheme's intake on the Waiwhakaiho River diverts water into Lake Mangamahoe via an approximately 580 m long tunnel (Figure 1.1). This diversion provides approximately 85% of the lake inflow, with the balance of the inflow (15%) derived from lake tributaries, principally the Mangamahoe Stream and Kent Road Stream (Tonkin and Taylor 2020). Lake Mangamahoe (Figure 1.5) was formed in 1931 by damming the Mangamahoe Stream with a concrete-cored earth dam and associated concrete spillway (Figure 1.6). The spillway has no residual flow to the lower Mangamahoe Stream although seepage water and occasional higher flows maintain some flow down the spillway most of the time. Further downstream in the lower Mangamahoe Stream there is also an older low head dam (constructed in 1918 and owned by NPDC) that is no longer operational but presents a barrier to fish passage (Figure 1.7).

The scheme's intake to the Mangorei Power Station penstocks is located in an arm at the northern end of Lake Mangamahoe (Figure 1.1 and Figure 1.8). The structure consists of four intake gates and a manually operated trash screen. The lake level must be maintained within an operating range of 0.75 m, and to achieve this the mean take from the lake to the power station over the last seven years (2013 – 2020) was 3.83 m^3/s (Tonkin and Taylor (2020)).

The penstocks feed into the Mangorei Power Station and generation water from the power station is discharged back to the Waiwhakaiho River at the Meeting of the Waters via a 250 m long open canal (Figure 1.9). The Mangorei Stream enters the Waiwhakaiho River approximately 700 m downstream of the scheme discharge and other small tributaries also contribute flow to the lower river.

Figure 1.1. Aerial map showing location of structures and surface waters associated with the Mangorei HEPS.

Figure 1.2. Mangorei HEPS low-head weir and fish pass on the Waiwhakaiho River.

Figure 1.3. Mangorei HEPS intake structure on the Waiwhakaiho River.

Figure 1.4. Waiwhakaiho River upstream of the Mangorei HEPS intake structure.

Figure 1.5. Lake Mangamahoe looking towards Mount Taranaki.

Figure 1.6. Standing on the Lake Mangamahoe earth dam looking across the concrete spillway.

Figure 1.7. Lower Mangamahoe Stream low-head NPDC dam.

Figure 1.8. Mangorei HEPS intake to penstocks at Lake Mangamahoe.

Figure 1.9. Mangorei Power Station with tailrace canal in the foreground.

2. Assessment methods

Available data and reports were reviewed to gain an understanding of the existing information on aquatic communities within the Waiwhakaiho River catchment. Sources included Taranaki Regional Council (TRC) annual compliance and regional monitoring reports for the scheme (e.g. TRC 2019, a, b and c), and New Zealand Freshwater Fish database records. From this literature review, data and information gaps were identified and a monitoring plan designed in April 2019 to ensure that the additional information required to prepare the assessment of effects was collected. Additional monitoring data was obtained during the period from April 2019 to March 2020. Monitoring methods, including a map of monitoring sites and location information and photographs, are presented in Appendix One (Sections 7.1, 7.2 and 7.3). It had been intended that monitoring would continue in April and May 2020, however Covid-19 restrictions meant that this was not possible. Monthly water quality monitoring resumed in June 2020.

The report is structured to begin with a review of 'Existing Values' arranged into sub-sections (e.g., water quality, benthic macroinvertebrate communities), including a comparison of these values to relevant standards and limits (e.g., NPS-FM, periphyton guidelines). At the start of each existing values sub-section a short 'Summary' paragraph is provided that covers the main findings of the review, a more detailed 'Analysis and Discussion' then follows. The 'Assessment of Effects' section then considers the effect of the Mangorei HEPS on each of the existing values separately, with a 'Summary' provided at the end of each sub-section. All of this information is then drawn together in the final 'Summary and Conclusion', which also includes options to reduce any adverse effects of the Mangorei HEPS on aquatic communities.

3. Existing values

3.1. Water quality – nutrients, clarity and bacteria

Summary

Physical and chemical measurements of water quality are used to assess pressures on the health of rivers. Nutrient and faecal bacteria concentrations in the Waiwhakaiho River reflect the agricultural nature of the catchment, with associated non-point source run-off and point source discharges. Phosphorus levels also reflect that the headwaters of the catchment drain Mount Taranaki, which is a naturally high source of phosphorus for Taranaki rivers. Ten-year trend analysis indicates that dissolved reactive phosphorus, total oxidised nitrogen, and faecal bacteria concentrations are all increasing in the river upstream of the Mangorei HEPS take. Monitoring during 2019-2020 identified that nitrogen concentrations are higher downstream of the Mangorei HEPS take than upstream.

Analysis and discussion

TRC measures the physical and chemical water quality[2] of the Waiwhakaiho River at the State Highway 3 (SH3) bridge in the middle of the catchment near Egmont Village (approximately 11 km downstream of the Egmont National Park boundary). This site is located approximately 2 km upstream of the Mangorei HEPS intake weir and within this report is referred to as the 'Upstream' site (a map of monitoring sites, location information and photographs is presented in Appendix One). TRC have undertaken monthly monitoring of a range of water quality parameters at the Upstream site since 1995 (i.e. for 25 years).

A summary of water quality data for the Upstream site from July 1995 to June 2018 is presented in Appendix Two. Table 3.1 (below) presents 5-year median data for a range of key monitoring parameters at the Upstream site, including phosphorus, nitrogen, clarity and faecal bacteria. Land and Water Aotearoa (LAWA) 10-year trend analysis results for the site are also shown, together with a comparison of median values with relevant National Objectives Framework (NOF) bands (MfE 2014, amended 2017).

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[2] These measures include bacteria levels, water clarity, conductivity and acidity (pH levels), nutrient levels, dissolved oxygen levels and the amount of oxygen consumed in the breakdown of organic matter (biochemical oxygen demand). In all, there are 13 individual measures, which the TRC monitors at 13 sites throughout the region.

Nutrient and faecal bacteria concentrations in the Waiwhakaiho River at the Upstream site reflect the agricultural nature of the catchment (40% of the catchment upstream is developed farmland), with associated non-point source run-off and point source discharges (and stock access) to the river (TRC 2019b). Phosphorus levels also reflect that the headwaters of the catchment drain Mount Taranaki, which is a naturally high source of phosphorus for Taranaki rivers.

Ten-year trend analysis indicates that dissolved reactive phosphorus and total oxidised nitrogen concentrations are both increasing at the Upstream site (Table 3.1). Ammoniacal nitrogen concentrations are however likely decreasing and fall within NOF band B (Table 3.1). Faecal bacteria concentrations are high (*Escherichia coli* 5-year median 280 per 100 mL, NOF band D), with trend analysis indicating increasing degradation (Table 3.1). A TRC-led programme of riparian fencing and planting is on-going in the catchment and as this becomes established, TRC is expecting water quality to improve.

Water clarity is high in the river at the Upstream site and likely improving (based on black disc measurements, Table 3.1), although at times it is impacted by upper catchment erosion events. Occasional headwater erosion events have been documented in the upper river with an instance of severe (orange) discolouration in spring 2014 due to release of naturally occurring iron oxide from a small headwater tributary (TRC 2019c).

Table 3.1. Five-year median water quality data for the Waiwhakaiho River Upstream site (2014-2018). 10-year trends (2009-2018) are also reported, as either indicating 'improving' or 'degrading' water quality. Where appropriate the relevant National Objectives Framework (NOF) Bands are also reported ('A', 'B', and 'C' indicates that water quality is considered suitable for the designated use, and 'D' indicates water quality is not considered suitable for the designated use). Data and interpretation sourced from the Land Air Water Aotearoa (LAWA) website.

	Parameter	**Value**	**Upstream site (SH3)**
Phosphorus	Total phosphorus (g/m^3)	5-year median	0.0375
		10-year trend	Indeterminate
	Dissolved reactive phosphorus (g/m^3)	5-year median	0.03
		10-year trend	Very likely degrading
Nitrogen	Total nitrogen (g/m^3)	5-year median	0.21
		10-year trend	Indeterminate
	Total oxidised nitrogen (g/m^3)	5-year median	0.15
		10-year trend	Likely degrading
	Ammoniacal nitrogen (g/m^3)	5-year median	0.0075
		10-year trend	Likely improving
		NOF band	B
Clarity	Black disc (m)	5-year median	2.87
		10-year trend	Likely improving
	Turbidity (NTU)	5-year median	0.8
		10-year trend	Indeterminate
Bacteria	*E. coli* (per 100 mL)	5-year median	280
		10-year trend	Very likely degrading
		NOF band	D

In order to compare water quality in the Waiwhakaiho River at the Upstream site to that downstream of the Mangorei HEPS intake, additional monthly water quality monitoring was undertaken at a further two sites downstream of the intake weir from April 2019 to March 2020 (by Riverwise Consulting[3] on behalf of Trustpower). One site was located within the residual flow reach at Hydro Road, which within this report it is referred to as the 'Residual' site. The second site was located downstream of the point where the Mangorei HEPS tailrace enters the river, and is

[3] Water samples were collected by Riverwise Consulting and sent to Hill Laboratories (Hamilton) for processing. Raw water quality data was then provided by Hill Laboratories directly to Ryder Environmental for analysis and interpretation.

referred to as the 'Downstream' site. On all except one occasion[4] sites were monitored on the same day (through co-ordination between Riverwise Consulting and TRC), using the same method, with the same laboratory used to process samples (Hill Laboratories, Hamilton).

Water quality monitoring data at each site from April 2019 to March 2020[5] is presented for key parameters in Figures 3.1 to 3.8, and a summary table of all data is presented in Appendix Three. Site names shown in the figures are as follows:

- Upstream: TRC SH3 Bridge, site code WKH000500 (approximately 2 km upstream of the intake weir).
- Residual: Trustpower Hydro Road (approximately 5 km downstream of the intake weir).
- Downstream: Trustpower Meeting of the Waters (approximately 6 km downstream of the intake weir and downstream of the Mangorei HEPS tailrace discharge).

During the 2019-2020 monitoring period phosphorus concentrations (particularly dissolved reactive phosphorus) tended to be higher at the Upstream site than at the Residual and Downstream sites (Figures 3.1 and 3.2, Appendix Three).

In contrast, some forms of nitrogen had higher concentrations at the Residual and Downstream sites than at the Upstream site (Figures 3.3 to 3.6). Median ammoniacal nitrogen concentrations were approximately three times higher at the Residual site and two times higher at the Downstream site than Upstream (Figure 3.6, Appendix Three). Median values of nitrate nitrogen were almost twice as high at the Downstream site than Upstream (Appendix Three). Maximum concentrations for nitrate-nitrogen at the Residual and Downstream sites also fell outside the upper bound of the long-term range (1995-2018) for values recorded at the Upstream site (Appendix Three).

Water turbidity was low (i.e. clarity high) and similar at all sites (Figure 3.7, Appendix Three).

Median faecal bacteria concentrations were lowest at the Residual site and highest at the Upstream site (Figure 3.8, Appendix Three).

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[4] The exception was in April 2019, when Riverwise Consulting monitored on the 9 April and TRC monitored on the 10 April. River flows on these two days were very similar so no major water quality differences are expected as a result.
[5] At the time of report preparation March 2020 water quality monitoring data for the SH3 site was not available from TRC.

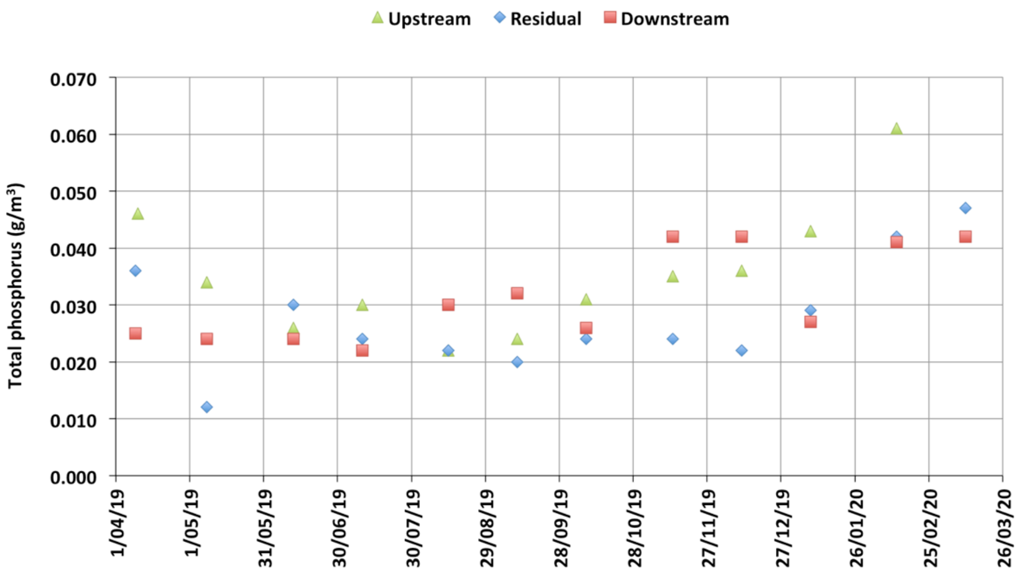

Figure 3.1. Total phosphorus concentration (g/m³) at Waiwhakaiho River sites, April 2019 – March 2020.

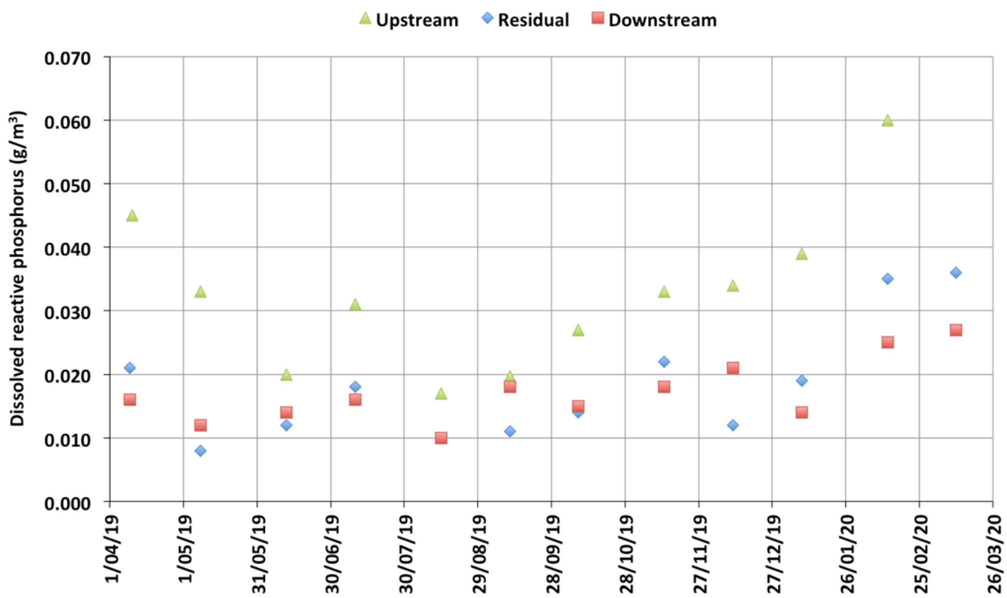

Figure 3.2. Dissolved reactive phosphorus concentration (g/m³) at Waiwhakaiho River sites, April 2019 – March 2020.

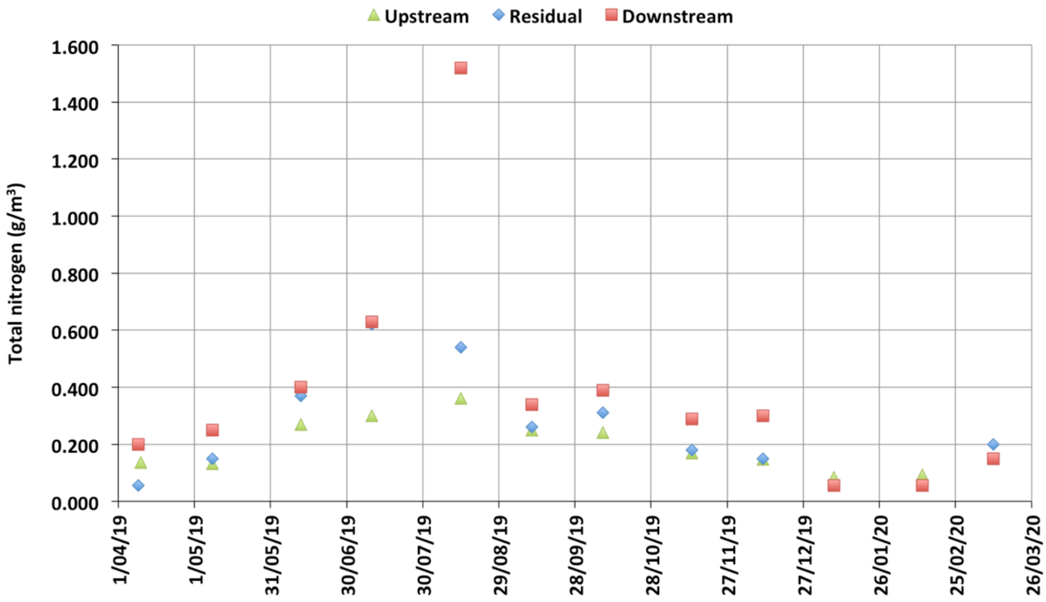

Figure 3.3. Total nitrogen concentration (g/m^3) at Waiwhakaiho River sites, April 2019 – March 2020.

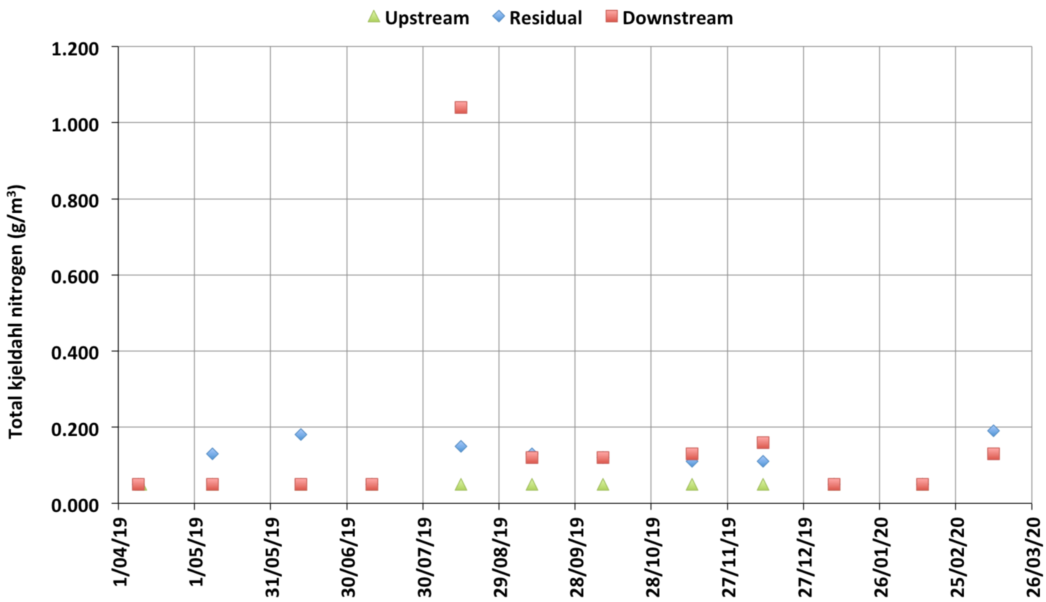

Figure 3.4. Total kjeldahl nitrogen concentration (g/m^3) at Waiwhakaiho River sites, April 2019 – March 2020.

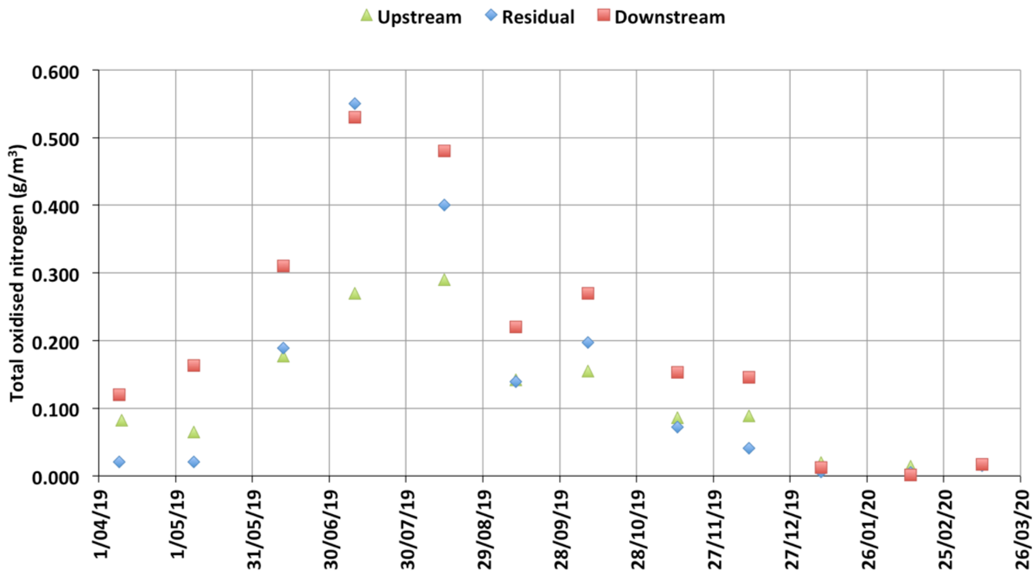

Figure 3.5. Total oxidised nitrogen concentration (g/m^3) at Waiwhakaiho River sites, April 2019 – March 2020.

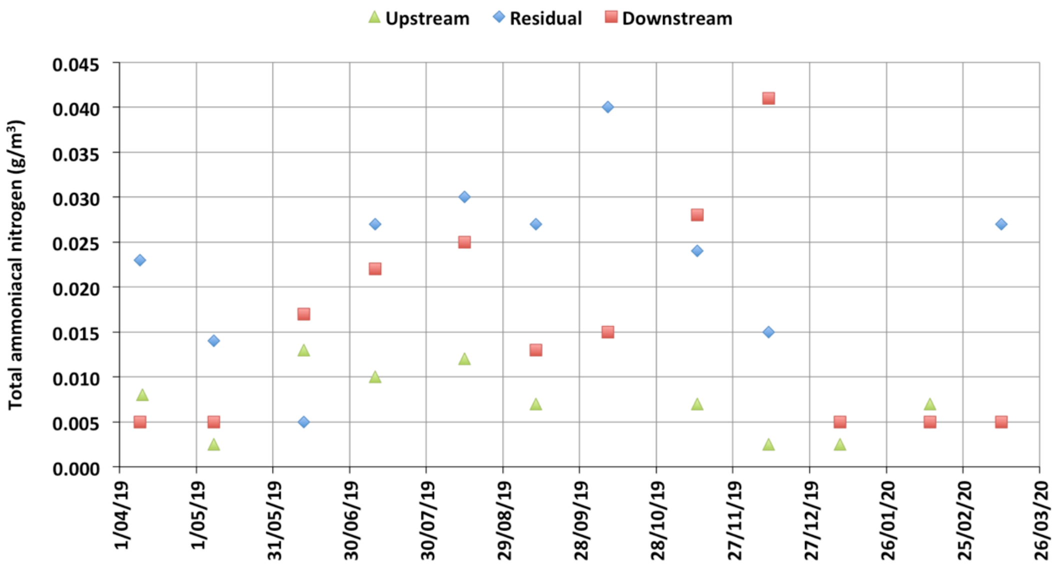

Figure 3.6. Total ammoniacal nitrogen concentration (g/m^3) at Waiwhakaiho River sites, April 2019 – March 2020.

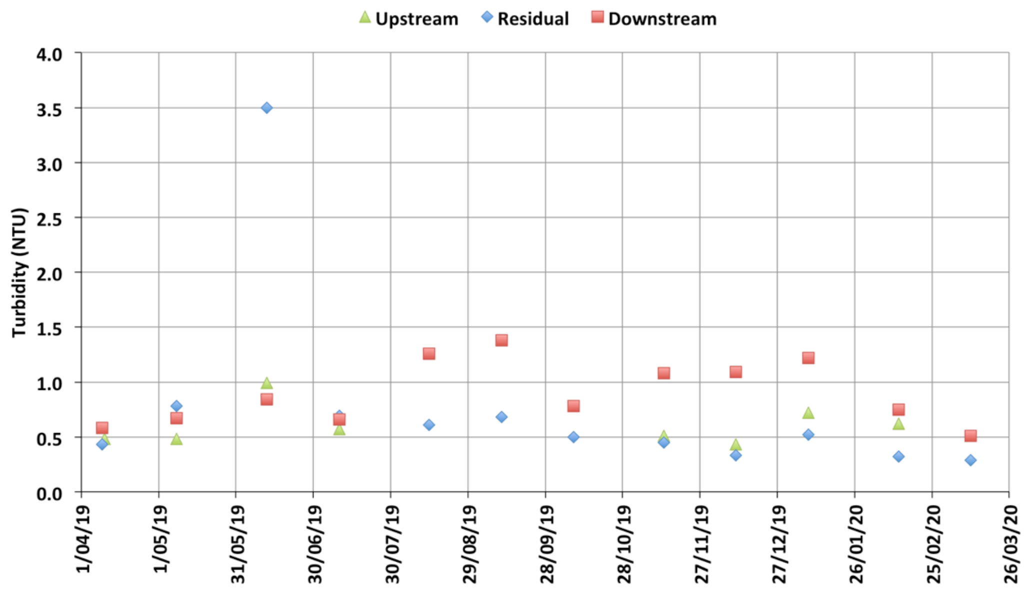

Figure 3.7. Turbidity level (NTU) at Waiwhakaiho River sites, April 2019 – March 2020.

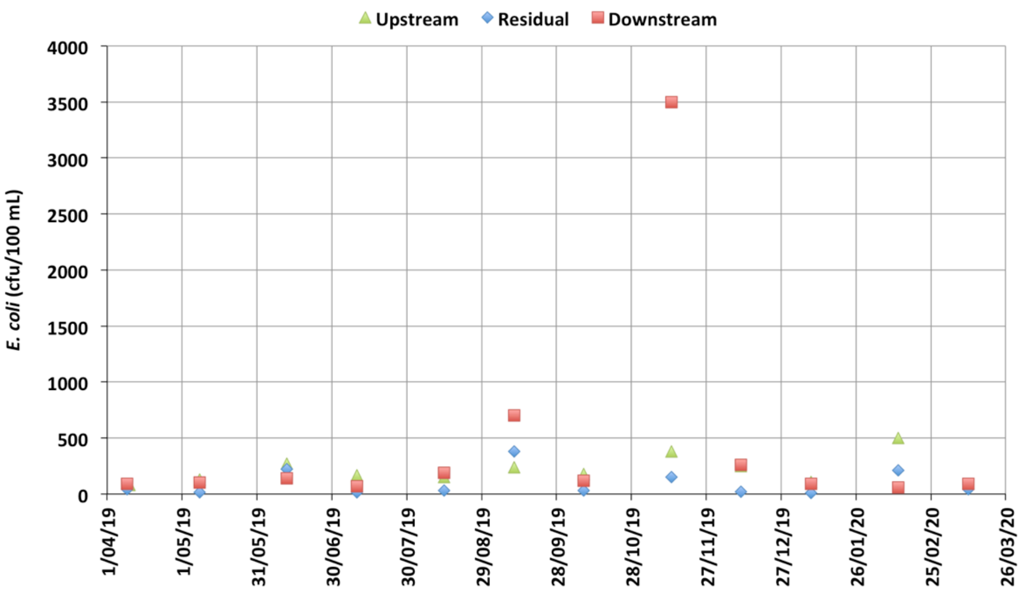

Figure 3.8.* E. coli *concentration (cfu/100 mL) at Waiwhakaiho River sites, April 2019 – March 2020.

3.2. Water quality – water temperature

Summary

Water temperatures outside an optimum range can have adverse effects on aquatic communities. Temperatures above the optimum can cause thermal stress and, if high and prolonged enough, death. Brown trout have lower temperature tolerances than native fish, with acute thermal criteria of 24.6 °C, and chronic thermal criteria of 19.6 °C (Todd *et al.* 2008). In the Waiwhakaiho River brown trout are therefore the main fish species of concern with respect to water temperature. The highest water temperatures occur in the river over January and February. Water temperatures are typically higher in the residual river reach downstream of the Mangorei HEPS intake than upstream during summer, and at times exceed the recommended thermal criteria for brown trout. Unfortunately the optimum temperature has not been determined for any native freshwater organisms. Thermal preferences and incipient lethal temperatures for a range of native fish and macroinvertebrate taxa however have been compiled. These indicate that water temperatures in the residual river reach are typically within the range of thermal preferences for native fish species, and also within the range when normal behaviour/development is apparent.

Analysis and discussion

Water temperature monitoring data for three sites in the Waiwhakaiho River is analysed annually as part of the TRC's compliance monitoring of the Mangorei HEPS. Water temperature at the Residual site is compared to that Upstream (SH3 bridge) and at Rimu Street (approximately 13 km downstream of the intake weir and 8 km downstream of the Mangorei HEPS tailrace discharge). This comparison was undertaken to assess the potential effects of the reduced flow through the residual flow reach, and the release of water through generation on water temperatures in the middle and lower reaches of the Waiwhakaiho River (TRC 2020).

TRC monitoring over the 2018-2019 period concluded that water temperatures in the river exhibited the effect of an unusually hot summer (Table 3.2), coupled with a typical change in water temperature in a downstream direction attributable to the HEPS (TRC 2020). Whether or not the temperature increase is attributable to the HEPS is investigated further below.

Table 3.2 Summary of maximum daily water temperatures in the Waiwhakaiho River at three monitored locations in summer (between 1 December and 31 March). Adapted from TRC (2020).

Site	Number of taxa	Number of days monitored	Percentage of maximum temperatures in this range (number of days)			
			10-15 °C	15-20 °C	20-25 °C	>25 °C
Upstream	1991-2018	3115	12.7	79.0	8.3	0
	2018-2019	121	1.7 (2)	74.4 (90)	24.0 (29)	0
Residual	1991-2018	2898	2.1	48.9	47.8	1.2
	2018-2019	121	0	32.2 (39)	62.8 (76)	5 (6)
Rimu Street	1991-2018	3251	1.0	52.2	45.8	0.9
	2018-2019	121	0	32.2 (39)	65.3 (79)	2.5 (3)

Water temperatures outside an optimum range can have adverse effects on aquatic communities. Most aquatic organisms have little or no ability to thermoregulate, so their growth is strongly linked to temperature and they have an optimum temperature at which growth is maximised. Below the optimum temperature growth gradually declines, but of more concern is temperatures above optimum, which can cause thermal stress and if high enough death (because of effects on cellular function, with enzymes becoming denatured). For most aquatic organisms there is a narrow temperature range between optimum and lethal temperatures (perhaps 5 °C), meaning that temperatures above optimum can rapidly become stressful (Davies-Colley *et al.* 2013).

The goal for long-term (chronic) management should be to avoid temperatures going into the 'stress zone' for organisms, unfortunately the optimum temperature has not been determined for any native freshwater organisms (Davies-Colley *et al.* 2013). Lethal temperatures are less difficult to determine so have been defined for more species (Davies-Colley *et al.* 2013).

Thermal preferences and incipient lethal temperatures for a range of native fish and macroinvertebrate taxa have been compiled by Olsen *et al.* (2012) (Figure 3.9). Of the invertebrate species for which data are available mayflies (Ephemeroptera) and stoneflies (Plecoptera) seem to be most sensitive to high temperatures, with incipient lethal temperatures of approximately 21 - 23 °C. All of the native fish species shown (inanga, smelt, longfin and shortfin eels) have incipient lethal temperatures greater than 25 °C. Brown trout have lower temperature tolerances than native fish, with acute thermal criteria of 24.6 °C, and chronic thermal criteria of 19.6 °C (Todd *et al.* 2008). In the Waiwhakaiho River, brown trout are therefore the main fish species of concern with respect to water temperature.

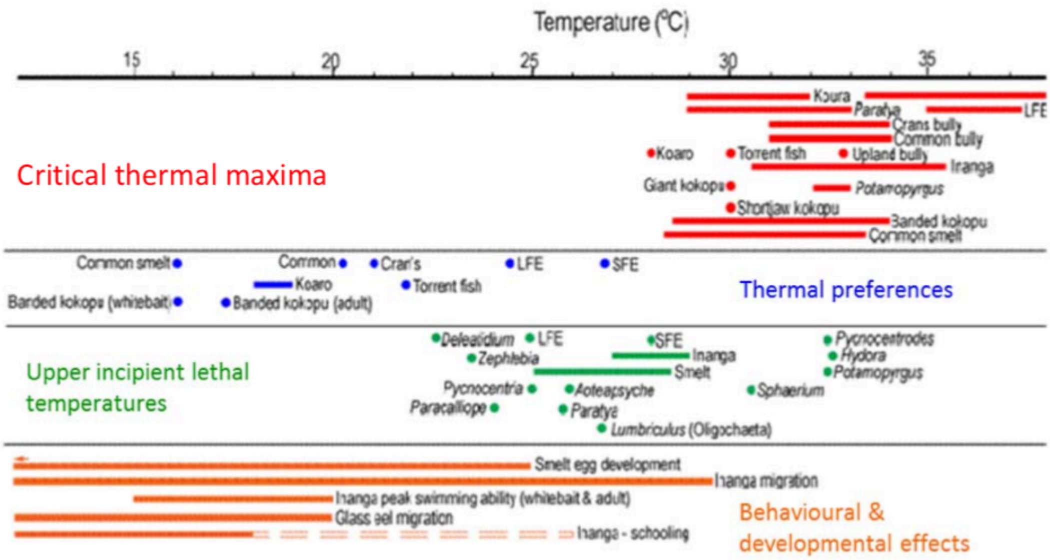

Figure 3.9. Summary of thermal tolerance of native fish and macroinvertebrates as defined by critical thermal maxima (CTM - red), thermal preferences (blue), upper incipient lethal temperature (UILT — green) and behavioural and developmental effects (orange). Where CTM or UILT have been determined for multiple acclimation temperatures, the range is shown as a bar. Behavioural and developmental effects are shown as bars representing the range of temperatures when normal behaviour/development is apparent. Inanga schooling is dependent on acclimation temperature (from Olsen **et al.** ***2011, Hay and Allen 2015).***

In order to understand how existing water temperatures in the river compared to brown trout thermal requirements, the long-term (2008 – 2020) water temperature monitoring data (15-minute measurements) was examined for two sites; Upstream (SH3) and Residual (Hydro Road). The Residual site is likely to provide the 'worst case scenario' for maximum water temperatures within the residual reach, as the site is located at the downstream end of the reach and water temperatures are expected to increase downstream. The number of days within the 12-year period that brown trout acute (24.6 °C, lethal but short duration) and chronic (19.6 °C, sub-lethal but prolonged) temperatures were exceeded was calculated for the two sites. For the acute criteria exceedance we calculated the highest two-hour average water temperature within any given 24-hour period. For the chronic criteria exceedance we calculated the maximum weekly average from the seven-day mean of consecutive daily mean temperatures, where daily means were calculated from multiple 15-minute interval values per day (Todd *et al.* 2008).

At both the Upstream and Residual sites the highest water temperatures occurred over the January to February period (Table 3.3 and Figure 3.10). The maximum hourly water temperature recorded at the Upstream site was 23.8 °C in January 2018, and at the Residual site 26.9°C in January 2019 (Table 3.3). Maximum daily average temperatures at the Upstream site were 21.7 °C, and at the Residual site 24.2 °C (Table 3.3).

In general, water temperatures at both the Upstream and Residual sites were below the critical thermal maxima and upper incipient lethal temperatures for most native fish species (Figure 3.9). Water temperatures were typically within the range of thermal preferences for native fish species and also within the range of temperatures when normal behaviour/development is apparent. However at times the incipient lethal temperatures of 'sensitive' benthic macroinvertebrates taxa (e.g., mayflies and stoneflies 21 - 23 °C) were exceeded.

The water temperature analysis found that brown trout acute thermal criteria were never exceeded at the Upstream site, but at the Residual site were exceeded 0.9% of the time (Table 3.3). The brown trout chronic thermal criteria was exceeded 0.3% of the time at the Upstream site (exceeded at times during the months of January and February, but not in other months), and at the Residual site was exceeded 8% of the time (at times during the months of January, February, March, November and December) (Figure 3.10). The maximum hourly and daily temperatures over the 12-year period were higher at the Residual site than the Upstream site (Table 3.3).

However, water temperatures typically naturally increase downstream in rivers, so even in the absence of water abstraction, higher water temperatures would be expected at the Residual site than the Upstream site given that the Residual site is 7 km downstream and at altitude approximately 100 m lower than the Upstream site (this is discussed further in Section 4.2).

Table 3.3. Maximum water temperatures, and exceedance of acute and chronic thermal criteria for the protection of brown trout at two sites in the Waiwhakaiho River during 2008 - 2020. Criteria based on Todd* et al*. (2008).

Site	Monitoring period	Number of days in data record	Maximum hourly temperature (°C)	Maximum daily average temperature (°C)	Percentage (and number) of days in data record exceeding thermal criteria	
					Acute (24.6 °C)	Chronic (19.6 °C)
Upstream	01/01/08 – 01/03/20	4,376	23.8 (29/01/18 18:00)	21.7 (01/30/19)	0	0.3% (14)
Residual	01/01/08 – 18/02/20	4,247	26.9 (29/01/19 15:00)	24.2 (01/30/18)	0.9% (37)	8% (332)

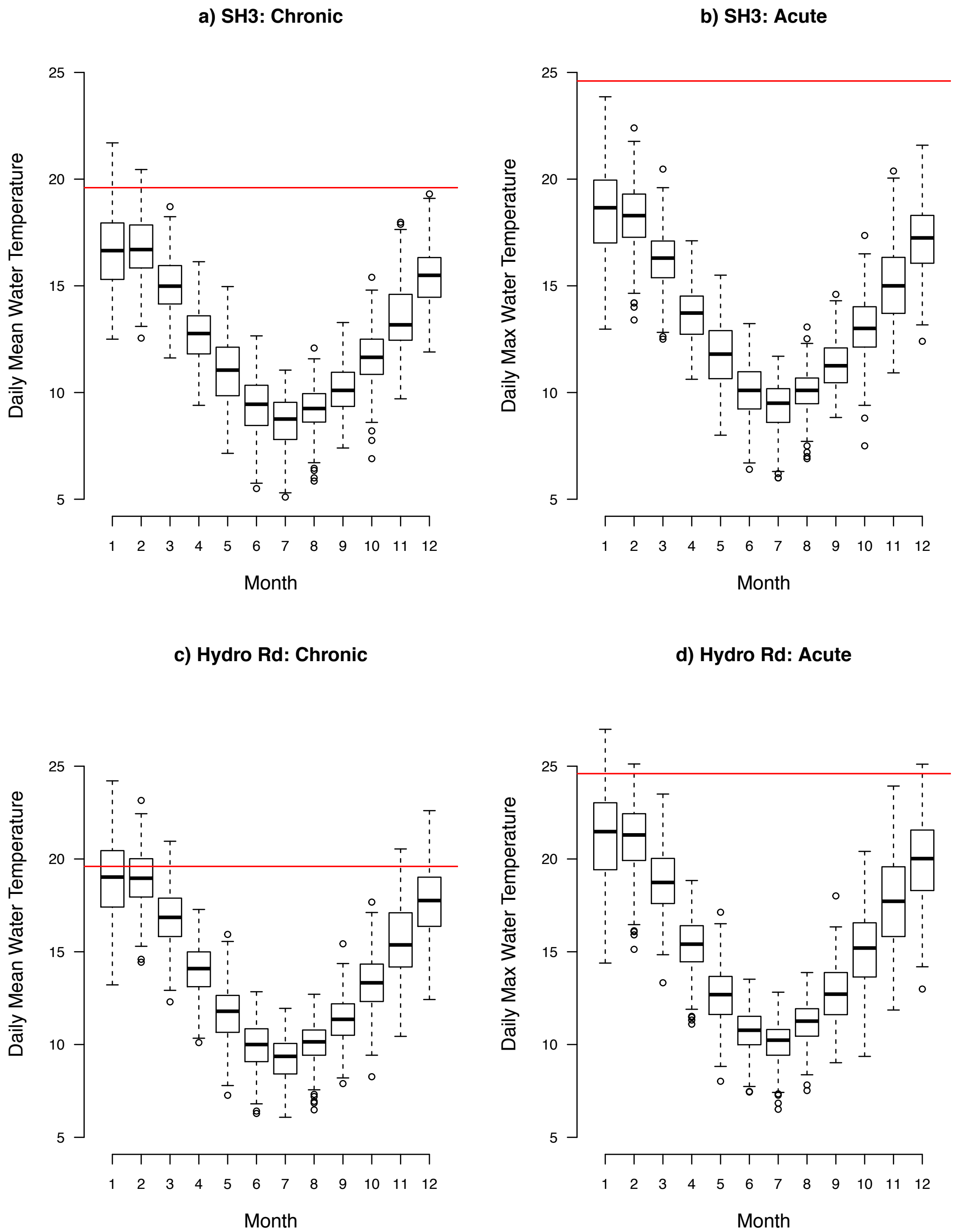

Figure 3.10. Boxplots showing monthly distribution of daily mean and maximum water temperatures from 2008 – 2020 at the Upstream (SH3) and Residual (Hydro Road) sites in the Waiwhakaiho River. Brown trout acute and thermal criteria are shown by the red lines. Criteria based on Todd **et al.** ***(2008).***

Top: SH3 - Upstream (a - chronic, b - acute). Bottom: Hydro Rd - Residual (c - chronic, d - acute).

TRC (2020) noted that the generation discharge from the Mangorei HEPS is thought to input cooler water into the Waiwhakaiho River, however, no temperature monitoring has previously been undertaken in Lake Mangamahoe or in the river immediately below the discharge to confirm if this is the case. To provide information for the assessment an additional water temperature logger was therefore installed in the river (by Trustpower together with Riverwise Consulting[6]) in August 2019 immediately downstream of the Mangorei HEPS tailrace (approximately 6 km downstream of the intake weir).

Water temperature data (15-minute measurements) at each site from August 2019 to February 2020 is presented in Figure 3.11, together with flow at the Upstream site (15-minute measurements). Site names shown are as follows:

- Upstream: TRC SH3 Bridge, site code WKH000500 (approximately 2 km upstream of the intake weir).
- Residual: TRC Hydro Road, site code WKH000655 (approximately 5 km downstream of the intake weir).
- Downstream: Trustpower Meeting of the Waters (approximately 6 km downstream of the intake weir and immediately downstream of the Mangorei HEPS tailrace discharge).
- Rimu Street: TRC, site code WKH000820 (approximately 13 km downstream of the intake weir and 8 km downstream of the Mangorei HEPS tailrace discharge).

As expected, water temperature at all sites followed a seasonal pattern with an overall increase in temperature from August 2019 to February 2020. There was some short-term variation in temperatures however these were related to weather events and resulting flow variation (e.g., 20 December 2019) (Figure 3.11). Maximum water temperatures were observed in late January 2020 (Figure 3.12). This was associated with a period of sustained low flow, with flows at the Upstream site ultimately dropping to levels around the mean annual low flow (MALF) of 2.110 m^3/s for approximately 16 days in February (5 – 21 February). Flows at Rimu Street showed more variation, as a result of generation discharges from the Mangorei HEPS.

Maximum water temperatures over the August 2019 to February 2020 period occurred at all sites on the 26 January 2020 (Figure 3.12). The maximum temperature and its timing varied among sites, with the highest temperature of 25.7 °C recorded at the Residual site at 17:00 hours and the lowest temperature of 21.5 °C recorded at the Upstream site at 16:15 hours. The generation discharge

[6] Water temperature loggers were installed and maintained by Riverwise Consulting. Raw temperature data was provided to Ryder Environmental for analysis and interpretation.

from the Mangorei HEPS appeared to have a slight cooling effect on water temperature, as the maximum temperature recorded at the Downstream site was 25.1 °C at 16:00 hours (i.e. lower than that at the Residual site approximately 500 m upstream). At Rimu Street maximum water temperatures occurred earlier in the day with 25.0 °C recorded at 15:00 hours. Variation in water temperatures among the four monitoring sites are not unexpected, as in addition to the flow variation amongst sites due to the Mangorei HEPS, they span a distance within the river of 15 km and range in altitude from 20 to 175 m above sea level. In order to separate out the effects of this variation from any effects of the operation of the Mangorei HEPS a water temperature model was therefore developed (this is presented in Section 4.2).

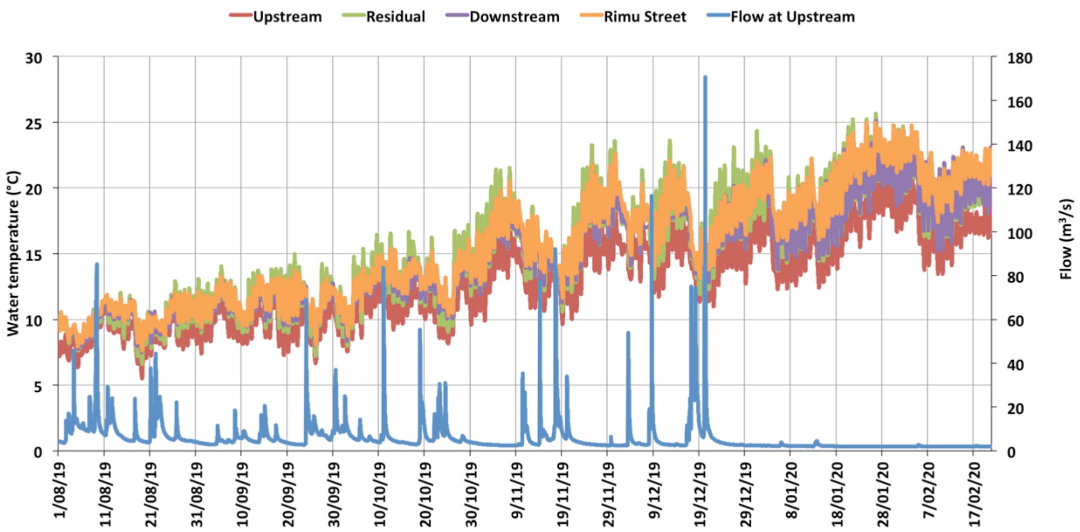

Figure 3.11. Water temperature (°C) at Waiwhakaiho River sites (15-minute measurements), August 2019 – February 2020. 15-minute flow (m^3/s) data for the Upstream (SH3) site over the same period is also shown.

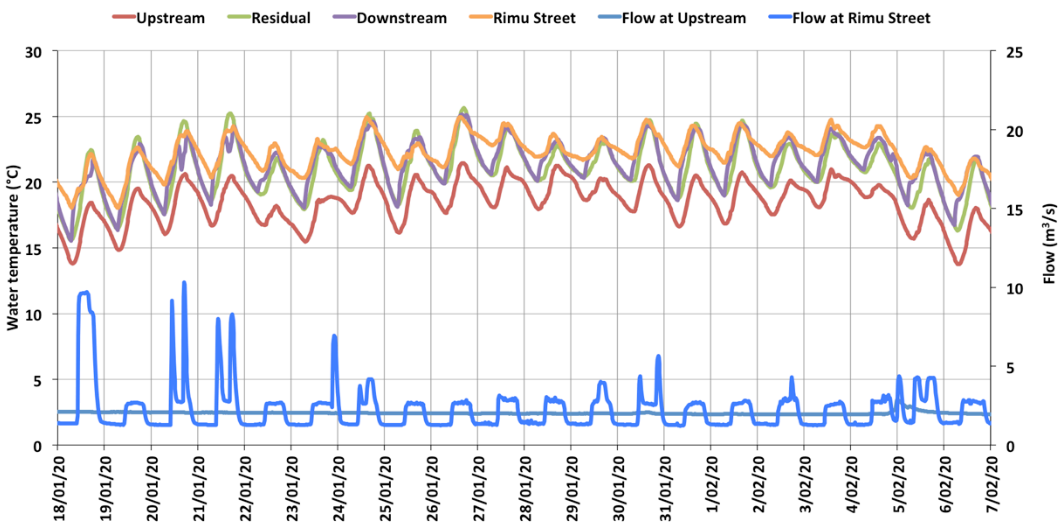

Figure 3.12. Water temperature (°C) at Waiwhakaiho River sites (15-minute measurements), 18 January – 7 February 2020. 15-minute flow (m^3/s) data for the Upstream (SH3) and Rimu Stream sites over the same period is also shown.

3.3. Water quality – dissolved oxygen

Summary

Low oxygen levels can have negative impacts on aquatic life particularly fish. The National Policy Statement for Freshwater Management (NPS-FM) includes nationally set minimum acceptable states for dissolved oxygen in rivers below point sources. Monitoring during 2019-2020 downstream of the Mangorei HEPS tailrace discharge found that for the majority of the monitoring period dissolved oxygen concentration was above the NPS-FM acceptable state. However, for a short period at the end of January 2020 dissolved oxygen concentrations fell below the NPS-FM minimum acceptable states, although this may have been related to erroneous measurements. In any case, low dissolved oxygen levels at this time were not related to the discharge of oxygen-depleted water from Lake Mangamahoe. In fact, the generation discharge had the effect of increasing dissolved oxygen levels in the river.

Analysis and discussion

If stratification[7] occurs in a hydroelectric reservoir power generation can result in oxygen-depleted water being discharged to the river downstream. Low oxygen levels can have negative impacts on aquatic life particularly fish.

Dissolved oxygen monitoring has not been undertaken previously in Lake Mangamahoe, or the river immediately below the discharge, so, to provide information to determine if oxygen-depleted water is being discharged, a dissolved oxygen logger was installed in the river (by Trustpower together with Riverwise Consulting[8]) in August 2019 immediately downstream of the Mangorei HEPS tailrace (approximately 6 km downstream of the intake weir).

Dissolved oxygen monitoring data (15-minute measurements) for the Downstream site from November 2019 to February 2020 is presented in Figure 3.13, together with flow at the Rimu Street site (15-minute measurements). Regular calibration

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[7] Stratification occurs in some reservoirs and lakes where the temperature profile of the lake stratifies vertically, resulting in an upper layer of warmer water and a deeper layer of cooler water, and limited mixing between the layers. The differences in temperature limits the two layers of water mixing to the extent that oxygen in the deeper water cannot be replenished from the upper layer. Stratification eventually 'breaks down' and when this occurs[7] the oxygen depleted bottom layer of water mixes with the more oxygen rich surface layer, causing oxygen levels in surface waters to decline.

[8] Dissolved oxygen loggers were installed and maintained by Riverwise Consulting. Raw dissolved oxygen data was provided to Ryder Environmental for analysis and interpretation.

checks of the dissolved oxygen logger were undertaken during the monitoring period using a hand-held field meter to provide a reference comparison. The percentage variation between logger and field meter measurements on four occasions ranged from 1.5 to 8.5% for dissolved oxygen concentration (i.e. variation range of 0.16 to 0.96 mg/L concentration) and 0.6 to 9.2% for dissolved oxygen saturation (i.e. variation range of 0.69 to 11.32% saturation). On all four calibration occasions during the November 2019 to February 2020 period the logger measurement was higher than the field meter measurement. No edits were made to the data to account for these differences as the variation was considered to be within acceptable bounds for the purpose of the analysis.

NPS-FM (MfE 2014, amended 2017[9]) includes nationally set minimum acceptable states for dissolved oxygen in rivers below point sources (which applies to the Mangorei HEPS tailrace discharge). There are two national numeric attribute states for dissolved oxygen, a 7-day mean minimum of 5.0 mg/L and a 1-day mean minimum of 4.0 mg/L. Both apply only over the summer period (defined as 1 November to 30 April).

For the majority of the monitoring period dissolved oxygen concentration at the Downstream site was above the NPS-FM acceptable state of a 7-day mean minimum of 5.0 mg/L (Figure 3.13). However, on the 23 January 2020 dissolved oxygen concentrations fell below 5.0 mg/L, and over the period 25 to 31 January a 7-day mean minimum of 2.1 mg/L was observed (i.e. below the NPS-FM minimum acceptable state). The minimum daily mean dissolved oxygen concentration (2.5 mg/L on the 28 January) was also below the NPS-FM 1-day minimum acceptable state. During this period of low dissolved oxygen levels there was a pattern of daily minimum dissolved oxygen levels occurring late at night, then increasing the following morning (Figure 3.14). The morning increase in dissolved oxygen levels was associated with the generation discharge, coinciding with the timing of the Mangorei HEPS consent condition to maintain a continuous generation flow release of at least 0.95 m^3/s between 8:00 am and 6:00 pm each day (Consent 2053-3.2 Special condition 1). The low levels of dissolved oxygen late at night coincided with times when there was no generation, and also occurred during the period when respiration by macrophytes and periphyton can deplete dissolved oxygen levels. The period of low dissolved oxygen levels continued through to the

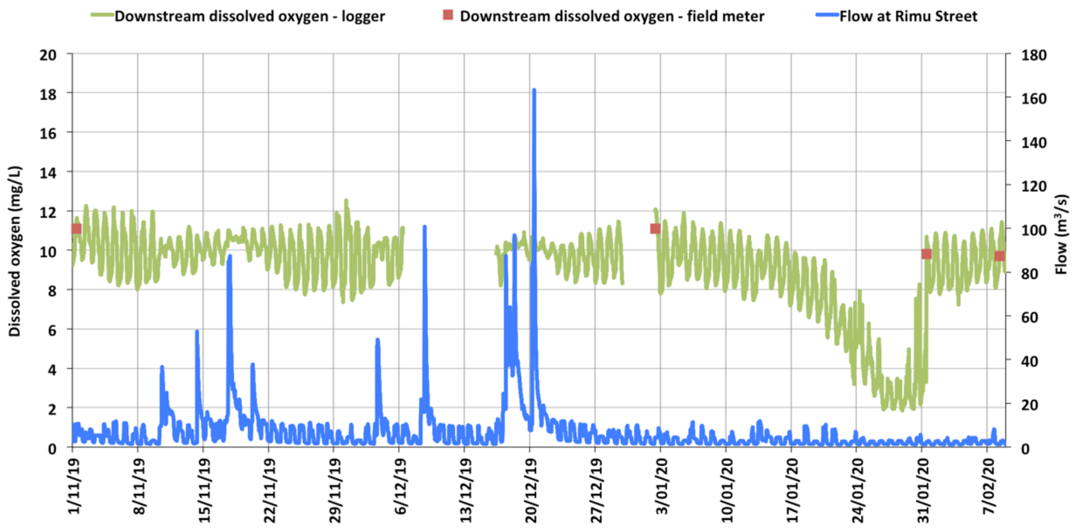
[9] A revised NPS-FM draft document was provided for public consultation in September 2019. A final document has not yet been issued, however it is noted that the draft NPS-FM 2019 document has the same national minimum acceptable states for dissolved oxygen as the previous version (MfE 2014, amended 2017).

morning of the 30 January 2020, when an increase in generation flows occurred[10] and raised concentrations above 5.0 mg/L (Figure 3.14). Throughout this period flows in the river upstream of the tailrace discharge remained low and relatively stable (Figure 3.14), as did flows in the river at the Upstream site (Figure 3.12).

An alternative explanation for the observed period of low dissolved oxygen is that the dissolved oxygen logger was in fact giving erroneous measurements. The logger was installed towards the true left side of the river (Figure A1.3) where it was protected from high flows but meaning that during low flows it was outside of the primary flow (Figure A1.3). This could have resulted in low dissolved oxygen readings in the local area of the logger. Calibration of the logger on the 31 January (red squares in Figures 3.13 and 3.14) was also associated with the end of the low dissolved oxygen period, also supporting the explanation of erroneous measurements (noting though the logger measurement of 10.6 mg/L did align reasonably well with the field meter measurement of 9.8 mg/L at the same time).

In any case, low dissolved oxygen levels in the river in late January 2020 were not related to the discharge of oxygen-depleted water from Lake Mangamahoe. In fact, the generation discharge had the effect of increasing dissolved oxygen levels in the river. Maximum summer water temperatures were also observed during this time and were associated with a period of sustained low flow, with flows at the Upstream site around low flow (MALF) conditions throughout (Figure 3.12).

[10] This included the use of a larger output generation unit for short periods on the 30 and 31 January 2020 (Chis England, Trustpower, pers. comm.).



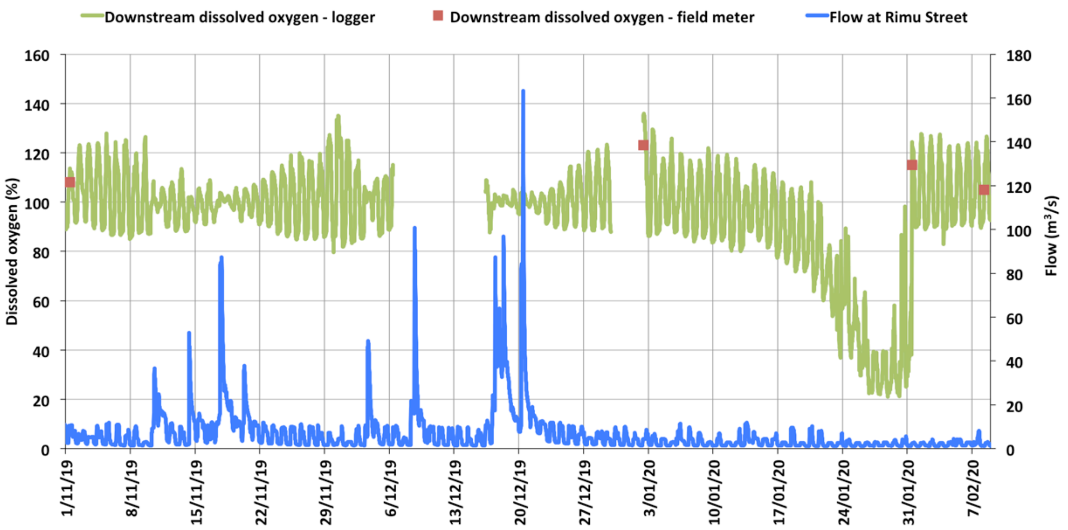
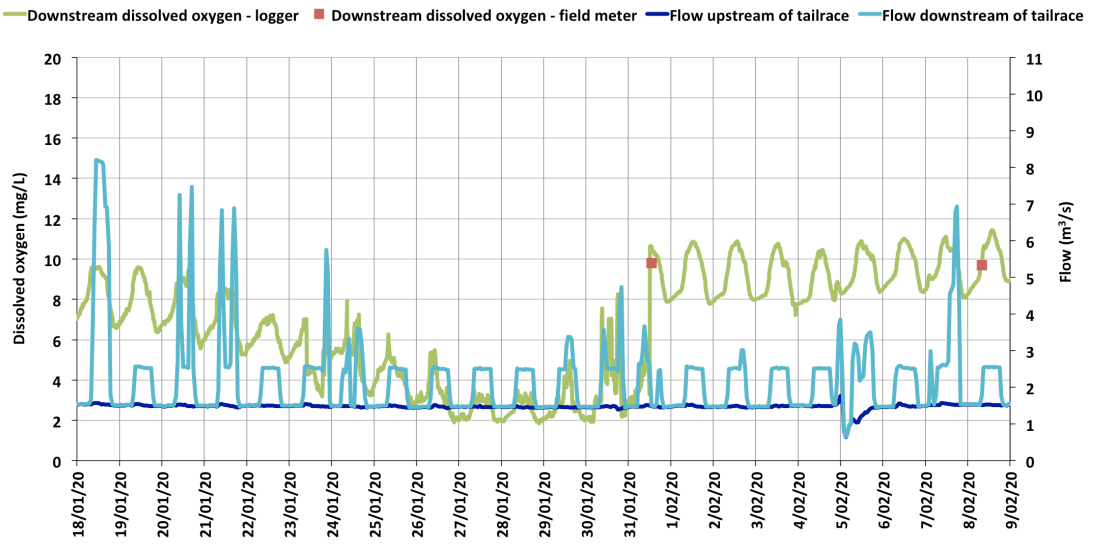


Figure 3.13. Dissolved oxygen levels at the Waiwhakaiho River Downstream site (15-minute logger and field meter spot measurements), 1 November – 9 February 2020. 15-minute flow (m^3/s) data for Rimu Street site over the same period is also shown.

Top: Dissolved oxygen concentration (mg/L). Bottom: Dissolved oxygen saturation (%).



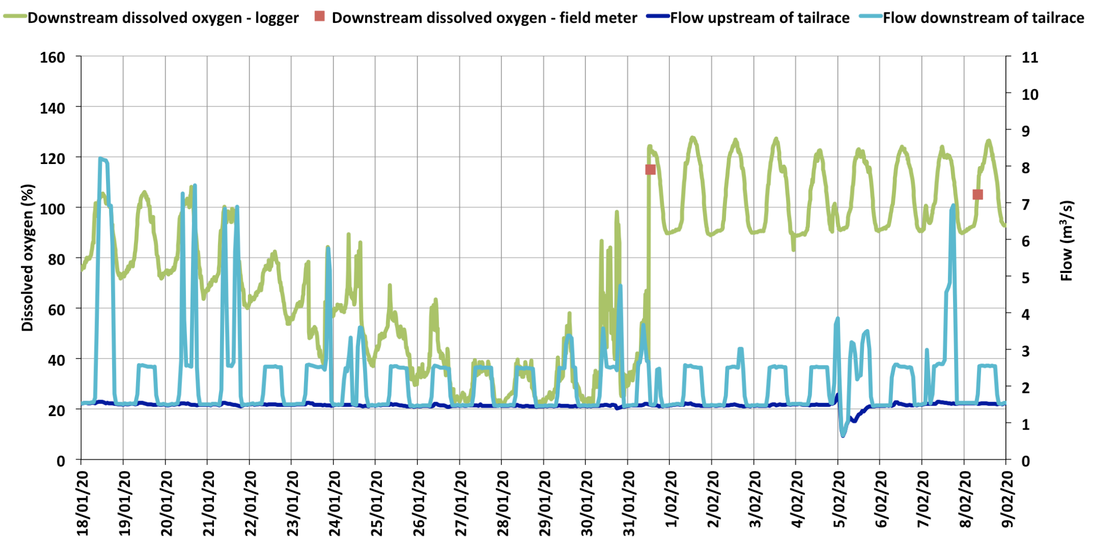


Figure 3.14. Dissolved oxygen levels at the Waiwhakaiho River Downstream site (15-minute logger and field spot measurements), 18 January – 9 February 2020. One hour flow (m^3/s) data upstream and downstream of the tailrace over the same period is also shown (data for these location synthesized by Tonkin and Taylor). Water temperature data for this period is shown in Figure 3.12.

Top: Dissolved oxygen concentration (mg/L). Bottom: Dissolved oxygen saturation (%).

3.4. Periphyton

Summary

Periphyton is essential for the functioning of healthy ecosystems, but when it proliferates it can become a nuisance by degrading instream values. Proliferations of long filamentous nuisance algae occur at times at all of the Waiwhakaiho River monitoring sites. Key factors controlling periphyton growth include sunlight, nutrient concentration, temperature, grazing by invertebrates and flow history (i.e. the history of bed disturbance). Monitoring over the 2019-2020 summer found that periphyton biomass was higher downstream of the Mangorei HEPS take than upstream. Over the April 2019 to February 2020 period the guideline for benthic biodiversity of 50 mg/m^2 was however exceeded at times at all three sites.

Analysis and discussion

TRC monitors the periphyton (algae)[11] community at two sites in the Waiwhakaiho River; Upstream (SH3 bridge, approximately 2 km upstream of the intake weir) and at Constance Street (approximately 15 km downstream of the intake weir and 2 km from the river mouth[12]).

Periphyton <u>cover</u> has been monitored at both sites twice annually since 2002 (except at times when high flows have prevented monitoring); in spring (15 September to 31 December) and summer (1 January to 15 April). The percentage cover of thick mats and long filaments is determined and compared to New Zealand Periphyton Guidelines for recreation (Biggs 2000). The guidelines are exceeded when at least 30% of the bed is covered by filamentous algae and/or at least 60% of the bed is covered by thick mats of algae. Thick mat cover has never exceeded guideline levels at either site, however long filamentous algae cover has exceeded the guidelines at both sites at times. At the Constance Street site long filamentous algae cover guideline exceeded the guideline on approximately 12% of monitoring occasions over the 16 years of monitoring (2002 to 2018). At the Upstream site long filamentous algae cover exceeded the guidelines on approximately 35% of monitoring occasions. At both sites guidelines were exceeded most frequently

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[11] The TRC freshwater nuisance periphyton programme has been designed to monitor the coverage and biomass of algae in Taranaki streams and rivers which may affect the instream values of these streams (TRC 2018).
[12] Note that TRC long-term periphyton monitoring sites were not specifically chosen to assess the effects of the Mangorei HEPS, so the Constance Street site is a long distance downstream of the intake.

during the period 2002 to 2006. Trend analysis over the full monitoring period 2002 to 2018 however found no change through time in the percentage cover of thick mats or the cover of long filaments at either site (TRC 2018).

Periphyton biomass (chlorophyll-*a*) has been monitored at the Upstream and Constance Street sites since 2011. Biomass monitoring was initially only undertaken during summer, but in March 2017 the frequency of monitoring at the Upstream site increased to monthly monitoring. Annual summer monitoring has continued at the Constance Street site.

The New Zealand Periphyton Guideline for the protection of benthic biodiversity is 50 mg/m^2 chlorophyll *a* (Biggs 2000). There is also a requirement through the NPS-FM to ensure streams and rivers are above the D band (chlorophyll *a* 200 mg/m^2 no more than 8% of the time) from 2025 onwards (MfE 2014, amended 2017). TRC's long-established annual chlorophyll *a* sampling protocol however differs from that for the National Objectives Framework (NOF), which requires monthly monitoring, and therefore results cannot yet be directly translated to NOF bands[13].

Periphyton biomass data for the Upstream and Constance Street sites from March 2011 to February 2020 is presented in Figure 3.15. Note that there was a change in laboratory for the periphyton biomass analysis in June 2018 (from the internal TRC laboratory to the Environment Bay of Plenty laboratory), and due to variation in processing methods this may have resulted in some differences in biomass through time (K. Blakemore, TRC pers. comm.) The guideline for benthic biodiversity (50 mg/m^2) was exceeded at times at both sites: at the Constance Street site on approximately 40% of monitoring occasions (4 out of 10 monitoring occasions), and at the Upstream site on approximately 28% of monitoring occasions (9 out of 32 monitoring occasions). The required three years of monthly monitoring data have not yet been collected for the Upstream site, however monitoring to date also indicates that this site would not meet the NOF band D requirements as the maximum concentration of 200 mg/m^2 was exceeded on two occasions (in May and June 2018, Figure 3.15).

Overall, the long-term monitoring of periphyton cover and biomass in the Waiwhakaiho River indicates that long filamentous nuisance algae proliferations occur at times at both the Upstream and Constance Street sites, slightly more often at the Upstream site.

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[13] The minimum record length for grading a site based on periphyton biomass (chl-*a*) is three years of monthly monitoring (MfE 2014, amended 2017). Monthly monitoring began at the Upstream (SH3) site in March 2017, however in some months monitoring has not been undertaken. Up until February 2020 there have been 26 measurements made, rather than the expected 36 for three years of monthly monitoring.

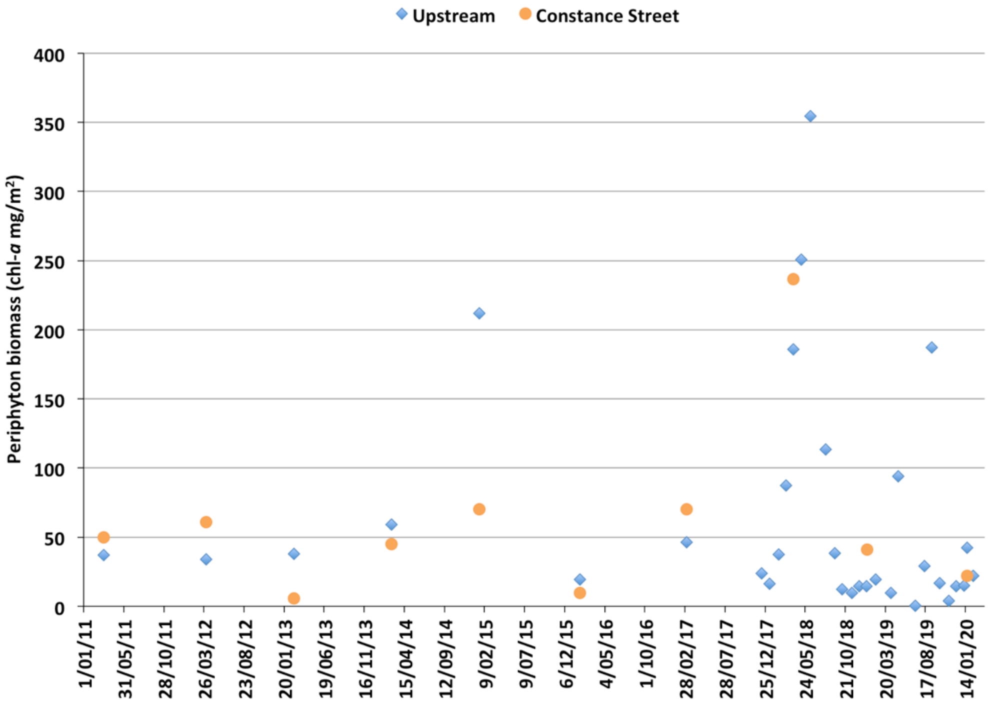


Figure 3.15. Periphyton biomass (chl-*a *mg/m²) at Waiwhakaiho River sites, March 2011 – February 2020.

In order to compare periphyton biomass at the Upstream site (where TRC monitors biomass monthly) to that at sites that may be impacted by activities downstream including the Mangorei HEPS, monthly biomass monitoring was also undertaken at two sites downstream of the intake weir from April 2019 to February 2020 (by Riverwise Consulting on behalf of Trustpower[14]). One site was located within the Residual flow reach (Hydro Road), and the second site downstream of the point where the Mangorei HEPS tailrace enters the river (Downstream site). Monthly monitoring data from March 2017 to February 2020 is presented in Figure 3.16.

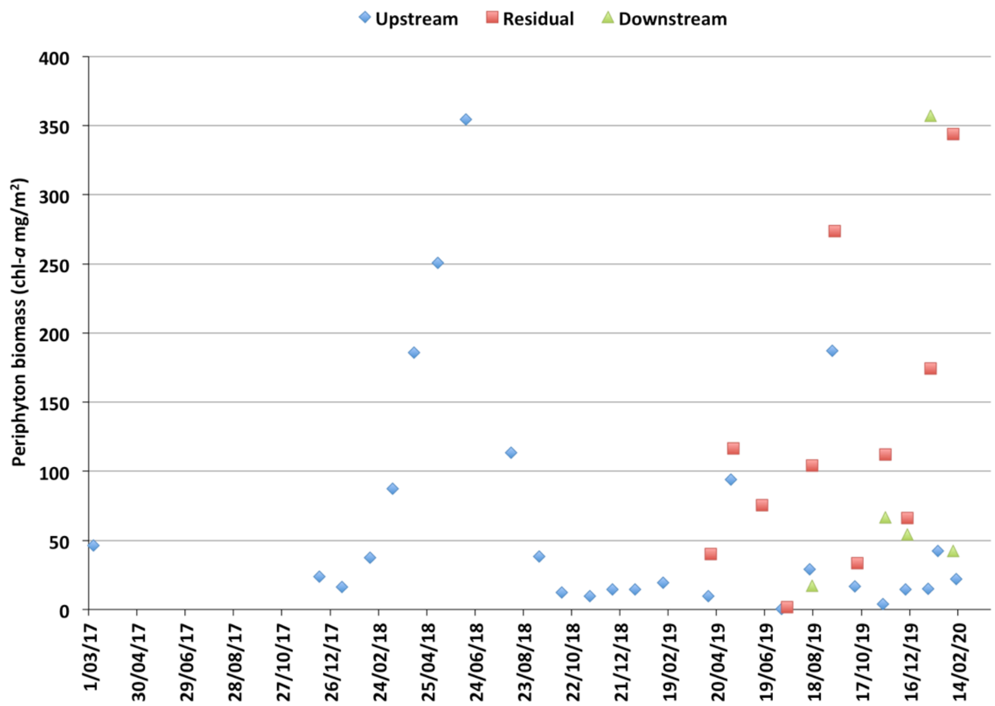
Sampling could not be undertaken at the Upstream site in June 2019 due to high flows, and similarly sampling was only possible at the Downstream site on five occasions due to high flows. Otherwise, all sites were monitored within 3 to 7 days of each other (through co-ordination between Riverwise Consulting and TRC), using the same method[15], with the same laboratory used to process samples

[14] Periphyton samples were collected by Riverwise Consulting and sent to Environment Bay of Plenty for processing. Raw biomass data was then provided to Ryder Environmental for analysis and interpretation.
[15] Specialised periphyton biomass sampling equipment was loaned by the TRC to Riverwise Consulting, and therefore monitoring could not take place at all three sites on the same day.

(Environment Bay of Plenty). Due to the 'flashy' nature of the river the timing of monitoring at each of the sites meant that there was some variation in flows between monitoring times that may have resulted in differences in periphyton biomass at each site that were related to increased flows (i.e. through flushing of periphyton off rocks) (Figure 3.16).

Over the April 2019 to February 2020 period the guideline for benthic biodiversity of 50 mg/m^2 was exceeded at times at all three sites. At the Upstream site the guideline was exceeded on 2 out of 11 monitoring occasions, at the Residual site on 9 out of 11 monitoring occasions, and at the Downstream site on 3 out of 5 monitoring occasions.

Flows were relatively stable in the river during January to February 2020, and comparing all three sites at this time periphyton biomass was higher at the Residual and Downstream sites than Upstream (Figure 3.16). Periphyton cover monitoring undertaken at the Residual site in spring and summer indicates that filamentous algae dominated the periphyton community. Maximum periphyton biomass at each of the Residual and Downstream sites over the January to February 2020 period was approximately 350 mg/m^2. Similarly, high biomass levels have however also been recorded at the Upstream site previously (in June 2018, Figure 3.16), due to long filamentous nuisance algae proliferations (TRC 2018).



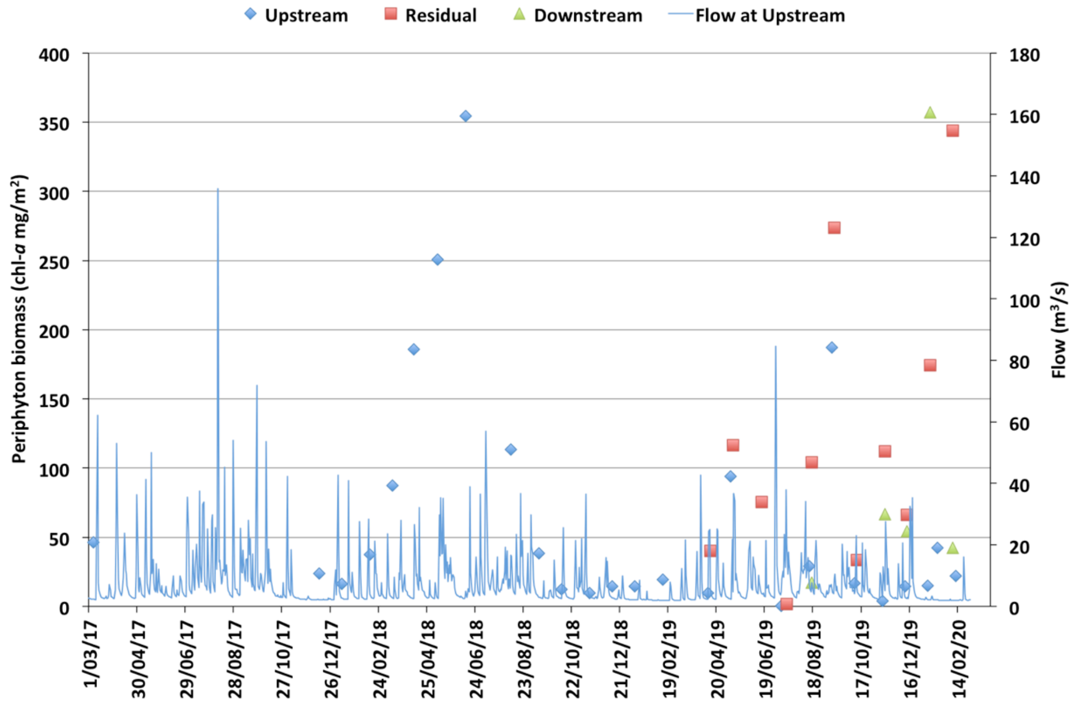


Figure 3.16. Periphyton biomass (chl-*a *mg/m²) at Waiwhakaiho River sites, March 2017 – February 2020.

Top: Without flow data. Bottom: Including mean daily flow (m³/s) at the Upstream site.

3.5. Macroinvertebrates

Summary

Benthic macroinvertebrates are a range of aquatic taxa (e.g. insects, crustaceans, molluscs, worms and leeches) that have a crucial role in freshwater ecology and respond to changes in water quality, hydrological patterns and/or habitat. Warm summer water temperatures, increased periphyton cover, and low flows (combined with lifecycle patterns) can result in less 'sensitive' macroinvertebrate taxa being present and/or increases in the abundance of lower scoring 'tolerant' taxa. With the exception of the number of taxa, the median values of macroinvertebrate metrics tend to decrease downstream in the Waiwhakaiho River, indicating a decline in community health downstream. This is expected as the river exits the national park and land-use intensity increases downstream. Ten-year trend analysis of MCI scores at long-term monitoring sites indicates degrading health at all except the National Park site. Macroinvertebrate community health has tended in the past to be higher upstream of the Mangorei HEPS take than downstream, however in February 2019, November 2019 and February 2020 macroinvertebrate community scores (SQMCI) at both the Upstream and Residual site were indicative of 'poor' health.

Analysis and discussion

TRC monitors the benthic macroinvertebrate community at five sites in the Waiwhakaiho River:

- National Park: TRC National Park boundary, site code WKH000100 (approximately 11 km upstream of the intake weir).
- Upstream: TRC SH3 Bridge, site code WKH000500 (approximately 2 km upstream of the intake weir).
- Residual: TRC Hydro Road, site code WKH000655 (approximately 5 km downstream of the intake weir).
- Constance Street: TRC, site code WKH000920 (approximately 15 km downstream of the intake weir and 9 km downstream of the Mangorei HEPS tailrace discharge).
- Downstream Lake Rotomanu: TRC, site code WKH000950 (approximately 18 km downstream of the intake weir and 12 km downstream of the Mangorei HEPS tailrace discharge).

Benthic macroinvertebrates have been monitored at three of these sites since 1995-1996. The National Park site was added in 2002-2003, and the Residual site has been monitored since February 2017 (as part of compliance monitoring for the Mangorei HEPS). The sites at Constance Street and adjacent to Lake Rotomanu are included as part of the TRC industrial discharges monitoring programme. Each of the five sites is currently monitored twice each year (spring; 15 September to 31 December and summer; 1 January to 15 April)[16]. Available monitoring data at each site for a range of macroinvertebrate community indices (see Appendix One for a description of each) from March 2010 to February 2020 is presented in Appendix Four.

Median macroinvertebrate metrics for each site over the February 2017 to February 2019 monitoring period are presented in Table 3.3 (this period was chosen as it was the most recent period where monitoring data was available for all sites). With the exception of the number of taxa, the median values of macroinvertebrate metrics tend to decrease downstream in the Waiwhakaiho River, indicating a decline in community health downstream (Table 3.3). This is expected as the river exits the national park and land-use intensity increases downstream. LAWA 10-year trend analysis of MCI scores at the long-term monitoring sites indicates degrading health at all except the National Park site (Table 3.3).

Table 3.3. Median (with range in brackets) macroinvertebrate metrics for Waiwhakaiho River sites, February 2017 – February 2019 (six monitoring occasions). Data provided by TRC. 10-year trend analysis for MCI scores sourced from the Land Air Water Aotearoa (LAWA) website.

Site	Number of taxa	Percent EPT taxa	MCI score	MCI score condition	SQMCI score	SQMCI score condition	LAWA 10-year MCI trend (2010-2019)
National Park	20 (15 – 33)	71 (58 – 77)	134 (126 – 140)	excellent	7.6 (6.8 – 7.9)	excellent	Very likely improving
Upstream	20 (17 – 25)	55 (36 – 71)	107 (96 – 122)	good	5.7 (3.3 – 7.6)	good	Very likely degrading
Residual	18 (9 – 24)	39 (22 – 63)	95 (62 – 104)	fair	3.1 (2.2 – 3.9)	poor	-*
Constance Street	15 (7 – 22)	31 (14 – 50)	92 (60 – 106)	fair	3.9 (3.0 – 5.0)	poor	Likely degrading
Downstream Lake Rotomanu	17 (8 – 21)	26 (13 – 50)	88 (80 – 101)	fair	2.9 (2.6 – 3.2)	poor	Likely degrading

* Monitoring period not long enough to calculate trend.

[16] Note that although both the benthic macroinvertebrate and periphyton monitoring take place in spring and summer they are typically not undertaken on the same day.

3.6. Fish

Summary

Eighteen species of freshwater fish have been identified in the Waiwhakaiho River catchment. All of the species, except brown trout and perch, are native and have threat classifications ranging from 'not threatened' to 'threatened – nationally vulnerable' (shortjaw kokopu and lamprey). The greatest numbers of records are for longfin eels, followed by redfin bullies and brown trout. Recent fish community surveys have confirmed that brown trout, inanga, redfin bullies, longfin eels and torrentfish are all present within the residual river reach. Densities of juvenile trout and redfin bullies in the residual reach are also similar to or higher than that elsewhere in the river. In addition, banded and shortjaw kokopu, brown trout, koaro, lamprey, redfin bullies, torrentfish and both longfin and shortfin eels have all previously been recorded upstream of the residual reach.

Analysis and discussion

Eighteen species of freshwater fish have been identified in the Waiwhakaiho River catchment (Table 3.4[17]). All of the species, except brown trout and perch, are native and have threat classifications ranging from 'not threatened' to 'threatened – nationally vulnerable' (shortjaw kokopu and lamprey). The greatest numbers of NZFFD records are for longfin eels, followed by redfin bullies and brown trout (Table 3.4). The remaining species have been recorded 14 or fewer times. There are no NZFFD fish records for Lake Mangamahoe.

[17] An additional four introduced fish species (goldfish, grass carp, koi carp and rudd) have also been recorded in Lake Rotomanu but not in the river so are not included in this total.

Table 3.4. Number of occurrences of fish species in the Waiwhakaiho River from the New Zealand Freshwater Fish Database (NZFFD). The number refers to the number of records that report the occurrence of the species and reflects the sampling effort rather than the number of fish found.

Common name	Species	Number of NZFFD occurrences	Migratory	Threat classification (Dunn *et al.* 2018)
Longfin eel	*Anguilla dieffenbachii*	74	Yes	At risk - declining
Redfin bully	*Gobiomorphis huttoni*	48	Yes	Not threatened
Brown trout	*Salmo trutta*	32	Yes	Introduced and naturalised
Common bully	*Gobiomorphis cotidianus*	14	Yes	Not threatened
Torrentfish	*Cheimarrichthys fosteri*	11	Yes	At risk - declining
Koaro	*Galaxias brevipinnis*	10	Yes	At risk - declining
Inanga	*Galaxias maculatus*	7	Yes	At risk - declining
Shortfin eel	*Anguilla australis*	6	Yes	Not threatened
Banded kokopu	*Galaxias fasciatus*	3	Yes	Not threatened
Giant kokopu	*Galaxias argenteus*	2	Yes	At risk - declining
Bluegill bully	*Gobiomorphis hubbsi*	2	Yes	At risk - declining
Lamprey	*Geotria australis*	2	Yes	Threatened - Nationally vulnerable
Common smelt	*Retropinnna retropinna*	1	Yes	Not threatened
Crans bully	*Gobiomorphis basalis*	1	No	Not threatened
Giant bully	*Gobiomorphis gobioides*	1	Yes	At risk – naturally uncommon
Shortjaw kokopu	*Galaxias postvectis*	1	Yes	Threatened - Nationally vulnerable
Grey mullet	*Mugil cephalus*	1	No	Not threatened
Perch	*Perca fluviatilis*	1	No	Introduced and naturalised

The most recent NZFFD fish survey records for the Waiwhakaiho River are from 2009[18]. Given that these records are now over 10 years old, to inform the preparation of this assessment of effects report Ryder Environmental carried out fish surveys at 15 sites in the Waiwhakaiho River catchment in February 2020. Single-pass electric fishing was undertaken in the river mainstem (using a Kainga electric fishing machine), and a combination of electric fishing and overnight sets of Gee-minnow traps (baited with Marmite) was used in the intake weir fish pass and in river and lake tributaries. In addition, fyke nets (baited with cat food sachets) were also set overnight in Lake Mangamahoe. Fish survey results are shown in Table 3.5.

Longfin eels were the most widely distributed species, being found at 11 of the 15 sites surveyed (Table 3.5). Redfin bullies and brown trout were also widespread. Torrentfish were caught in two locations within the residual river reach, including in a riffle directly below the Mangorei HEPS intake weir fish pass. Redfin bullies and

[18] Note that there are more recent NZFFD records for the catchment in general, however not for the mainstem river itself.

eels were caught in the fish pass itself and in the river upstream. Banded and shortjaw kokopu, brown trout, koaro, lamprey, redfin bullies, torrentfish and both longfin and shortfin eels have previously been recorded upstream of the fish pass.

Longfin and shortfin eel were caught in Lake Mangamahoe, and bullies and brown trout were also caught in the two tributary streams that enter at the head of the lake (i.e. Mangamahoe Stream and Kent Road Stream). Trout were released into Lake Mangamahoe soon after it was formed and the lake has been open to trout fishing by licensed anglers since 1933 (Lake Mangamahoe Management Plan, NPDC 2011). Lake Mangamahoe is identified by Fish and Game as Taranaki's most popular lake fishery, holding brown trout up to 2.6 kg and rainbow trout up to 2.25 kg[19]. Modest numbers of adipose fin-clipped hatchery rainbow trout are released annually to maintain the rainbow trout fishery.

Adult eels are trapped in Lake Mangamahoe each year during the downstream eel migration season at the intake to the Mangorei HEPS penstocks as part of Trustpower's eel trap and transfer programme. In 2008 an adult giant kokopu was also captured during this trapping (Chris England, TPL, pers. comm.). Recent environmental (DNA)[20] survey work at 20 sites undertaken by Freshwater Solutions (Susan McKegg, pers. comm.) has provided strong evidence that another native galaxiid species, koaro, is also present in the lake.

Upstream migrating juvenile eels (elvers) that enter the Mangorei HEPS tailrace are trapped in the power station and returned to the river to continue their upstream migration.

Taranaki Fish and Game have recently surveyed (December 2018) juvenile brown trout populations by electric fishing in the Waiwhakaiho River catchment (Fish and Game 2019). The survey found that the highest densities of trout were in the upper reaches of the river mainstem, and that the size of juvenile trout increased between the upper and lower catchment sites (Table 3.6). Trout density in the residual river reach was similar to that upstream of the Mangorei HEPS intake. Comparison of results from the current survey with those for three other catchments within the region indicated that maximum and average juvenile trout densities recorded in the Waiwhakaiho River were similar to (albeit slightly higher than) those for Kaupokonui Stream, another Taranaki ringplain catchment, but lower than those for the Mangawhero and Manganuioteao Rivers which have their sources on Mount Ruapehu (Fish and Game 2019). Native fish species were also caught during the

[19] https://fishandgame.org.nz/taranaki/freshwater-fishing-in-new-zealand/fishing-locations-and-access/taranaki-ringplan/

[20] Fish continuously shed tissue such as mucus and scales into the water. This material contains DNA and can be collected from the water and read by scientists to identify the fish present in the water.

survey with eels, bullies and a torrentfish caught in the residual reach, and common and redfin bullies, eels and koaro caught in the upper river (i.e. upstream of the Mangorei HEPS intake weir). The density of redfin bullies in the residual reach was higher than that recorded elsewhere in the mainstem (Table 3.6).

Table 3.6. Density and average length of brown trout and redfin bullies (fish caught per minute of electric fishing machine time) at Waiwhakaiho River mainstem sites in December 2018 (upstream to downstream). Adapted from Fish and Game (2019).

		Brown trout		Redfin bullies	
Site name	**Description**	**Density (fish per minute)**	**Average length (mm)**	**Density (fish per minute)**	**Average length (mm)**
Upper	Below Peters Road Bridge	1.00	67	0.50	83
Above confluence	Above Kai Auaki Stream confluence	1.50	67	0.33	69
Above intake	Upstream of Mangorei HEPS take	0.30	69	1.95	60
Residual flow	Araheke walkway bridge	0.34	78	2.87	72
Lower	Rimu Street	0.16	76	0.81	70

Table 3.5. February 2020 fish survey results for the Waiwhakaiho River catchment. Length range (mm) is shown in brackets, note some are estimated.

Site	Reference	Redfin bully	Torrentfish	Inanga	Longfin eel	Shortfin eel	Unidentified eel	Brown trout	Unidentified bully
Waiwhakaiho River: at SH3	E1698306 N5666995	1 (45)			1 (400)		4 (102 – 130)	3 (99 – 150)	
Waiwhakaiho River: true left tributary at intake access road	E1697661 N5667974	6 (46 – 86)			1 (650)				
Waiwhakaiho River: upstream of HEPS intake	E1697732 N5667997	2 (58 - 76)			1 (230)		2	3 (138 - 140)	
Waiwhakaiho River: weir fish pass	E1697757 N5668065	2 (41)					1 (83)		
Waiwhakaiho River: downstream of HEPS intake	E1697879 N5668134	1 (61)	1 (138)		3 (120 - 160)		2 (120 - 170)	4 (119 - 274)	1 (40)
Waiwhakaiho River: at Mangamahoe Stream confluence	E1698071 N5670450				2 (162)		1 (90)	2 (126 - 250)	
Waiwhakaiho River: at upstream end of Hydro Road	E1698386 N5671019		1 (93)		3 (135 - 224)		15 (80 - 200)		2 (26 - 27)
Waiwhakaiho River: at TOPEC Bridge	E1697004 N5671240	3 (48 – 76)			3 (150 – 310)		2 (110, elver)		3 (29 – 30)
Un-named true left Waiwhakaiho River tributary: upstream of TOPEC Bridge	E1697031 N5671235			5 (84 – 111)					9 (30 – 95)
Mangamahoe Stream: upstream of Lake Mangamahoe, downstream of SH3 culvert	E1697084 N5667933				3 (430)				1 (66)
'Kent Road' Stream: upstream of SH3 culvert	E1696856 N5668018							3 (97)	9 (40 – 70)
'Kent Road' Stream: downstream of SH3 culvert	E1696891 N5668138				1 (500)		4	1 (80)	59 (28 – 72)
Lake Mangamahoe	E1697192 N5668942				4 (700 – 800)	4 (400 – 600)			
Mangamahoe Stream: upstream of NPDC Dam	E1697451 N5669682	1 (observed)			1 (observed)				
Mangamahoe Stream: downstream of NPDC Dam	E1697851 N5670349	1 (55)				1 (210)	5 (inc. elvers)		

3.7. Lake Mangamahoe

Summary

Lake Mangamahoe is an artificial lake, formed to provide a water supply and power generation. In addition to these primary functions the lake supports a native fish community and a popular trout fishery.

Analysis and discussion

Lake Mangamahoe was formed in 1931 by damming the Mangamahoe Stream. In addition to providing water for power generation, water is taken from the lake by NPDC to provide drinking water. The majority of the inflow (85%) to the lake is from the Waiwhakaiho River diversion tunnel, with the balance (15%) is derived from natural tributaries to the lake (Tonkin and Taylor 2020). Approximately 91% of the outflow from the lake passes through the Mangorei HEPS and returns to the river. The majority of the outflow balance (8.5%) is drawn into the NPDC take and therefore does not return to the river (Tonkin and Taylor 2020).

Trustpower is required to maintain a minimum lake level of 750 mm below the crest of the spillway, except during lake weed maintenance periods when the lake level can be temporarily lowered. Lake levels generally fluctuate within a 1 m operating range (between RL 149.3 m and RL 150.3 m), with negligible differences across the seasons. NPDC has access to storage in Lake Mangamahoe below the minimum operating level of the Mangorei HEPS. Power generation results in daily fluctuation in lake levels from 0.12 m during summer low flows to over 0.4 m for normal flow periods (Tonkin and Taylor 2020). The lake is small, with a narrow operating range, and water quality in the lake broadly reflects that of the Waiwhakaiho River upstream of the take[21] (as described in Section 3.1). Trout were released into Lake Mangamahoe soon after it was formed and the lake is now identified by Fish and Game as Taranaki's most popular lake fishery. The lake also supports a native fish community including bullies, and longfin and shortfin eels. Giant kokopu have been found in the lake and it is likely that koaro are also present, however it is not known if these two migratory fish species have entered the lake from the river or could have established land-locked populations in the lake.

[21] Based on water quality sampling at one site in the lake in July 2018 and May 2019 by NPDC, and at three sites in the lake in March 2020 by Freshwater Solutions (Susan McKegg, pers. comm.).

3.8. Lower Mangamahoe Stream

Summary

The lower section of Mangamahoe Stream (approximately 1.3 km long) was dammed around 1930 to form Lake Mangamahoe. Flow and fish passage in the Mangamahoe Stream has been restricted for over 100 years, since the construction of the first dam approximately 900 m downstream of the lake in 1914. This NPDC owned dam is no longer operational and is a barrier to fish passage within the stream from the river. Water quality in the lower stream is sufficient to maintain a native fish community that includes eels and redfin bullies.

Analysis and discussion

Mangamahoe Stream is bisected by Lake Mangamahoe. The upper section flows into the head of the lake (near State Highway 3), and the lower section was dammed around 1930 to form the lake (Figure 1.1). The lower Mangamahoe Stream, from the lake to the Waiwhakaiho River confluence, is approximately 1.3 km long. In the section immediately downstream of the dam the lower stream receives spill flow from the lake (Figure 3.17), and an indeterminate amount of leakage/seepage through the spillway flashboards and dam (Tonkin and Taylor 2020). It is not possible to determine the frequency of spill flows from the lake (due to the presence of tipping flashboards on the spillway), however Riley (2020) determined that the peak spillway flow is 160 m^3/s, and in a 100-year ARI flood spillway flow is 59 m^3/s (Tonkin and Taylor 2020).

In the stream, approximately 900 m downstream of the lake, there is also an NPDC owned dam (constructed in 1918 and no longer operational). There is also no residual flow requirement for this dam, but a small amount of water leaks through a pipe at the base of the dam, and during high flow events water spills over the top (Figure 3.18). This dam is a barrier to fish passage from the Waiwhakaiho River.

Benthic macroinvertebrate communities were sampled in the lower Mangamahoe Stream, near its confluence with the Waiwhakaiho River, in February 2019. The community was dominated by snails and worms, and was indicative of 'poor' health (i.e. MCI 86, SQMCI 3.7). Periphyton biomass and cover were sampled at this same site in November 2019. Cover was dominated by mat algae and was below guideline levels, biomass was however slightly over the guideline of 50 mg/m^2. Fish communities were surveyed at two sites in lower Mangamahoe Stream in February 2020. Eels and redfin bullies were both found at sites upstream and downstream of the NPDC dam (Table 3.6). At the time of the February 2020 survey there was no surface flow connection between the stream and the Waiwhakaiho River.

To provide information on water quality in the lower Mangamahoe Stream two combined water temperature and dissolved oxygen loggers were installed in the stream (by Trustpower together with Riverwise Consulting[22]) in August 2019. One logger was located approximately 50 m downstream of the lake ('Lake'), and the second near the confluence of the stream with the Waiwhakaiho River ('Confluence'). Maximum water temperatures over the August 2019 to February 2020 period were lower at the Lake site than the Confluence site (Table 3.7) as expected (as water temperature typically increases downstream). Maximum temperatures at both sites were lower than those recorded in the Waiwhakaiho River residual reach over the same period. Dissolved oxygen concentrations at the Lake site met the NPS-FM national minimum acceptable states[23]. At the Confluence site there appeared to be an error with the dissolved oxygen logger measurement for the January to February 2020 period, as logger measurements did not align well with field meter calibrations. Dissolved oxygen data for this site after the 2 January 2020 has therefore been disregarded. Dissolved oxygen concentrations at the Confluence site for the period August 2019 to January 2020 met the NPS-FM 1-day minimum national minimum acceptable state, but in late November-early December 2019 did not meet the 7-day mean minimum (was just below the 5.0 mg/L standard). It is not known what the flow was in the lower Mangamahoe Stream at this time, but it is possible that at the time there was no spill flow at the NPDC dam and therefore the only flow at the Confluence site was through leakage of the pipe at the base of the NPDC dam (Figure 3.18).

Table 3.7. Water temperature and dissolved oxygen concentration (15-minute measurements) at two sites in the lower Mangamahoe Stream. Lake site data period 3 August 2019 – 27 February 2020. Confluence site temperature data period 3 August 2019 – 27 February 2020, dissolved oxygen data period 3 August 2019 – 2 January 2020.

Site	Water temperature (°C)		Dissolved oxygen (mg/L)	
	Maximum hourly temperature	Maximum daily average	7-day mean minimum	1-day minimum
Lake	22.9 (30/01/2020 14:00)	21.1 (30/01/2020)	6.8 (07/02/2020)	6.5 (01/12/2019)
Confluence	24.1 (30/01/2020 14:00)	22.5 (03/02/2020)	4.7 (27/11/2019)	6.0 (07/12/2019)

[22] Dissolved oxygen and water temperature loggers were installed and maintained by Riverwise Consulting. Raw dissolved oxygen and water temperature data was provided to Ryder Environmental for analysis and interpretation.
[23] There are two national minimum numeric attribute states for dissolved oxygen, a 7-day mean minimum of 5.0 mg/L and a 1-day minimum of 4.0 mg/L. Both apply only over the summer period (defined as 1 November to 30 April).

Figure 3.17. Lower Mangamahoe Stream, downstream of Lake Mangamahoe, February 2020.

Top: Mangamahoe Stream approximately 200 m downstream of the lake dam spillway. Bottom: Mangamahoe Stream near its confluence with the Waiwhakaiho River.

Figure 3.18. NPDC Dam in lower Mangamahoe Stream, February 2020.

Top: View from top of spillway looking upstream. Middle: View from base of spillway looking upstream. Bottom: Pipe leaking water at the base of the dam.

3.9. Overall summary of existing values

The Mangorei HEPS first supplied power to New Plymouth in 1906. The power generation capacity of the scheme was extended in 1931 when Lake Mangamahoe was formed by damming the Mangamahoe Stream. Up to 1991, when consents for the operation of the scheme were renewed, there was no residual flow regime in the Waiwhakaiho River downstream of the of the Mangorei HEPS intake. Following the renewal of the consents in 1991 a residual flow regime of 400 L/s for six months and 600 L/s for six months was applied. In 1996 the current residual flow regime was implemented.

The existing residual flow regime supports a diverse native fish community, with inanga, redfin bullies, longfin eels and torrentfish all present within the residual river reach. Brown trout are also present throughout, and densities of juvenile trout and redfin bullies in the residual reach are similar to or higher than that elsewhere in the river. In addition to these species, banded and shortjaw kokopu, koaro, lamprey, and shortfin eels (which are all native species with migratory life cycles) have previously been recorded upstream of the Mangorei HEPS intake weir and fish pass.

In summer water temperatures in the residual river reach can exceed thermal criteria for brown trout, however temperatures are typically within the range of thermal preferences for native fish species.

Warm water temperatures, high nutrient concentrations and stable, low flow conditions favour periphyton growth. Proliferations of long filamentous nuisance algae occur at times at all Waiwhakaiho River monitoring sites, although generally to a lesser extent upstream of the Mangorei HEPS intake.

Respiration by periphyton (and macrophytes) can deplete dissolved oxygen levels in rivers at night. There has been limited monitoring of dissolved oxygen levels in the river, however monitoring downstream of the Mangorei HEPS tailrace discharge found a short period during late January 2020 when daily minimum dissolved oxygen levels were low late at night, increasing the following morning in association with the generation discharge from the Mangorei HEPS. Dissolved oxygen monitoring throughout 2019-2020 found that outside of this short period dissolved oxygen concentrations downstream of the Mangorei HEPS tailrace discharge were above guideline levels.

Warm water temperatures and increased periphyton cover can result in lower macroinvertebrate community health. Macroinvertebrate community health has tended in the past to be higher upstream of the Mangorei HEPS take than downstream, although during recent summers sites communities upstream of the take and in the residual reach were both indicative of 'poor' health. Overall, macroinvertebrate community health tends to decrease downstream in the river, which is expected as it exits the national park and land-use intensity increases downstream. Ten-year trend analysis indicates degrading macroinvertebrate community health upstream of the Mangorei HEPS take, in combination with increases in nutrient (dissolved reactive phosphorus and total oxidised nitrogen) and faecal bacteria concentrations.

Lake Mangamahoe is an artificial lake, formed to provide a water supply and power generation. In addition to these primary functions the lake supports a native fish community and a popular trout fishery.

The lower section of Mangamahoe Stream (approximately 1.3 km long) was dammed around 1930 to form Lake Mangamahoe. Flow and fish passage in the lower Mangamahoe Stream has been restricted for over 100 years, since the construction of the first dam approximately 900 m downstream of the lake in 1914. This NPDC owned dam is no longer operational and is a barrier to fish passage within the stream. Water quality in the lower stream is however sufficient to maintain a native fish community that includes eels and redfin bullies.

4. Assessment of effects

4.1. Flow reductions in the Waiwhakaiho River downstream of the Mangorei HEPS take

The Mangorei HEPS is authorised to divert up to 10 m^3/s from the Waiwhakaiho River, and must maintain a residual flow of between 0.4 m^3/s (1 May - 31 October), 0.6 m^3/s (1 November – 31 December and April) and 0.7 m^3/s (1 January - 31 March) downstream of the intake (Table 4.1)[24].

Flows increase naturally within the approximately 6 km long residual reach as a result of inflows, and at the downstream end of the reach (upstream of the Araheke Stream confluence) are at least 82 L/s higher than immediately downstream of the intake (Table 4.1). Most of the time flows in the residual reach are higher than the consented residual flow, with median flows immediately downstream of the intake

[24] Additionally, no water is permitted to be diverted when the flow in the Waiwhakaiho River is greater than or equal to 85 m^3/s.

ranging from 804 L/s to 1,355 L/s and at the downstream end of the residual reach from 1,036 L/s to 1,429 L/s (Table 4.1).

The effect of the residual flow regime on water temperature, nuisance algae growths, macroinvertebrate community health and fish habitat within the residual river reach are discussed in the following Sections 4.1.1 to 4.1.5.

Table 4.1. Waiwhakaiho River minimum and median flows (L/s) at the upstream and downstream end of the residual reach, January 2013 – July 2019.

Month	Immediately downstream of intake		Immediately upstream of tailrace*	
	Consented minimum flow (L/s)	Median flow (L/s)	Low flow (L/s)	Median flow (L/s)
January - March	700	1,355	782	1,429
November, December and April	600	945	685	1,093
May - October	400	804	483	1,036

* And upstream of Araheke Stream confluence.

4.1.1. Effect of abstraction on water temperature

Existing water temperature data indicates that water temperatures in the Waiwhakaiho River are higher in the residual river reach downstream of the Mangorei HEPS intake than upstream (at SH3). The percentage of time thermal criteria for brown trout are exceeded is also greater in the residual reach than upstream. Water temperatures typically increase naturally downstream in rivers, so even in the absence of water abstraction, higher water temperatures would be expected at the Residual site than the Upstream site, given that the Residual site is approximately 7 km downstream and the difference in elevation between the sites is approximately 100 m. Therefore, in order to understand what portion of temperature increase within the residual reach is related to water abstraction, a model was used to predict the natural water temperature increase downstream.

Water temperature modelling was undertaken with the computer software SEFA (System for Environmental Flow Analysis, Jowett *et al.* 2015). The model predicts the daily mean and maximum water temperatures as a function of river distance and environmental heat flux[25]. Water temperatures were modelled downstream of

[25] The model assumes that water flowing downstream will increase or decrease in temperature until the incoming temperature equals the heat lost from the river through radiation and evaporation.

a section of river under various flow scenarios. Water temperature measurement data (15-minute measurements) for two sites on the Waiwhakaiho River were used in the model; Upstream (SH3) and Residual (Hydro Road). Instream habitat data for the Upstream site (Jowett 1993) was used in the model to determine how the river's physical character (e.g., wetted width, water depth and velocity) varied with flow. Flow data was available for the Upstream site, and for the Residual site daily flow was synthesized (by Tonkin and Taylor) based on relationships derived from same day flow gaugings at the Upstream site and downstream at Rimu Street. Meteorological data was obtained from the New Plymouth and Stratford weather stations. Detail on the model development and calibration is presented in Appendix Five.

SEFA reach water temperature models were used to predict the 'natural' water temperature increase downstream by using the actual flows recorded on the warmest day of December, January, February, and March from 2008 – 2020 (Appendix Five, Table A5.2). The observed increase in water temperature downstream includes both the natural temperature increase downstream and the increase related to water abstraction at the Mangorei HEPS intake. The temperature model predicted the expected increase in water temperature downstream under the actual flow conditions on the warmest day (i.e. the natural temperature increase downstream). The difference between the observed and the predicted is an estimate of the temperature increase downstream attributable to the water take on that day.

Increases in mean summer water temperatures on the warmest day each month are presented in Table 4.2. Note that at the time flows in the residual reach were higher than the consented minimum residual flows of 600 – 700 L/s for December to March.

The effect of the water abstraction varied among months. For example, in February, the abstraction was possibly responsible for up to a 1.9 °C increase in mean water temperature downstream. In contrast, abstraction in March was likely not influencing water temperatures any more than may be expected with no abstraction, because the increase in temperature (0.1 °C) was so low as to be within the range of model error (which was ± 0.66 °C for daily mean temperature).

The temperature at which incoming energy equals the outgoing energy and there is no further increase in water temperature is known as the equilibrium temperature.

Table 4.2. Mean water temperature differences between Upstream and Residual sites in the Waiwhakaiho River under observed and predicted 'natural' warmest day summer conditions (1 December to 31 March, 2008 - 2020).

Month	Warmest day	Upstream flow (L/s)	Downstream flow in residual reach (L/s)	Temperature (°C) increase observed downstream	Temperature (°C) increase predicted downstream	Temperature (°C) increase due to water abstraction (Observed minus predicted)
December	25/12/2012	3,770	-*	3.5	2.3	1.2
January	30/01/2018	2,500	1,335	2.5	2.0	0.5
February	03/02/2013	1,830	1,190	4.5	2.6	1.9
March	07/03/2016	2,500	2,107	2.2	2.1	0.1

* Flow data not available for this day.

Section 2.2. of Appendix V of the TRC Regional Freshwater Plan (2001) sets out guidelines for surface water quality in the region for the purposes of aquatic ecosystem provision. There are no water quality guidelines that apply to water abstraction, however the temperature guideline for the discharge of contaminants requires that the natural temperature of the water is not to be changed by more than 3 °C as a result of a discharge. Having corrected for natural increases in water temperature downstream, on the warmest summer day (which occurred on the 3 February 2013) the increase in water temperature downstream of the Mangorei HEPS take was only 1.9 °C (Table 4.1), and therefore within the TRC Regional Freshwater Plan (2001) guideline limit for a 3 °C change for discharges. Temperature increases downstream of the take are lower under less extreme conditions.

Although very high water temperatures can be detrimental, warm water temperatures can increase productivity in aquatic communities. Fish and Game (2019) observed that the size of juvenile brown trout increased between sites in the upper and lower Waiwhakaiho River catchment. They suggested that this could be due to downstream movement of young trout as they grew, or warmer water temperatures in the lower reaches mean that fish residing there grow faster (Fish and Game 2019).

Summary

Water temperatures are naturally high in the residual reach during summer and at times exceed the recommended thermal criteria for brown trout. The abstraction of water at the Mangorei HEPS exacerbates this, although the magnitude of the increase due to the take is within the TRC Regional Freshwater Plan (2001) guideline limit for a 3 °C temperature change downstream (temperature guideline for the discharge of contaminants). Although very high water temperatures can be detrimental, warm water temperature can increase productivity in aquatic communities. Fish are also able to respond to water temperatures above their thermal preferences by temporarily moving to cooler locations (e.g. where a tributary or groundwater inflow enters). However, in order to ensure that water temperatures in the residual reach do not remain at very high temperatures for an extended period, it is recommended that a temporary reduction in take be implemented if temperatures in the residual reach exceed 25 °C (and the water temperature upstream of the intake is 25 °C or lower). If water temperatures upstream of the intake exceed 25 °C, then a temporary reduction in take should be implemented if there is a greater than 3 °C temperature increase within the residual reach relative to upstream of the take (e.g., upstream temperature 25 °C, residual reach temperature limit 28 °C).

The above mitigation could be achieved by installing telemetered water temperature loggers upstream of the take and at the downstream end of the residual reach and monitoring to determine if the rolling one hour average temperature exceeds 25°C, or if greater than 25°C upstream an increase of greater than 3 °C downstream. If the temperature was exceeded this would then trigger the requirement to reduce the water take by 100 L/s to reduce the water temperature.

4.1.2. Effect of abstraction on nuisance algae growths

Proliferations of long filamentous nuisance algae occur at times at all of the Waiwhakaiho River monitoring sites. Key factors controlling periphyton growth include sunlight, nutrient concentration, temperature, grazing by invertebrates and flow history (i.e. the history of bed disturbance). Monitoring over the 2019-2020 summer found that periphyton biomass was higher at the Residual site downstream of the Mangorei HEPS intake than Upstream.

As discussed in Section 4.1.1 water temperatures are higher at the Residual site than Upstream and this will account for some of the increase in periphyton biomass between the sites. Water quality monitoring during 2019-2020 has also identified that nitrogen concentrations are higher at the Residual site than Upstream (Section 3.1). High nutrient concentrations favour periphyton growth.

Multiple point and non-point discharges contribute nutrients to the Waiwhakaiho River within the 6 km long residual reach downstream of the Mangorei HEPS take (examples shown in Table 4.3) and this is reflected in the higher nitrogen concentrations at the Residual and Downstream sites than Upstream. Water abstraction does not directly result in elevated nutrient concentrations; however downstream of the intake less water is available to dilute nutrient inputs.

Table 4.3. Examples of current resource consents for discharges to the Waiwhakaiho River, or to land adjacent to the river, within the approximately 6 km long reach between the Mangorei HEPS intake and the tailrace discharge. Source https://maps.trc.govt.nz/LocalMapsViewer/?map=5113f49337a84cf098db177c728b1361

Resource consent number	Location (NZTM)	Distance downstream of the Mangorei HEPS take (km)	Activity	Description	Consent expiry
R2/9499-1	1697970 5668610	0.5	Discharge permit; Land – Animal waste	To discharge poultry washdown water onto and into land	2032
R2/4349-2	1698110 5669700	1	Discharge permit; Land/Water – Animal waste	To discharge treated farm dairy effluent from an oxidation pond treatment system into the Waiwhakaiho River and/or to discharge untreated farm dairy effluent by holding pond and spray irrigation onto and into land	2026
R2/4349-2.0	1697175 5671159	5	Discharge permit; Land – Animal waste	To discharge effluent from a farm dairy onto and into land	2038

Nuisance periphyton growths are more likely to occur under stable low flow conditions. The amount of available habitat (described by area weighted suitability, m^2/m) for long filamentous algae growths under different flow conditions in the river was predicted using instream habitat data for the Upstream site (Jowett 1993) within the computer software SEFA (Jowett *et al.* 2015) (Figure 4.1). At flows from 300 L/s up to approximately 2,200 L/s the amount of available habitat for long filamentous algae is fairly consistent (i.e. approximately 7.5 m^2/m) but as flows increase above this habitat begins to decline.

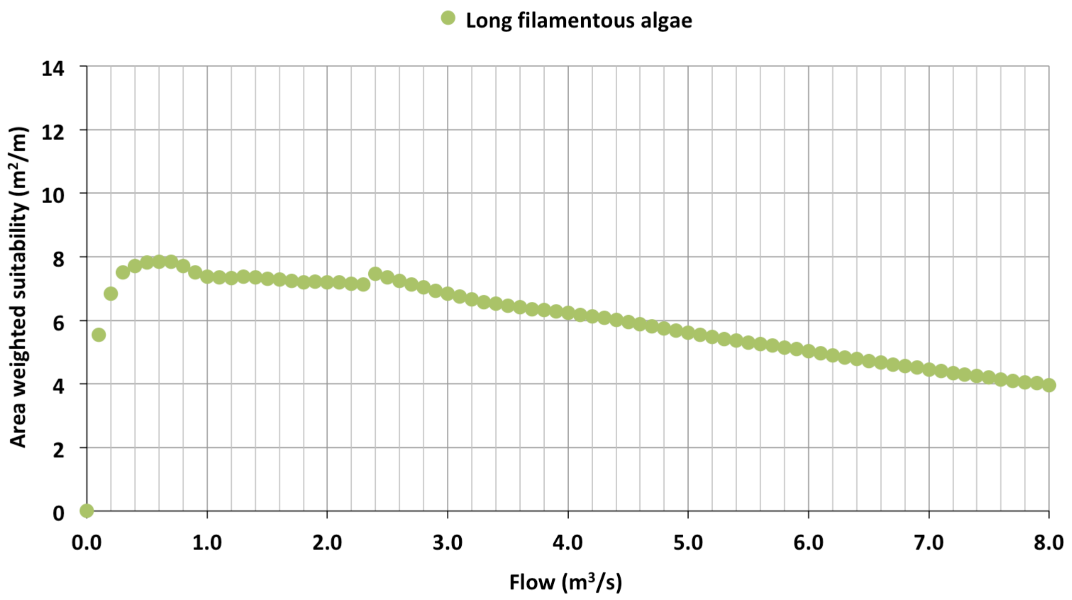
High flows result in periphyton being scoured off the riverbed, with the magnitude of flushing flows required to remove periphyton varying depending on the physical character of the river (e.g. water velocity, substrate size). To understand this process in the Waiwhakaiho River the instream habitat data for the Upstream site (Jowett 1993) was used within SEFA to predict the area of surface and deep riverbed flushing as flows increase (Figure 4.2). Surface flushing occurs at lower flows than deep flushing (as expected), and surface flushing of approximately 80% of the riverbed can be achieved with flows of 21 m^3/s while deep flushing of 80% of the riverbed requires flows of at least 70 m^3/s. Above these flows the rate of increased flushing achieved with increasing flow slows (Figure 4.2).

The Mangorei HEPS is consented to divert up to 10 m^3/s from the river, so depending on the river flow at the time, the take could result in a relatively large reduction in the amount of surface flushing achieved downstream. For example, if upstream flows were 21 m^3/s a take of 10 m^3/s would result in a 20% reduction in the area of surface flushing (i.e. from 80 to 60%). However, if upstream flows were 31 m^3/s a take of 10 m^3/s would only result in a 5% reduction in the area of surface flushing (i.e. from 85 to 80%).

The frequency of high flow events that are sufficient to cause periphyton flushing is important in understanding how the Mangorei HEPS take effects nuisance periphyton growths in the river downstream. The FRE3 statistic (the number of events per year when the flow exceeds three times the median flow) is used to describe the 'flashiness' of a river, and provides an indication of the frequency of events sufficient to flush periphyton from the riverbed. At the Upstream site there are an average of 29 events per year (range 20 to 37 events per year from 2013 – 2019) when the flow exceeds three times the median flow (i.e. flow exceeds 12 m^3/s). In the residual reach the number of FRE3 events is however reduced to 22 events per year (range 13 to 26 events per year from 2013 – 2019) as a consequence of the take (David Leong, Tonkin and Taylor, pers. comm.). The distribution of FRE3 events through the year is also important, as nuisance periphyton growths are more likely to occur under stable low flow conditions during summer.

Summary

Nuisance growths of periphyton occur in the residual river at times and this is due to a combination of factors including naturally high water temperatures and nutrient inputs from discharges within the residual reach. The operation of the Mangorei HEPS is also contributing through a reduction in the magnitude of flows downstream by up to 10 m^3/s. It is recommended that a flushing flow regime be implemented to allow higher flows to pass through the residual reach. If the flow in the residual reach has not exceeded 12 m^3/s (i.e., three times the median flow) for 30 days between 1 November and 31 March, then restrict the water take for six hours during the next fresh event to allow a flushing flow of at least 12 m^3/s to pass down the residual river reach.



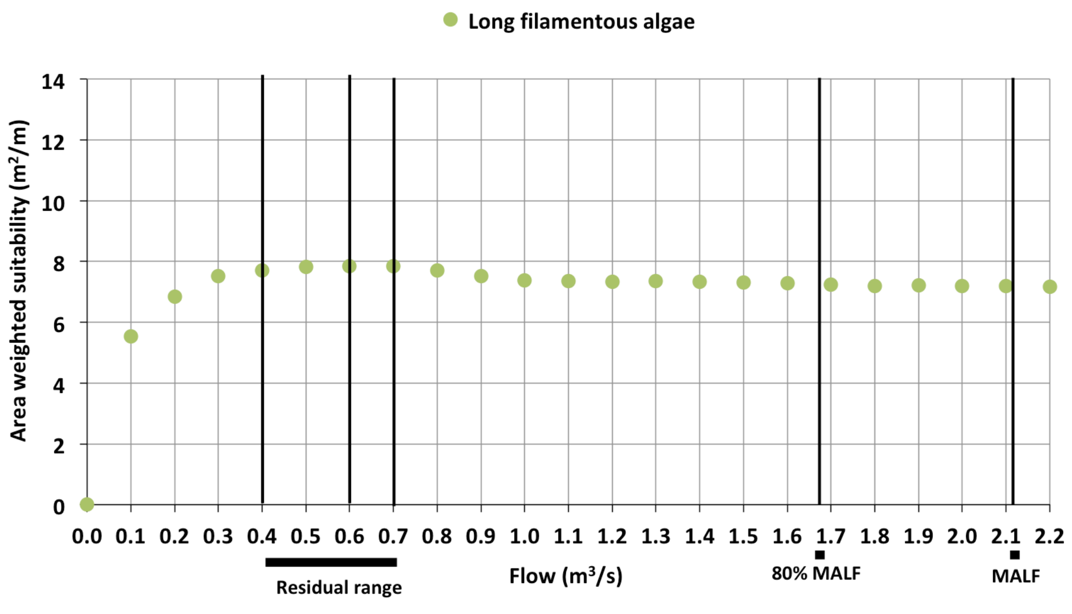


Figure 4.1. Variation of average weighted suitability (AWS m^2/m) with flow for long filamentous algae in the Waiwhakaiho River upstream of the Mangorei HEPS.
Top: Flows ranging up to 8 m^3/s.
Bottom: Flows ranging up to 2.2 m^3/s.

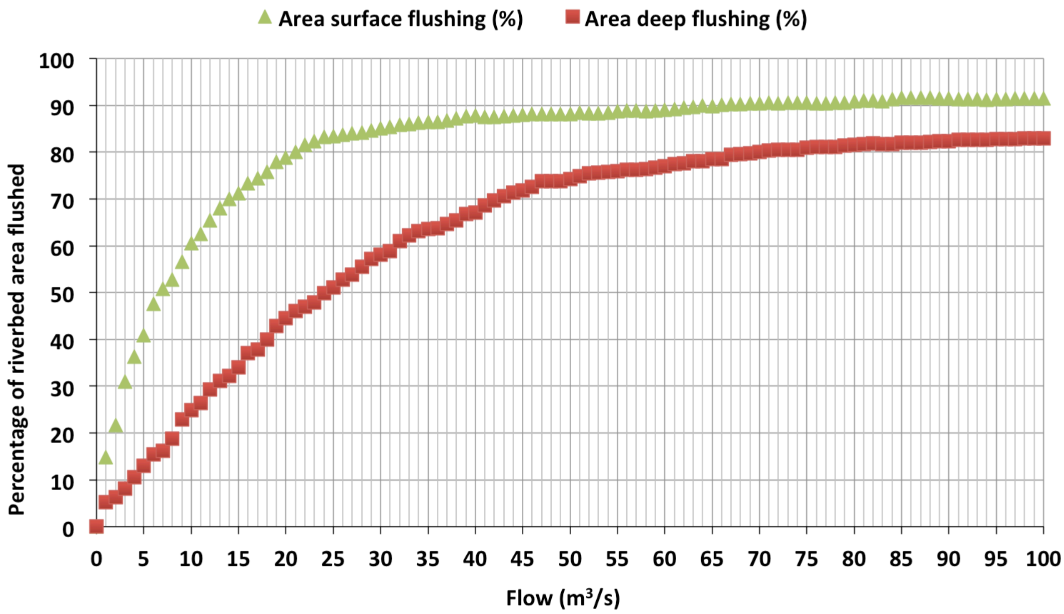


Figure 4.2. Percentage of riverbed area undergoing surface and deep flushing with increasing flow in the Waiwhakaiho River upstream of the Mangorei HEPS.

4.1.3. Effect of abstraction on macroinvertebrate community health

Long-term monitoring by TRC has indicated that sites in the middle and the lower reaches of rivers in the Taranaki region generally have lower macroinvertebrate health in summer than spring. This difference has been related to summer warmer water temperatures, increased periphyton cover, and lower flows, resulting in additional less 'sensitive' taxa being present and/or increases in the abundance of lower scoring 'tolerant' taxa, combined with lifecycle patterns.

The warm water temperatures and nuisance algae proliferations that occur in the Waiwhakaiho River during summer are therefore expected to have negative impacts on macroinvertebrate communities. This pattern has been apparent at the Upstream and Residual sites in the past, with higher MCI and SQMCI scores in spring than in summer at both sites (Figures A4.3 and A4.4).

Macroinvertebrate community health has also tended to be higher at the Upstream site than the Residual site in the past, being indicative of 'good' or 'excellent' health at the Upstream site in contrast to 'poor' at the Residual site. However, in February 2019, November 2019 and February 2020 SMCI scores at the Upstream and Residual sites were both indicative of 'poor' health (Figure 4.3). The reason for degraded macroinvertebrate health at the Upstream site in those surveys does not appear to be related to nuisance algae growths, as periphyton biomass was mostly below guideline levels at the Upstream site at the time (Figure 4.3).

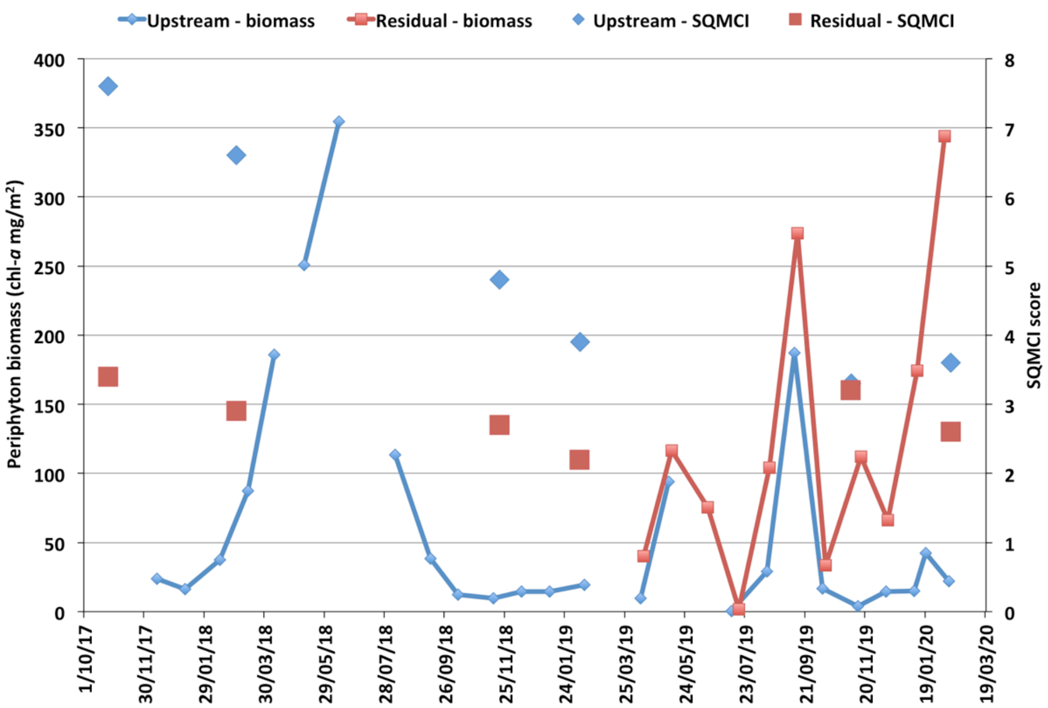


Figure 4.3. Periphyton biomass (chl-a mg/m^2, shown by lines) and macroinvertebrate community health (SQMCI) scores at the Upstream and Residual sites in the Waiwhakaiho River, October 2017 to February 2020.

Water temperatures at the Upstream site were however higher over the 2018-2019 and 2019-2020 summer periods than the historical long-term average and it is possible that this impacted sensitive macroinvertebrate taxa. Mayflies and stoneflies seem to be most sensitive to high temperatures, with incipient lethal temperatures of approximately 21 - 23 °C (Figure 3.9). A decline in the abundance of mayflies was apparent at the Upstream site between November 2018 and February 2019[26], with *Deleatidium* mayflies declining from 'very abundant' to 'rare', and similarly *Nesameletus* mayflies declining from 'common' to absent. At the Residual site *Deleatidium* mayflies declined from 'common' to absent over the same period.

[26] TRC internal memorandum (2019). Biomonitoring of the Waiwhakaiho River in relation to the Mangorei H.E.P diversion of water, 20 November 2018. Report number KC003.
TRC internal memorandum (2019). Biomonitoring of the Waiwhakaiho River in relation to the Mangorei H.E.P diversion of water, 8 February 2019. Report number KC004.

Summary

High summer water temperatures in the Waiwhakaiho River impact macroinvertebrate community health. This is apparent at sites both upstream and downstream of the Mangorei HEPS take, particularly in recent summers. In the past macroinvertebrate community health at the Upstream site has been higher than at the Residual site being indicative of 'good' or 'excellent' health at the Upstream site in contrast to 'poor' at the Residual site, but on recent monitoring occasions (February 2019, November 2019 and February 2020) community health (SQMCI) at both the Upstream and Residual sites was 'poor'. The Mangorei HEPS take contributes to the high summer water temperatures in the residual reach, which impacts macroinvertebrate communities within this reach, however the magnitude of the temperature increase due to the take is within the TRC Regional Freshwater Plan (2001) guideline limit for a 3 °C temperature change downstream (temperature guideline for the discharge of contaminants). However, (as discussed in Section 4.1.1), in order to ensure that water temperatures in the residual reach do not remain at very high temperatures for an extended period, it is recommended that a temporary reduction in take be implemented if, when the water temperature upstream of the intake is 25 °C or lower, temperatures in the residual reach exceed 25 °C. If water temperatures upstream of the intake exceed 25 °C, then a temporary reduction in take should be implemented if there is a greater than 3 °C temperature increase within the residual reach relative to upstream of the take (e.g., upstream temperature 25 °C, residual reach temperature limit 28 °C).

4.1.4. Effect of abstraction on fish habitat

The reduced flow in the Waiwhakaiho River residual reach downstream of the Mangorei HEPS intake has over many decades resulted in changes to water depths, velocities and channel widths. This in turn changed the habitat available for aquatic communities. To assess the on-going effects of these historic changes on key fish species, the amount of potential habitat at a range of flows was determined using the instream habitat model for the Upstream site (Jowett 1993). Details of the modelling are provided in Appendix Six.

Predictions of the amount of available habitat (measured as 'area weighted suitability') for different fish species (and life history stages) and their food resources (i.e. benthic invertebrate density and food producing habitat) with varying flow are presented in Figures 4.4 to 4.6. The amount of habitat available for a species depends on its habitat requirements, for some species the amount of habitat increases as flows increase (e.g. adult brown trout and torrentfish) and for other species it decreases (e.g. inanga feeding and redfin bully). To determine the effect of the Mangorei HEPS on instream habitat, the amount of habitat for each species at the residual flow range of 400 – 700 L/s was compared to that at natural minimum flows (i.e. MALF 2,110 L/s) and the percentage change in habitat calculated (Table 4.4).

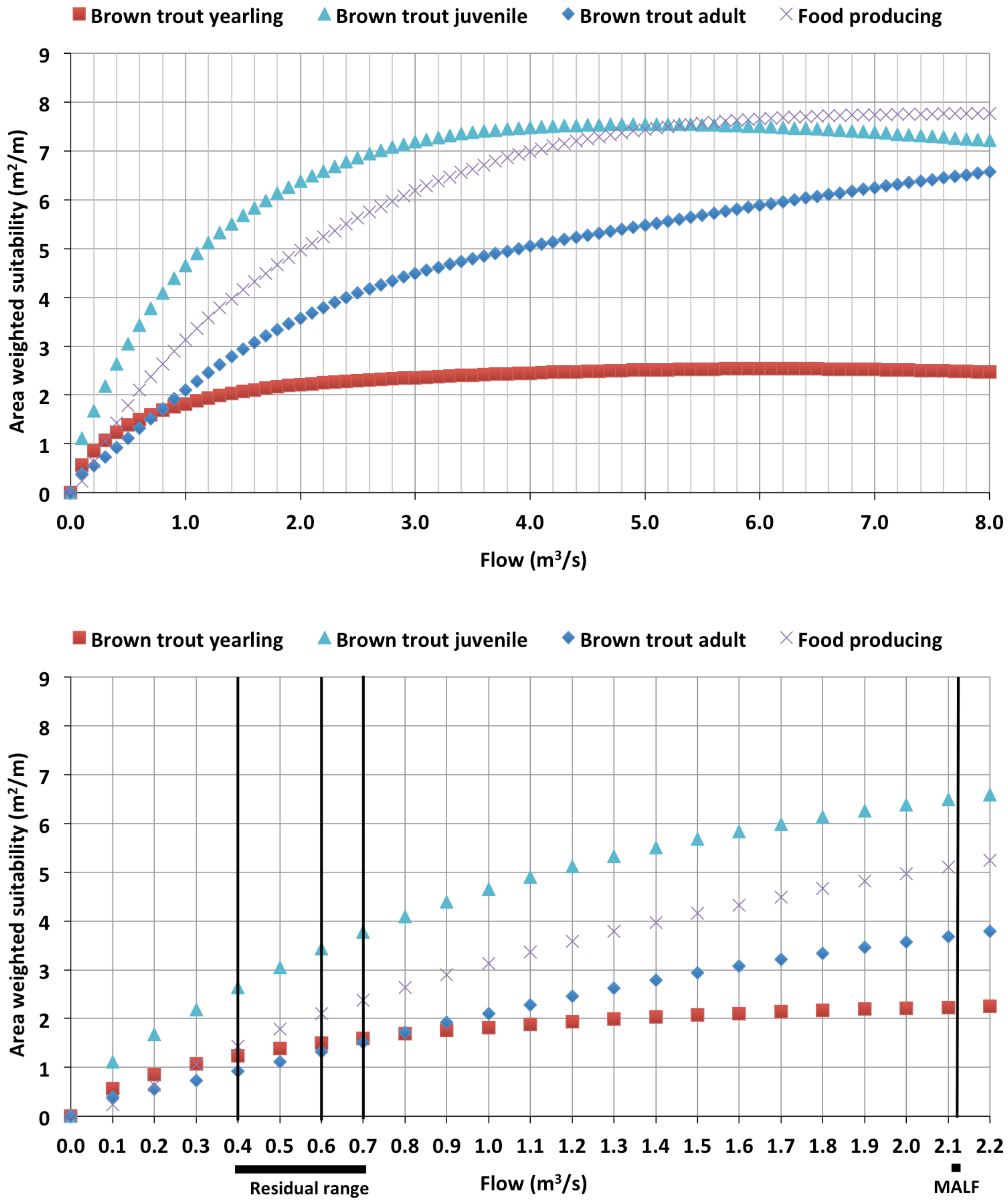


Figure 4.4. Variation of average weighted suitability (AWS m^2/m) with flow for brown trout and food producing habitat in the Waiwhakaiho River upstream of the Mangorei HEPS.
Top: Flows ranging up to 8 m^3/s. Bottom: Flows ranging up to 2.2 m^3/s.

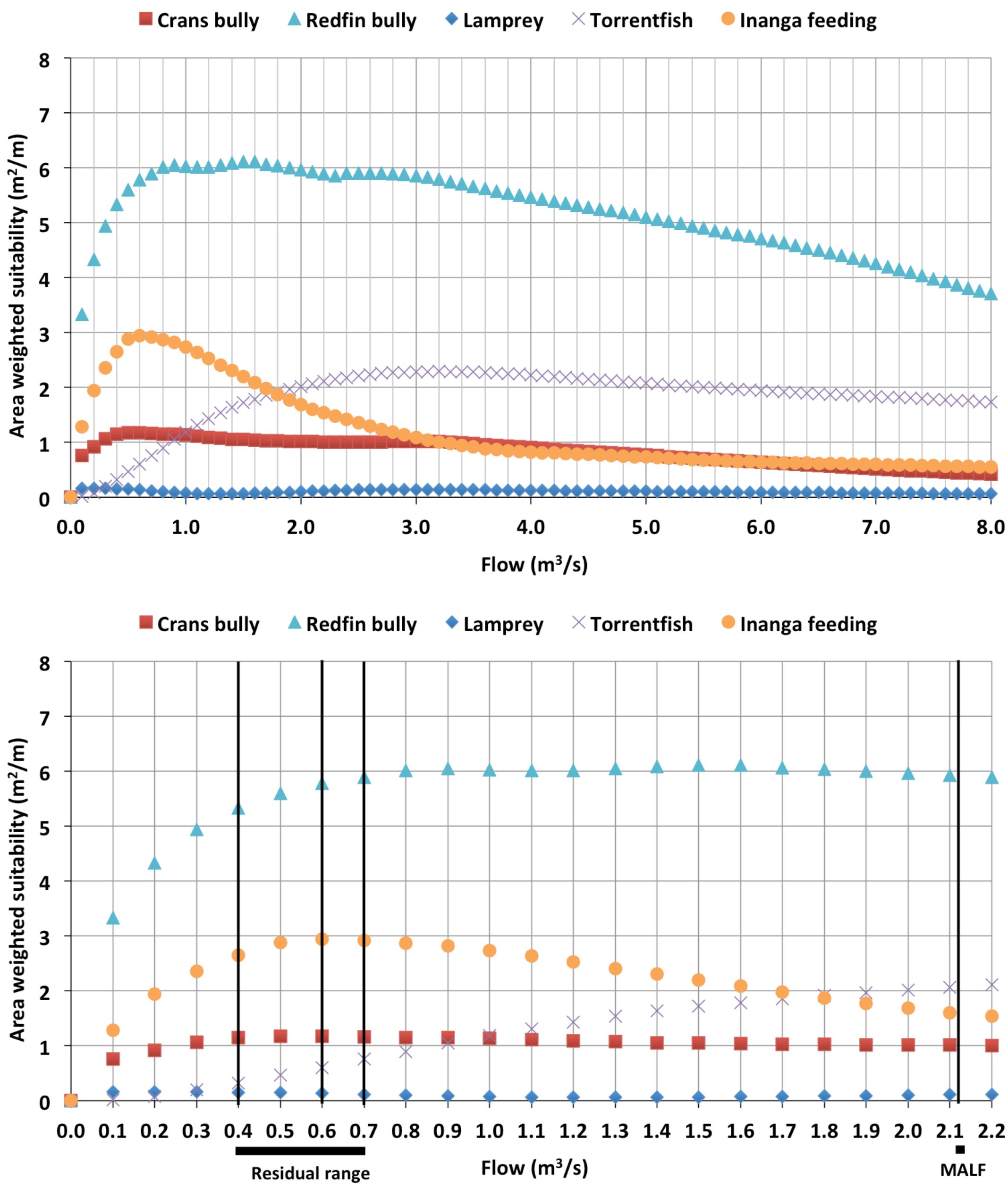


Figure 4.5. Variation of average weighted suitability (AWS m^2/m) with flow for native fish habitat in the Waiwhakaiho River upstream of the Mangorei HEPS.
Top: Flows ranging up to 8 m^3/s. Bottom: Flows ranging up to 2.2 m^3/s.

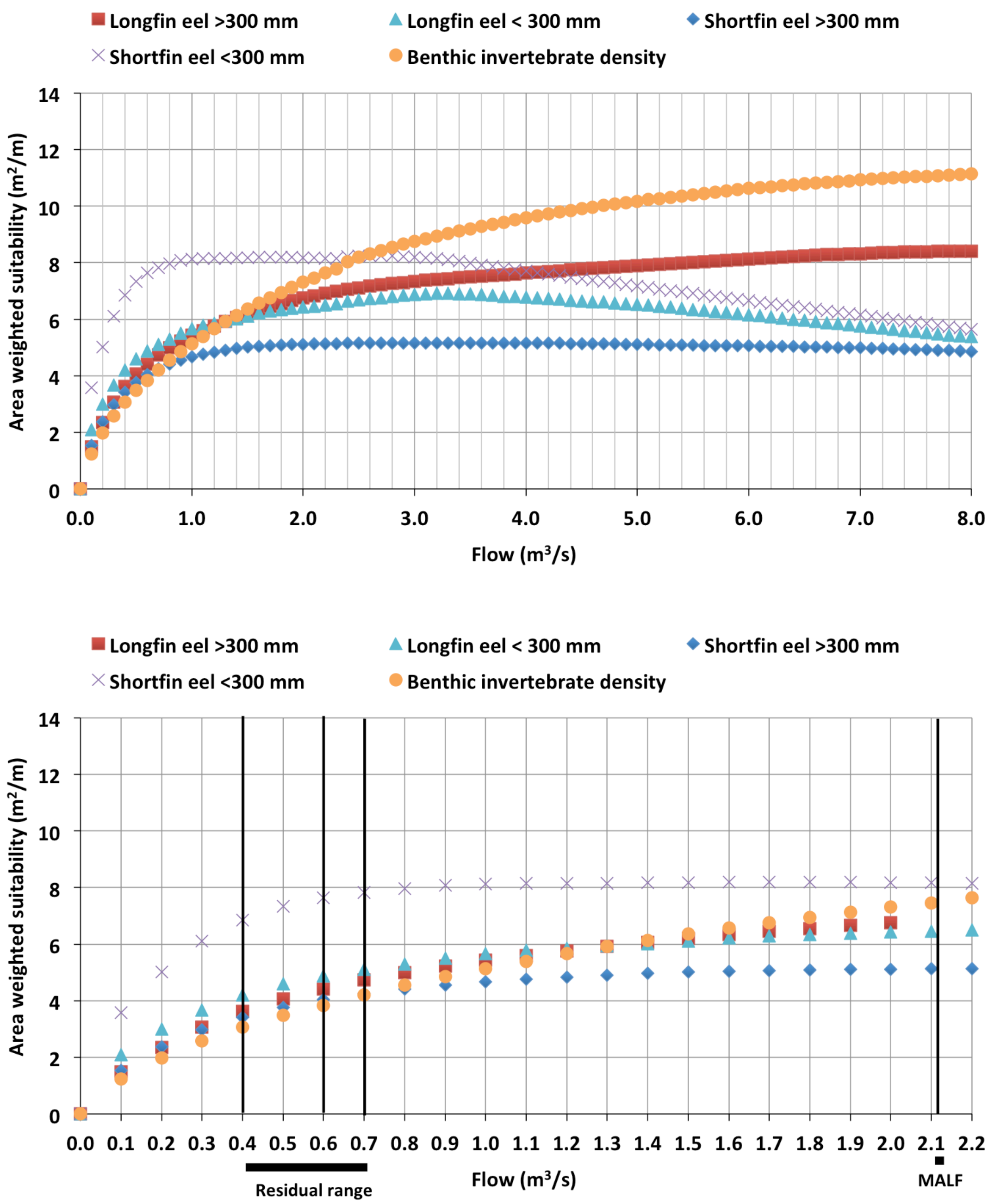


Figure 4.6. Variation of average weighted suitability (AWS m^2/m) with flow for eels and benthic invertebrate habitat in the Waiwhakaiho River upstream of the Mangorei HEPS. Top: Flows ranging up to 8 m^3/s. Bottom: Flows ranging up to 2.2 m^3/s.

For most fish species and food resources there is a decline in the amount of available habitat under the Mangorei HEPS flow regime relative to natural low flow conditions (i.e. the MALF upstream of the take). The exceptions are Crans bully, inanga feeding, lamprey and shortjaw kokopu, which are predicted to have an increase in habitat ranging from 9 to 84% (Table 4.4). There is a moderate decline in habitat for redfin bully and shortfin eels, ranging from 1 to 33%. Declines in the habitat for the various brown trout life history stages range from 28 – 75%. The largest declines are for torrentfish (63 – 84%), as they prefer high water velocities (Table 4.4). These predictions of habitat loss however represent somewhat of a worst-case scenario, as they related to a 'without-scheme' flow regime, flows increase along the residual river reach, and for approximately 20% of the time flows in the residual reach are greater than those expected under natural low flow conditions.

Recent fish community surveys have also confirmed that brown trout, inanga, redfin bullies, longfin eels and torrentfish are all present within the residual river reach. Fish and Game (2019) found that juvenile brown trout density in the residual river reach was similar to that upstream of the Mangorei HEPS intake, and that the density of redfin bullies was higher in the residual river than at any of the other four mainstem sites surveyed.

In addition, banded and shortjaw kokopu, brown trout, koaro, lamprey, redfin bullies, torrentfish and both longfin and shortfin eels have all previously been recorded upstream of the residual reach, indicating that passage for these species through the residual reach is provided and the fish pass is effective. Operation and maintenance of the fish pass should therefore continue.

Summary

The reduced flow in the Waiwhakaiho River residual reach downstream of the Mangorei HEPS take resulted in changes to water depths, velocities and channel widths. The amount of habitat available for a species depends on its habitat requirements, for some the amount of habitat decreases as flows are reduced downstream of the Mangorei HEPS take (e.g. torrentfish 63 – 84% decrease) and for other species it increases (e.g. Crans bully 14 – 16% increase). Despite this recent fish community surveys have confirmed that brown trout, inanga, redfin bullies, longfin eels and torrentfish are all present within the residual river reach. Densities of juvenile trout and redfin bullies in the residual reach are also similar to or higher than that elsewhere in the river. In addition, banded and shortjaw kokopu, brown trout, koaro, lamprey, redfin bullies, torrentfish and both longfin and shortfin eels have all previously been recorded upstream of the residual reach, indicating that passage for these species through the residual reach and fish pass to the river upstream of the Mangorei HEPS intake is maintained. Operation and maintenance of the fish pass should therefore continue.

Table 4.4. Comparison of the amount of available habitat (average weighted suitability, m^2/m) for a range of key aquatic species in the Waiwhakaiho River, for the residual flow range (400 – 700 L/s) and at the MALF (2,110 L/s). Increases in available habitat compared to that at the MALF are shaded in green and decreases are shaded in yellow. Predicted using the Upstream IFIM model (Jowett 1993).

Common name	**Life history stage**	**Average weighted suitability (m^2/m)**				**Percentage change in available habitat compared to that at 2,110 L/s**		
	Flow (L/s)	**400**	**600**	**700**	**2,110**	**400**	**600**	**700**
Benthic invertebrate density		3.1	3.8	4.2	7.5	-59	-48	-44
Food producing habitat		1.4	2.1	2.4	5.1	-72	-59	-53
Brown trout	Adult (> 400 mm)	0.9	1.3	1.5	3.7	-75	-64	-59
	Juvenile (100-170 mm)	2.6	3.4	3.8	6.5	-59	-47	-42
	Yearling (< 100 mm)	1.2	1.5	1.6	2.2	-44	-33	-28
Crans bully		1.2	1.2	1.2	1.0	14	16	15
Inanga	Feeding	2.7	2.9	2.9	1.6	65	84	82
Lamprey		0.2	0.1	0.1	0.1	42	23	9
Longfin eel	< 300 mm	3.6	4.4	4.7	6.8	-47	-35	-31
	> 300 mm	4.2	4.9	5.1	6.5	-35	-24	-21
Redfin bully		5.3	5.8	5.9	5.9	-10	-3	-1
Shortfin eel	< 300 mm	3.4	4.0	4.2	5.1	-33	-21	-17
	> 300 mm	6.8	7.6	7.8	8.2	-16	-7	-4
Shortjaw kokopu		1.8	1.8	1.8	1.6	18	19	19
Torrentfish		0.3	0.6	0.8	2.1	-84	-71	-63

4.2. Lake Mangamahoe

Lake Mangamahoe was formed in 1931 by damming the Mangamahoe Stream. In addition to providing water for power generation, water is taken from the lake by NPDC to provide drinking water.

Trustpower is required to maintain a minimum lake level of 750 mm below the crest of the spillway, except during lake weed maintenance periods when the lake level can be temporarily lowered. Lake levels generally fluctuate within a 1 m operating range (between RL 149.3 m and RL 150.3 m), with negligible differences across the seasons. NPDC has access to storage in Lake Mangamahoe below the minimum operating level of the Mangorei HEPS. Power generation results in daily fluctuation in lake levels from 0.12 m during summer low flows to over 0.4 m for normal flow periods (Tonkin and Taylor 2020). The lake is small, with a narrow operating range, and water quality in the lake broadly reflects that of the Waiwhakaiho River upstream of the take. Trout were released into Lake Mangamahoe soon after it was formed and the lake is now identified by Fish and Game as Taranaki's most popular lake fishery. The lake also supports a native fish community including bullies, and longfin and shortfin eels.

Summary

Lake Mangamahoe is an artificial lake, formed to provide a water supply and power generation. In addition to these primary functions the lake supports a native fish community and a popular trout fishery.

4.3. Flow reductions and fish passage in lower Mangamahoe Stream downstream of Lake Mangamahoe

There are no existing residual flow requirements in the lower Mangamahoe Stream, however it receives spill flow from Lake Mangamahoe and leakage through the dam. Monitoring in the stream immediately downstream of the lake over the 2019-2020 summer found that water temperatures in the stream were lower than those in the residual Waiwhakaiho River and dissolved oxygen concentrations were above NPS-FM acceptable states.

Further downstream in the lower Mangamahoe Stream, near the confluence with the Waiwhakaiho River and downstream of the NPDC dam, benthic macroinvertebrate communities were indicative of 'poor' health and in late November-early December 2019 dissolved oxygen concentrations did not meet the

NPS-FM minimum acceptable states. It is not known what the flow was in the lower Mangamahoe Stream at this time, but it is possible that at the time there was no spill flow at the NPDC dam and therefore the only flow at the Confluence site was through leakage of the pipe at the base of the NPDC dam.

Mangamahoe Stream is split into lower and upper sections by the lake dam and spillway. Additionally, the lower section of the stream is split into two sections by the NPDC dam. These two dams present barriers to upstream fish passage from the Waiwhakaiho River to the lake and onto the upper Mangamahoe Stream. Downstream migrating fish also encounter these same barriers.

The NPDC dam was constructed in 1918 (Figure 4.7) and pre-dates the lake dam, which was built in 1931 (Figure 4.8). Fish passage within the Mangamahoe Stream has therefore been restricted for approximately 100 years. Two migratory fish species (eels and redfin bullies) were however found in the lower Mangamahoe Stream during recent surveys and this indicates that fish passage must be possible in the lower stream at times. Eels are also found in Lake Mangamahoe and in the upper Mangamahoe Stream, however it is not clear if they have accessed these habitats by moving upstream via the NPDC dam and lake dam spillways or moving downstream into the lake via the tunnel intake from the river.

Summary

Flow and fish passage in the Mangamahoe Stream has been restricted for over 100 years, since the construction of the first dam in the lower stream in 1914. The fish passage barrier due to the NPDC dam is unrelated to the on-going operation of the scheme. The water quality in the lower stream is sufficient to maintain a native fish community that includes migratory species. Provision of a residual flow at the lake dam spillway is therefore not required, and in the continued presence of the NPDC dam, would not improve habitat greatly in the stream downstream.

Figure 4.7. NPDC dam in the lower Mangamahoe Stream c.1950. The downstream dam was built in 1914 but washed out, and was replaced in 1917-1918 by the upstream dam. (Photo J. A. Austin, PHO2002-826, Puke Ariki Collection).

Figure 4.8. Lake Mangamahoe Dam construction c.1930. (From "The Alchemy of the Engineer: Taranaki Hydro-electricity" [http://ketenewplymouth.peoplesnetworknz.info/documents/0000/0000/2379/Taranaki_Hydro_A_3.pdf)](http://ketenewplymouth.peoplesnetworknz.info/documents/0000/0000/2379/Taranaki_Hydro_A_3.pdf).

4.4. Flow fluctuations in the Waiwhakaiho River downstream of the Mangorei HEPS tailrace

The maximum generation discharge from the Mangorei HEPS tailrace to the Waiwhakaiho River at the Meeting of the Waters is just under 10 m^3/s (typically 8.3 m^3/s). The Mangorei HEPS consent also requires that a continuous generation flow release of at least 0.95 m^3/s be maintained to the lower river between 8:00 am and 6:00 pm each day (i.e. during daylight hours) (Consent 2053-3.2 Special condition 1). When the power station is unable to generate during the day (for example from a network or station outage) a bypass valve is opened to release a flow of 1.15 m^3/s (Tonkin and Taylor 2020).

The current consent conditions do not set any constraints on generation flow ramping of the power station discharge. Low flows at the downstream end of the residual reach range from 0.48 to 0.78 m^3/s (depending on the time of year), so flows within the river at the Meeting of the Waters can therefore range from 0.48 m^3/s (0.95 m^3/s during daylight hours) to 10 m^3/s (typically 8.3 m^3/s) within a day depending on scheme operation. The variation in generation outflow continues downstream in the lower Waiwhakaiho River with only minor attenuation (smoothing) of the generation pulse, reflected in river level variation of up to around 450 mm, as measured at Rimu Street (Tonkin and Taylor 2020). Tributary inflows also contribute water to the lower river downstream of the Mangorei HEPS discharge, and at Rimu Street low flows are in the range of 1.8 to 2.1 m^3/s (Table 4.5, Tonkin and Taylor 2020). This is similar to the low flow range upstream of the Mangorei HEPS intake, where flows range from 2.0 to 2.1 m^3/s (Table 4.5, Tonkin and Taylor 2020). Median flows are higher at Rimu Street than Upstream, and flood flows are similar at both sites (Table 4.5, Tonkin and Taylor 2020).

Flow fluctuations in the lower river as a result of power generation result in changes to water depths, velocities and channel widths. As in the residual river, this changes the habitat available for aquatic communities. The variation is most marked on the margins of the river channel, which is known as the varial zone. Aquatic communities in the varial zone can experience large changes in water depths and velocities within a short period, and therefore the species that live here have to be tolerant of these conditions. Fish are able to move in and out of the varial zone as the habitat changes, but the macroinvertebrate community that lives in the varial zone tends to be dominated by those species that are indicative of lower health (e.g. snails, worms). The macroinvertebrate community in the lower river at Constance Street (approximately 9 km downstream of the Mangorei HEPS discharge is however similar to that in the residual reach (and also during recent summers to that upstream of the Mangorei HEPS intake), being typically indicative of 'poor' community health. The Constance Street monitoring site is part of the TRC industrial discharges monitoring programme, and therefore other pressures are also likely impacting on macroinvertebrate communities in this location.

Generation discharges from the Mangorei HEPS do however also have beneficial effects on the lower Waiwhakaiho River. The discharge of water from the lake via the power station appears to have a slight cooling effect on water temperatures in the river, and increases in dissolved oxygen levels are observed due to generation. Flow increases due to generation are also effective in flushing nuisance periphyton growths. Long-term monitoring of periphyton indicates that nuisance algae proliferations occur slightly less often at the Constance Street site than upstream of the Mangorei HEPS intake (Upstream (SH3) site).

Table 4.5. Flow (m^3/s) statistic summary for the Upstream and Rimu Street Waiwhakaiho River sites (Tonkin and Taylor 2020).

Site	1-day MALF	7-day MALF	Median	Mean annual flood
Upstream (SH3)	2.0	2.1	3.9	333
Rimu Street	1.8	2.1	6.7	353

Summary

Varying generation outflow from the Mangorei HEPS results in daily fluctuations in water level and flow in the lower Waiwhakaiho River. This changes the habitat available for aquatic communities, most markedly on the margins of the river channel. Fish are able to move in and out of the channel margins as the habitat changes, however macroinvertebrates cannot respond quickly and therefore the species that live here have to be tolerant of these conditions. The macroinvertebrate community in the lower river is similar to that in the residual reach (and also during recent summers to that upstream of the Mangorei HEPS intake), being typically indicative of 'poor' community health.

Generation discharges from the Mangorei HEPS do however also have beneficial effects on the lower Waiwhakaiho River. The discharge of water from the lake via the power station appears to have a slight cooling effect on water temperatures in the river, and increases in dissolved oxygen levels are observed due to generation. Flow increases due to generation are also effective in flushing nuisance periphyton growths.

5. Summary and Conclusion

The Mangorei scheme is located within the Waiwhakaiho River catchment to the south of New Plymouth. The scheme diverts water from the Waiwhakaiho River into the artificially constructed Lake Mangamahoe, from where it is directed through an intake to penstocks that carry the water through to the Mangorei Power Station. Generation water from the Mangorei Power Station is returned back to the Waiwhakaiho River, at a site known as the Meeting of the Waters, approximately 6 km downstream of the original diversion.

The Mangorei HEPS can divert up to 10 m^3/s from the Waiwhakaiho River, and must maintain a residual flow of between 0.4 m^3/s (1 May - 31 October), 0.6 m^3/s (1 November – 31 December and April) and 0.7 m^3/s (1 January - 31 March) downstream of the intake (Table 4.1)[27]. These residual flow requirements have been in place since 1996. In order to determine the effects of the water abstraction on water quality and aquatic communities downstream, existing information on aquatic communities were reviewed, and additional monitoring was undertaken in the catchment during 2019 to 2020.

The existing residual flow regime supports a diverse native fish community, with inanga, redfin bullies, longfin eels and torrentfish all present within the residual river reach. Brown trout are also present throughout, and densities of juvenile trout and redfin bullies in the residual reach are similar to or higher than that elsewhere in the river. In addition to these species, banded and shortjaw kokopu, koaro, lamprey, and shortfin eels (which are all native species with migratory life cycles) have previously been recorded upstream of the Mangorei HEPS intake weir and fish pass - confirming that fish passage through the residual reach and fish pass to the river upstream of the Mangorei HEPS intake is being maintained.

In summer water temperatures in the residual river reach can exceed thermal criteria for brown trout, however temperatures are typically within the range of thermal preferences for native fish species. Although very high water temperatures can be detrimental, warm water temperature can increase productivity in aquatic communities. Fish are also able to respond to water temperatures above their thermal preferences by temporarily moving to cooler locations (e.g. where a tributary or groundwater inflow enters). However, in order to ensure that water temperatures in the residual reach do not remain at very high temperatures for an

[27] Additionally, no water can be diverted when the flow in the Waiwhakaiho River is greater than or equal to 85 m^3/s.

extended period, it is recommended that a temporary reduction in take be implemented when temperatures are high.

Proliferations of long filamentous nuisance algae occur at times at all Waiwhakaiho River monitoring sites, although generally to a greater extent downstream of the Mangorei HEPS intake. Warm water temperatures and increased periphyton cover can result in lower macroinvertebrate community health. Macroinvertebrate community health has tended in the past to be higher upstream of the Mangorei HEPS take than downstream, although during recent summers sites communities upstream of the take and in the residual reach were both indicative of 'poor' health. Overall, macroinvertebrate community health tends to decrease downstream in the river, which is expected as it exits the national park and land-use intensity increases downstream. Ten-year trend analysis indicates degrading macroinvertebrate community health upstream of the Mangorei HEPS take, in combination with increases in nutrient (dissolved reactive phosphorus and total oxidised nitrogen) and faecal bacteria concentrations.

Nuisance growths of periphyton in the residual river are due to a combination of factors (including nutrient inputs from discharges within the residual reach), however the operation of the Mangorei HEPS is also contributing through a reduction in the magnitude of flows downstream by up to 10 m^3/s. It is therefore recommended that a flushing flow regime be implemented to allow higher flows to pass through the residual reach during 1 November to 31 March.

The damming of the lower section of Mangamahoe Stream to form Lake Mangamahoe has provided a water supply and power generation. In addition to these primary functions the lake supports a native fish community and a popular trout fishery. Flow and fish passage in the Mangamahoe Stream has been restricted for over 100 years. Despite this the water quality in the lower stream is sufficient to maintain a native fish community that includes migratory species. Provision of a residual flow at the lake dam spillway is therefore not required, and in the continued presence of the NPDC dam, would not improve habitat greatly in the stream downstream.

Varying generation outflow from the Mangorei HEPS results in daily fluctuations in water level and flow in the lower Waiwhakaiho River. This changes the habitat available for aquatic communities, most markedly on the margins of the river channel. Fish are able to move in and out of the channel margins as the habitat changes, however macroinvertebrates cannot respond quickly and therefore the species that live here have to be tolerant of these conditions. The macroinvertebrate community in the lower river is similar to that in the residual reach (and also during recent summers to that upstream of the Mangorei HEPS intake), being typically indicative of 'poor' community health. Generation discharges from the Mangorei HEPS do however also have beneficial effects on the lower Waiwhakaiho River. The discharge of water from the lake via the power station appears to have a slight cooling effect on water temperatures in the river, and increases in dissolved oxygen levels are observed due to generation. Flow increases due to generation are also effective in flushing nuisance periphyton growths.

6. References

Biggs, B.J.F. 2000. New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. Ministry for the Environment, Wellington.

Boothroyd, I.G. and Stark, J.D. 2000. Use of invertebrates in monitoring. Chapter 14 in Collier, K.J. and Winterbourn, M.J. eds. New Zealand stream invertebrates: ecology and implications for management. New Zealand Limnological Society, Christchurch. Pp. 344-373.

Dunn, N.R., Allibone, R.M., Closs, G.P., Crow, S.K., David, B.O., Goodman, J.M., Griffiths, M., Jack, D.C., Ling, N., Waters, J.M., and J. R. Rolfe. 2018. Conservation status of New Zealand freshwater fishes, 2017. New Zealand Threat Classification Series 24. Department of Conservation, Wellington. 11 p.

Fish and Game. 2019. Juvenile trout survey of the Waiwhakaiho River, December 2018. An internal report prepared for Taranaki Fish and Game Council, March 2019.

Hay, J., and C., Allen. 2015. Managing potential water temperature effects of discharges from the Maitai Reservoir. Prepared for Nelson City Council. Cawthron Report No. 2732. 40 p. plus appendix.

Leathwick J., Julian K., Elith J., and D. Rowe. 2009. 'Predicting the distributions of freshwater fish species for all New Zealand's rivers and stream'. Prepared by NIWA for the Department of Conservation. NIWA Client Report: HAM2009-005.

Jowett, I.G. 1993. Report on minimum flow requirements for instream habitat in Taranaki rivers. NZ Freshwater Miscellaneous Report No. 75. National Institute of Water and Atmospheric Research, Christchurch. 35 p.

Jowett, I.G., Payne, T., Milhous, R., and J.M.D Hernández. 2015. System for Environmental Flow Analysis (SEFA), software package. Available from http://sefa.co.nz.

Ministry for the Environment, 2014 amended 2017. National Policy Statement for Freshwater Management 2014. Wellington: Ministry for the Environment.

Olsen, D., Tremblay, L., Clapcott, J., and R. Holmes. 2012. Water temperature criteria for native aquatic biota. Auckland Council Technical Report 2012/036.

Riley Consultants Ltd. 2020. Lake Mangamahoe Flood Assessment Mangorei Hydro Electric Power Scheme, prepared for Trustpower Ltd, February 2020.

Stark, J.D. 1993. Performance of the Macroinvertebrate Community Index: effects of sampling method, sample replication, water depth, current velocity, and substratum on index values. *New Zealand Journal of Marine and Freshwater Research.* **27**: 463-478.

Stark, J.D. 1998. SQMCI: a biotic index for freshwater macroinvertebrate coded abundance data. *New Zealand Journal of Marine and Freshwater Research.* **32**: 55-66.

Stark, J.D. and Maxted, J.R. 2007. A biotic index for New Zealand's soft-bottomed streams. *New Zealand Journal of Marine and Freshwater Research.* **41**: 43-61.

Stark, J.D., Boothroyd, I.K.G., Harding, J.S., Maxted, J.R. and Scarsbrook, M.R. 2001. Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for the Ministry for the Environment.

Todd, A. S., Coleman, M. A., Konowal, A. M., May, M. K., Johnson, S., Vieira, N. K. M., and J. F. Saunders. 2008. Development of New Water Temperature Criteria to Protect Colorado's Fisheries. *Fisheries* **33**: 433-443.

Tonkin and Taylor. 2020. Reconsenting of Mangorei Hydroelectric Power Scheme: Hydrology Report. Prepared for Chancery Green on behalf of Trustpower Limited, November 2020.

TRC. 2016. Freshwater bodies of outstanding or significant value in the Taranaki region Review of the Regional Fresh Water Plan for Taranaki. Document: 1602585

TRC. 2016. Native fishery species of significance in the Taranaki region. Review of the Regional Freshwater Plan for Taranaki. Document: 1190381

TRC. 2018. Trustpower Ltd Mangorei Hydroelectric Power Scheme Monitoring Programme Annual Report, 2016-2017: Technical Report 2017-102. Document: 1978920.

TRC. 2018. Freshwater periphyton monitoring programme (periphyton monitoring in relation to amenity values): State of the environment monitoring report, 2016-2018. Technical Report 2018-7, July 2018.

TRC 2019a. Mangorei Hydroelectric Power Scheme Monitoring Programme Annual Report 2017-2018: Technical Report 2018-93. Document: 2174298

TRC. 2019b. Freshwater Physicochemical Programme State of the Environment Monitoring Annual Report 2017-2018. Technical Report 2018-103, June 2019.

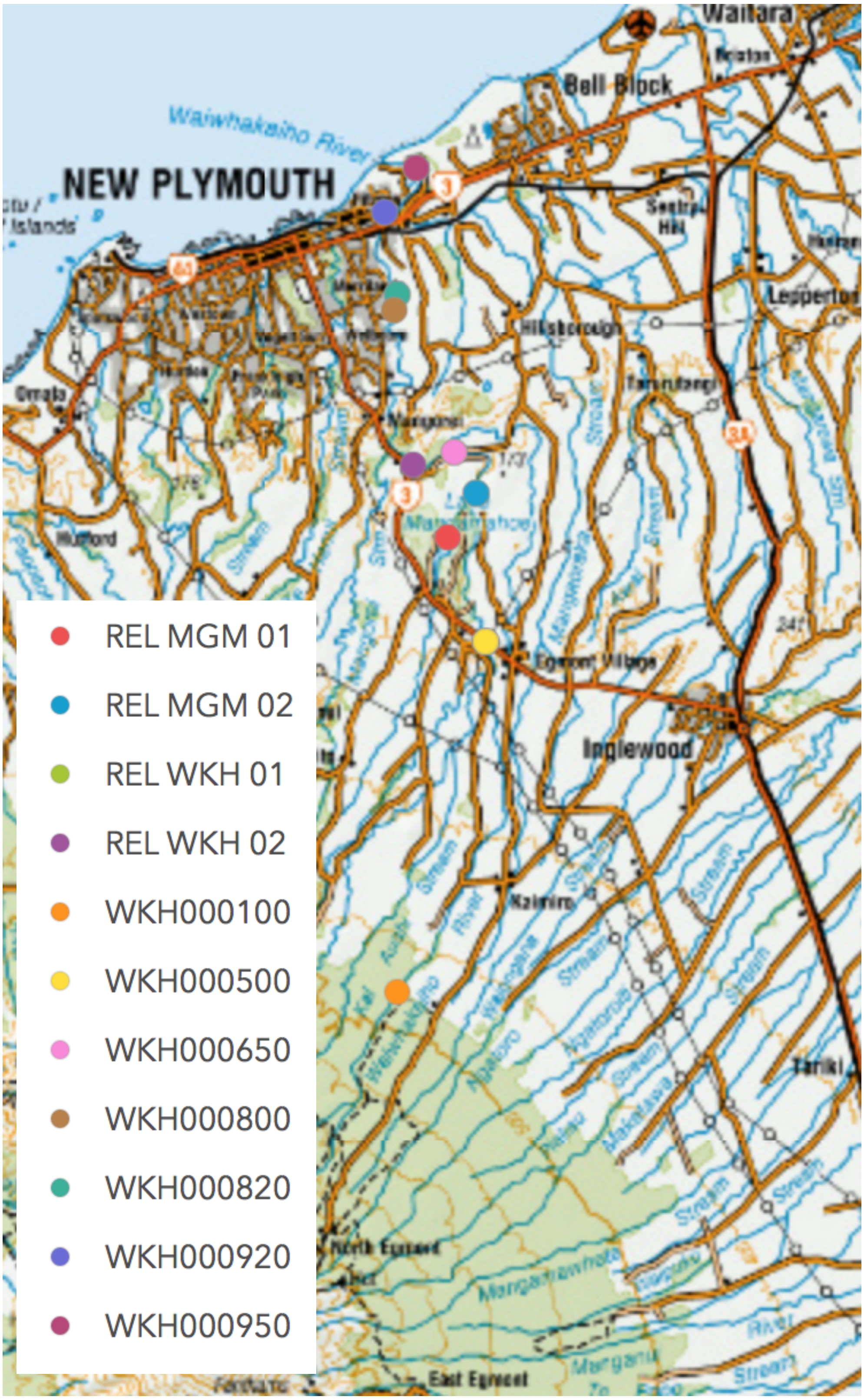
TRC. 2019c. Freshwater Macroinvertebrate Fauna Biological Monitoring Programme Annual State of the Environment Monitoring Report 2017-2018: Technical Report 2018-61 (and Report DS104). Document: 2277172.

TRC 2020, DRAFT. Mangorei Hydroelectric Power Scheme Monitoring Programme Annual Report 2018-2019: Technical Report 2019-65. Document: 2324529, March 2020.

Winterbourn, M.J., Gregson, K.L.D. and Dolphin, C.H. 2006. Guide to the aquatic insects of New Zealand. *Bulletin of the Entomological Society of New Zealand*. **14**.

7. Appendix One: Monitoring methods

7.1. Monitoring site map



7.2. Monitoring site location information

Watercourse	Site name	Organisation	Site code	Type	Easting	Northing
Waiwhakaiho River	National Park	TRC	WKH000100	Benthic macroinvertebrates	1696096	5658351
Waiwhakaiho River	Upstream (SH3 Egmont Village)	TRC	WKH000500	River flow	1698297	5666893
Waiwhakaiho River	Upstream (SH3 Egmont Village)	TRC	WKH000500	River level	1698297	5666893
Waiwhakaiho River	Upstream (SH3 Egmont Village)	TRC	WKH000500	Water temperature logger	1698297	5666893
Waiwhakaiho River	Upstream (SH3 Egmont Village)	TRC	WKH000500	Water quality	1698297	5666893
Waiwhakaiho River	Upstream (SH3 Egmont Village)	TRC	WKH000500	Benthic macroinvertebrates	1698297	5666893
Waiwhakaiho River	Upstream (SH3 Egmont Village)	TRC	WKH000500	Periphyton	1698297	5666893
Waiwhakaiho River	Residual (Hydro Road)	TRC	WKH000650	Water temperature logger	1697474	5671435
Waiwhakaiho River	Residual (Hydro Road)	Ryder/TPL	REL WKH 01	Water quality	1697474	5671435
Waiwhakaiho River	Residual (Hydro Road)	Ryder/TPL	REL WKH 01	Periphyton	1697474	5671435
Waiwhakaiho River	Downstream (Downstream Mangorei HEPS tailrace)	Ryder/TPL	REL WKH 02	Water quality	1696538	5671128
Waiwhakaiho River	Downstream (Downstream Mangorei HEPS tailrace)	Ryder/TPL	REL WKH 02	Periphyton	1696538	5671128
Waiwhakaiho River	Merrilands Domain	TRC	WKH000800	E. coli	1696059	5674931
Waiwhakaiho River	Merrilands Domain	TRC	WKH000800	Benthic cyanobacteria	1696059	5674931
Waiwhakaiho River	Rimu Street	TRC	WKH000820	River flow	1696149	5675261
Waiwhakaiho River	Rimu Street	TRC	WKH000820	River level	1696149	5675261
Waiwhakaiho River	Rimu Street	TRC	WKH000820	Water temperature logger	1696149	5675261
Waiwhakaiho River	Constance Street	TRC	WKH000920	Benthic macroinvertebrates	1695827	5677271
Waiwhakaiho River	Constance Street	TRC	WKH000920	Periphyton	1695827	5677271
Waiwhakaiho River	Adjacent to Lake Rotomanu	TRC	WKH000950	Benthic macroinvertebrates	1696587	5678336
Waiwhakaiho River	Adjacent to Lake Rotomanu	TRC	WKH000950	E. coli	1696587	5678336
Waiwhakaiho River	Adjacent to Lake Rotomanu	TRC	WKH000950	Benthic cyanobacteria	1696587	5678336
Mangamahoe Stream	Downstream Lake Mangamahoe spillway	Ryder/TPL	REL MGM 01	Water temperature logger	1697385	5669421
Mangamahoe Stream	Downstream Lake Mangamahoe spillway	Ryder/TPL	REL MGM 01	Dissolved oxygen logger	1697385	5669421
Mangamahoe Stream	Upstream Waiwhakaiho River confluence	Ryder/TPL	REL MGM 02	Water temperature logger	1698040	5670480
Mangamahoe Stream	Upstream Waiwhakaiho River confluence	Ryder/TPL	REL MGM 02	Dissolved oxygen logger	1698040	5670480
Mangamahoe Stream	Upstream Waiwhakaiho River confluence	Ryder/TPL	REL MGM 02	Periphyton	1698040	5670480
Mangamahoe Stream	Upstream Waiwhakaiho River confluence	Ryder/TPL	REL MGM 02	Benthic macroinvertebrates	1698040	5670480

7.3. Monitoring site photographs

Figure A1.1. Waiwhakaiho River, 'Upstream' (looking downstream from the SH3 bridge).

Figure A1.2. Waiwhakaiho River, 'Residual'.

Figure A1.3. Waiwhakaiho River, 'Downstream'. The dissolved oxygen logger unit (white tube) is visible attached to the boulder on the right hand site of the photograph (Riverwise Consulting).

Figure A1.4. Waiwhakaiho River, 'Rimu Street'.

Figure A1.5. Waiwhakaiho River, 'Constance Street'.

Figure A1.6. Waiwhakaiho River, 'Downstream of Lake Rotomanu'.

7.4. Macroinvertebrates

Benthic macroinvertebrates were sampled using a kicknet with 500 µm diameter mesh, following Ministry for the Environment's 'Protocols for sampling macroinvertebrates in wadeable streams' (Stark *et al.* 2001). Macroinvertebrate samples were processed for macroinvertebrate taxa identification and their relative abundance using the semi-quantitative protocols outlined in the Ministry for the Environment's 'Protocols for sampling macroinvertebrates in wadeable streams' (Stark *et al.* 2001). Protocol 'P1: Coded abundance' was used, which is summarised briefly below.

In the laboratory, samples were passed through a 500 µm sieve to remove fine material and residual ethanol. Contents of the sieve were then placed in a white tray. Each taxon present in the sample was assigned to one of five coded abundance categories using the codes established by Stark (1998) (Table A1.1). Up to 20 individuals representative of each taxon were removed from each sample to confirm identifications under a dissecting microscope (10-40x) using criteria from Winterbourn *et al.* (2006).

Table A1.1. Coded abundance scores used to summarise macroinvertebrate data (after Stark 1998).

Abundance	Coded abundance	Weighting factor
1 - 4	Rare (R)	1
5 - 19	Common (C)	5
20 - 99	Abundant (A)	20
100 - 499	Very abundant (VA)	100
> 500	Very very abundant (VVA)	500

For each site, benthic macroinvertebrate community health was assessed by determining the following characteristics:

Number of taxa: A measurement of the number of taxa present.

Number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa, and percentage of the total number of taxa comprising EPT taxa (% EPT taxa): These insect groups are generally dominated by invertebrates that are indicative of higher quality conditions. In stony bed rivers, these indexes usually increase with improved water quality and increased habitat diversity.

Macroinvertebrate Community Index (MCI) (Stark 1993): The MCI uses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream. Taxon scores are between 1 and 10, 1 representing species highly tolerant to organic pollution (e.g., worms and some dipteran species) and 10 representing species highly sensitive to organic pollution (e.g., most mayflies and stoneflies). A site score is obtained by summing the scores of individual taxa and dividing this total by the number of taxa present at the site. These scores can be interpreted in comparison with national standards (Table A1.2). For example, a low site score (e.g., 40) represents 'poor' conditions and a high score (e.g., 140) represents 'excellent' conditions.

$$\text{MCI} = \left(\frac{\text{Sum of taxa scores}}{\text{Number of scoring taxa}} \right) \text{x } 20$$

Semi-quantitative MCI (SQMCI) (Stark 1998): The SQMCI uses the same approach as the MCI but weights each taxa score based on how abundant the taxa is within the community. Abundance of all taxa is recorded using a five-point scale (Table A1.1). As for MCI, SQMCI scores can be interpreted in the context of national standards (Table A1.2).

$$\text{SQMCI} = \frac{\text{Sum of (Taxa coded abundance x Taxa score)}}{\text{Sum of coded abundances for sample}}$$

Table A1.2. Interpretation of macroinvertebrate community index values from Boothroyd and Stark (2000) (Quality class A) and Stark and Maxted (2007) (Quality class B).

Quality Class A	**Quality Class B**	**MCI**	**SQMCI**
Clean water	Excellent	≥ 120	≥ 6.00
Doubtful quality	Good	100 – 119	5.00 – 5.99
Probable moderate pollution	Fair	80 – 99	4.00 – 4.99
Probable severe pollution	Poor	< 80	< 4.00

8. Appendix Two: Water quality data summary, 1995-2018

Table A2.1. Waiwhakaiho River at Upstream/SH3 (TRC site code WKH000500) water quality data summary, July 1995 to June 2018 (from TRC 2019b).

Parameter	Unit	Minimum	Maximum	Median	N	Standard deviation
Temperature	°C	4.8	18.3	11.2	276	2.9
Flow	m^3/s	1.705	180	3.818	276	14.282
Dissolved oxygen concentration	g/m^3	9.1	12.8	10.8	276	0.7
Dissolved oxygen saturation	%	91	110	101	276	3
Biochemical oxygen demand (5-day)	g/m^3	<0.5	5	<0.5	276	0.6
pH	pH	6.8	8.5	7.9	276	0.3
Conductivity @ 20°C	mS/m	1.8	17.4	12.2	276	3.4
Black disc transparency	m	0.12	8.05	3.06	276	1.42
Turbidity (Hach 2100A)	NTU	0.4	26	0.7	245	2.8
Turbidity (Cyberscan WTW)	NTU	0.3	41	0.7	157	4.9
Absorbance @ 340nm filtered	/cm	0.005	0.095	0.015	276	0.018
Absorbance @ 440nm filtered	/cm	0	0.022	0.003	276	0.004
Absorbance @ 770nm filtered	/cm	0	0.007	0	276	0.001
Ammoniacal nitrogen	g/m^3N	<0.003	0.157	0.008	276	0.022
Nitrite nitrogen	g/m^3N	<0.001	0.01	0.002	276	0.001
Nitrate nitrogen	g/m^3N	0.01	0.47	0.11	276	0.1
Total kjeldahl nitrogen	g/m^3N	<0.01	1.95	0.07	276	0.21
Total nitrogen	g/m^3N	<0.05	2.1	0.2	276	0.26
Dissolved reactive phosphorus	g/m^3P	<0.004	0.108	0.025	276	0.011
Total phosphorus	g/m^3P	0.014	0.437	0.035	276	0.047
Total alkalinity	g/m^3 $CaCO_3$	5	76	48	276	17
Suspended solids	g/m^3	<2	280	<2	276	19
E.coli bacteria	cfu/100 mL	23	57,000	210	252	5,619
Enterococci bacteria	cfu/100 mL	1	40,000	100	276	3,742
Faecal coliforms	cfu/100 mL	23	83,000	225	276	7,694

9. Appendix Three: Water quality data summary, 2019-2020

Table A3.1. Waiwhakaiho River median water quality data at three sites, April 2019 to February 2020. Long-term (1995-2018) minimum, maximum and median data for the Upstream/SH3 site is also shown for comparison.

Parameter	Unit	Upstream (SH3)				Residual (Hydro Road)	Downstream (Meeting of the Waters)
		1995-2018 Minimum	1995-2018 Maximum	1995-2018 Median	2019-2020 Median	2019-2020 Median	2019-2020 Median
Biochemical oxygen demand (5-day)	g/m^3	<0.5	5	<0.5	<0.5	<2	<2
pH	pH	6.8	8.5	7.9	8.0	8.6	7.8
Conductivity @ 20°C	mS/m	1.8	17.4	12.2	14.3	15.1	13.6
Turbidity (Hach 2100A)	NTU	0.4	26	0.7	0.5	0.5	0.8
Ammoniacal nitrogen	g/m^3N	<0.003	0.157	0.008	0.007	0.023	0.015
Nitrite nitrogen	g/m^3N	<0.001	0.01	0.002	0.001	0.001	0.003
Nitrate nitrogen	g/m^3N	0.01	0.47	0.11	0.09	0.07	0.16
Total kjeldahl nitrogen	g/m^3N	<0.01	1.95	0.07	0.05	0.15	0.05
Total nitrogen	g/m^3N	<0.05	2.1	0.2	0.2	0.2	0.3
Dissolved reactive phosphorus	g/m^3P	<0.004	0.108	0.025	0.033	0.014	0.016
Total phosphorus	g/m^3P	0.014	0.437	0.035	0.034	0.024	0.027
E.coli bacteria	cfu/100 mL	23	57,000	210	180	30	120

10. Appendix Four: Benthic macroinvertebrate data summary, 2010-2020

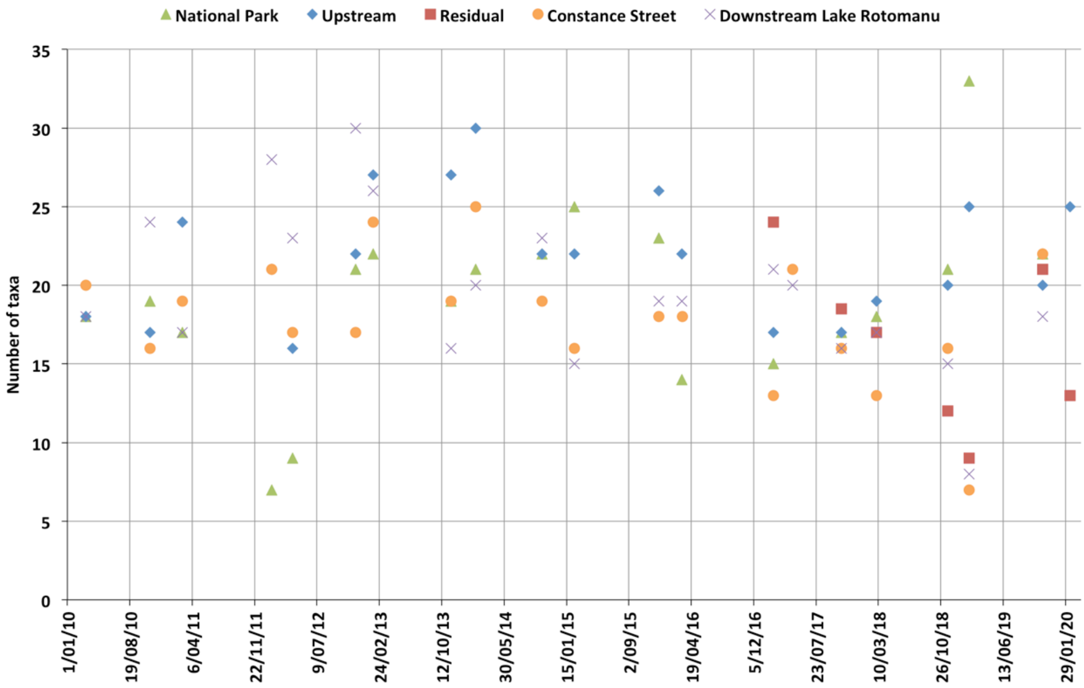


Figure A4.1. Number of taxa at Waiwhakaiho River sites, March 2010 – February 2020.

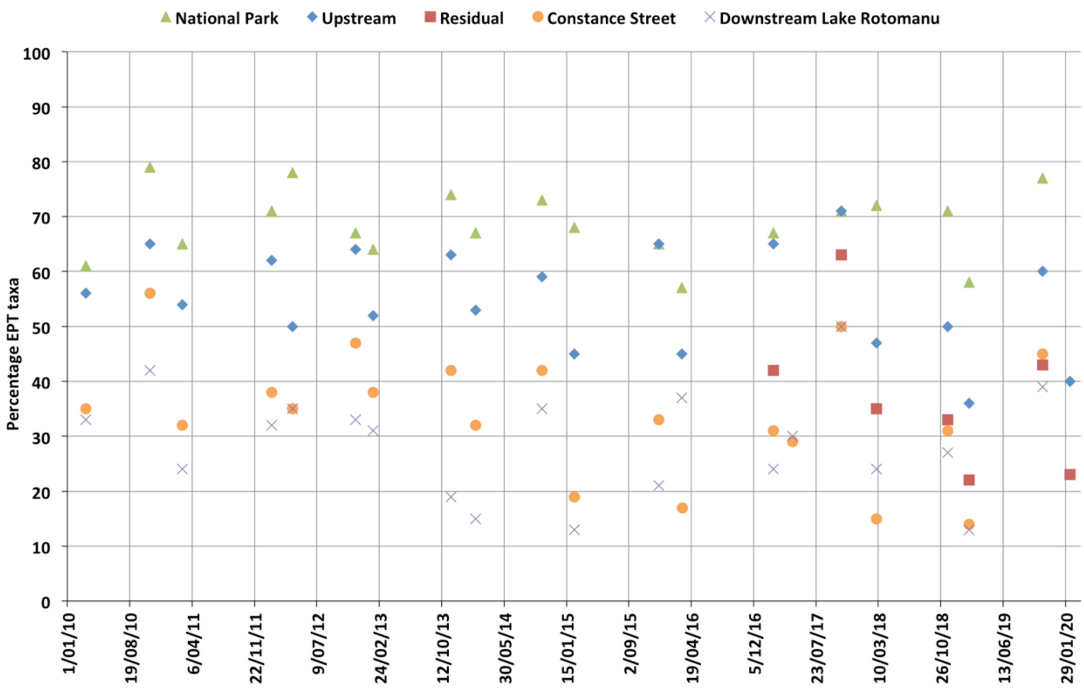


Figure A4.2. Percentage of EPT taxa at Waiwhakaiho River sites, March 2010 – February 2020.

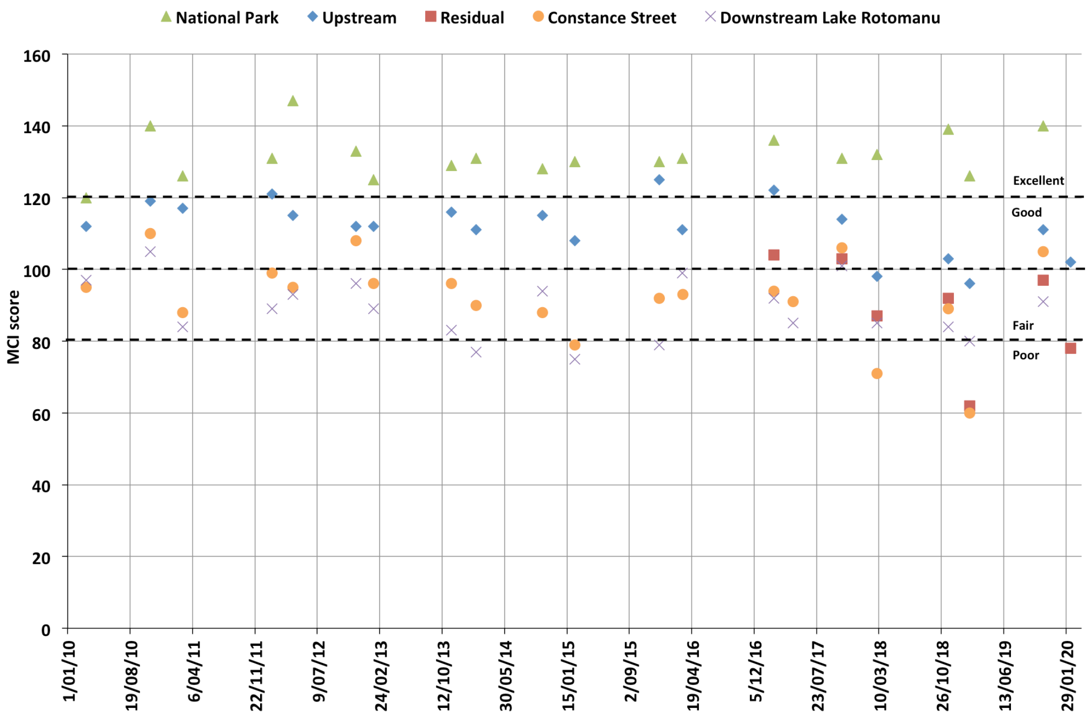


Figure A4.3. MCI scores at Waiwhakaiho River sites, March 2010 – February 2020. Interpretations for macroinvertebrate community health based on MCI scores are also shown.

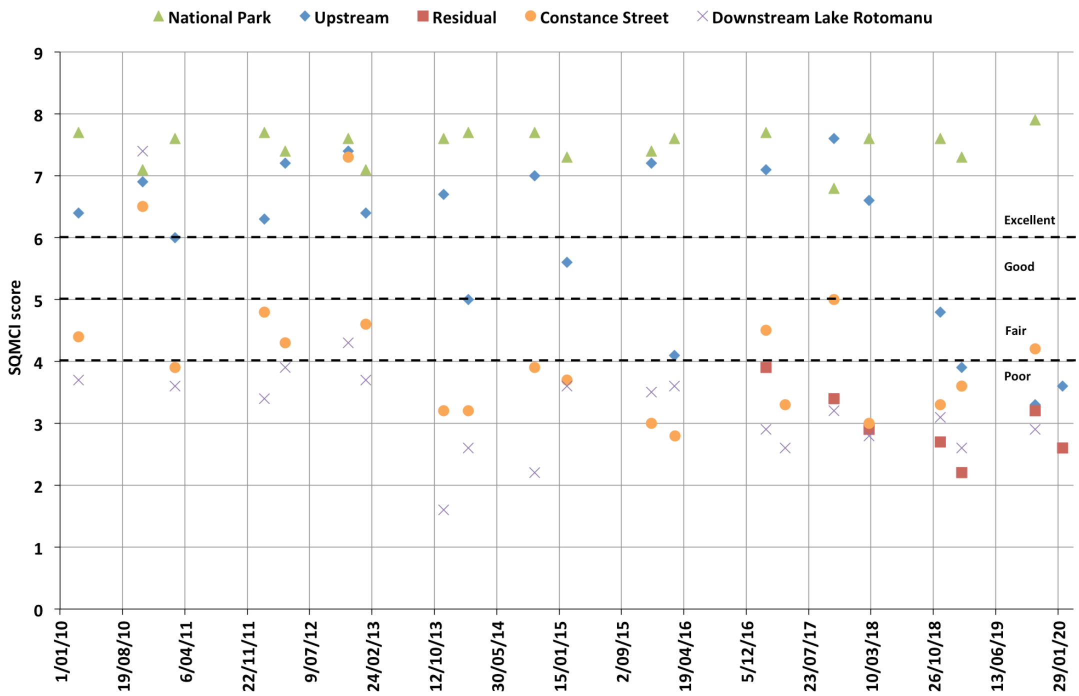


Figure A4.4. SQMCI scores at Waiwhakaiho River sites, March 2010 – February 2020. Interpretations for macroinvertebrate community health based on SMCI scores are also shown.

11. Appendix Five: Water temperature model

Temperature modelling was undertaken with the computer software SEFA (System for Environmental Flow Analysis, Jowett *et al.* 2015). The model is a mechanistic, one-dimensional heat transport model that predicts the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux. Water temperatures are modelled downstream of a section of river under various flow scenarios.

Net heat flux is calculated as the sum of heat to or from long-wave atmospheric radiation, short-wave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, and the water's back radiation (Jowett *et al.* 2015). The model assumes that water flowing downstream will increase or decrease in temperature until the incoming temperature equals the heat lost from the river through radiation and evaporation. The temperature at which incoming energy equals the outgoing energy and there is no further increase in water temperature is known as the equilibrium temperature.

Temperature models were run for the reach between the Upstream site (SH3) and the Residual site (Hydro Road) (a distance of 7 km) using hydraulic characteristics derived from the instream habitat survey, and daily water temperature, river flows and meteorological data (derived from the New Plymouth and Stratford weather stations).

The temperature models were calibrated by manipulating shade, wind speed and bed conductivity parameters to optimise predictions of mean and maximum water temperature relative to observed data at a given location (i.e., minimise the root-mean-squared-error of prediction of these two parameters). Model calibration was performed using both the Lagrangian (dynamic) and Theurer calculation methods provided in the SEFA program. The measured and predicted daily mean and maximum temperatures for each modelled reach on the Waiwhakaiho River, using the calibrated model, are presented in Figure A5.1. Model inputs and calibrated values are summarized for the reach and model scenario in Table A5.1.

The calibrated model reproduced observed patterns of mean and maximum daily water temperature on average within 0.3 and 0.2 °C, respectively. We also determined the accuracy of the model by regressing observed vs. predicted water temperatures (Figure A5.2). The model is more often under predicting mean water temperatures by 0.4 °C than over predicting by 0.6 °C, and is equally over and under predicting maximum water temperatures by 0.7 °C.

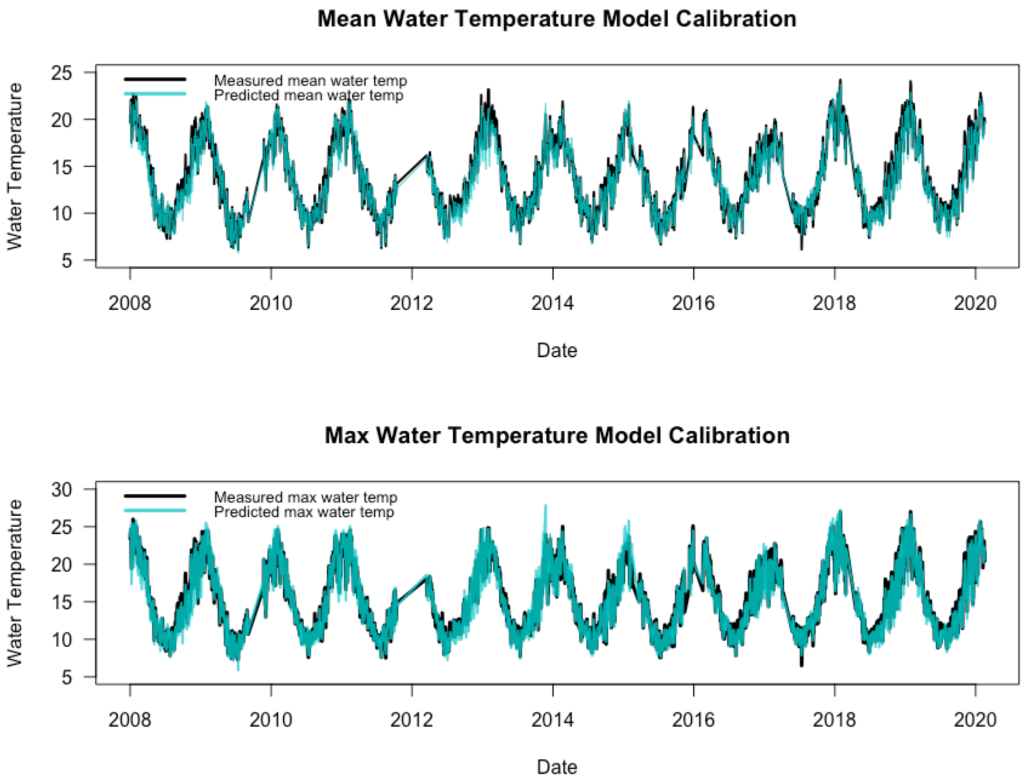


Figure A5.1. Measured (black) mean (top) and maximum (bottom) water temperature and predicted (teal) downstream water temperatures for the Waiwhakaiho River study reach using the calibrated SEFA temperature model.

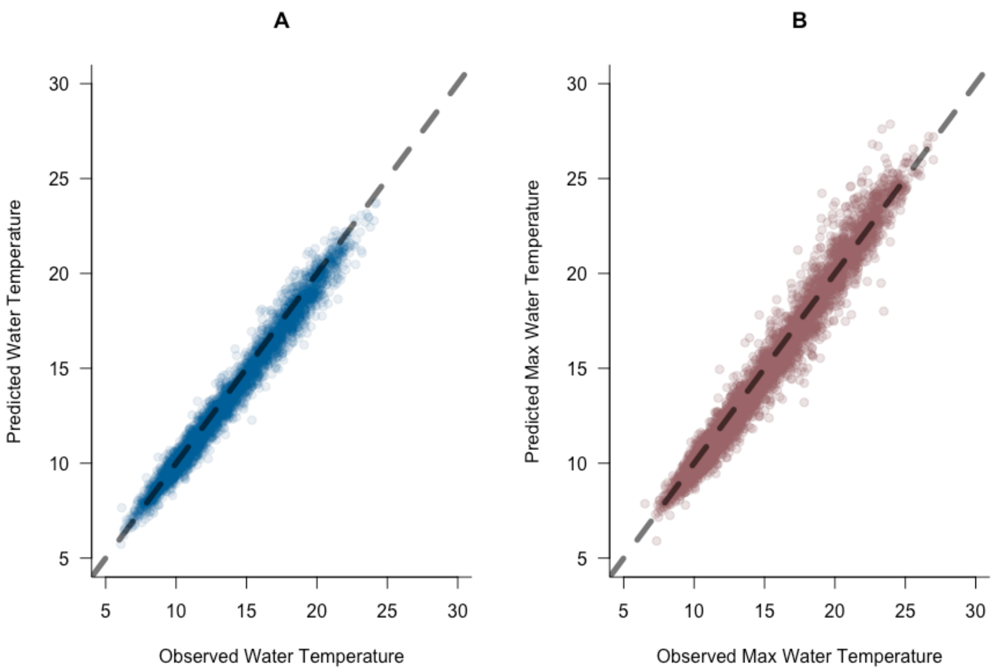


Figure A5.2. Observed vs. calibrated model predicted mean (a) and maximum (b) water temperature and 1:1 line (dashed).

Table A5.1. Calibration parameters used in the longitudinal water temperature modelling. Variables were used from 1 January 2008 to 18 February 2020.

Parameter	Unit	Source
Reach		
Stream bed conductivity	J/m/s/°C	calibrated
Stream bed thickness	m	default
Stream bed temperature (earth 100 cm deep)	°C	Stratford AWS
Reach shading topographic angle	°	calibrated
Reach shading average canopy angle	°	calibrated
Reach shading fraction through canopy		calibrated
Reach Elevation	m asl	Topomap
Upstream		
Mean daily water temperature at start of reach	°C	Observed (SH3)
Maximum daily water temperature at start of reach	°C	Observed (SH3)
Elevation (top of reach)	m asl	Topomap (SH3)
Meteorology		
Maximum daily air temperature	°C	New Plymouth AWS
Mean daily air temperature	°C	New Plymouth AWS
Time of maximum air temperature	h	New Plymouth AWS
Wind velocity	m/s	New Plymouth AWS
Sunshine hours	hours	Stratford AWS
Mean daily solar radiation	$J/s/m^2$	New Plymouth AWS
Mean relative humidity	fraction	Stratford AWS

Calibrated model:

RMS error in daily mean temperature 0.66

RMS error in daily max temperature 0.86

Calibrated values: Shade 0.12, Wind multiplying factor 0.46, Bed conductivity 9.14.

Table A5.2. Climate variables for the warmest day in January, February, March, November, December from 2008 – 2020. Variables were input into the SEFA reach models.

Month	**January**	**February**	**March**	**November**	**December**
Date	**30/01/18**	**3/02/13**	**7/03/16**	**24/11/13**	**25/12/12**
Min. Residual flow (L/s)	700	700	700	600	600
US temp (max)	23.6	20.5	20.47	19.8	21.1
US temp (mean)	21.7	18.65	18.71	17.55	19.1
DS temp (max)	26.7	24.8	23.5	23.93	24.58
DS temp (mean)	24.2	23.155	20.955	20.54	22.605
US flow (L/s)	2500	1830	2500	2040	3770
DS flow (L/s)	1335	1190	2107	1293	n/a
Humidity (%)	83.5	76.1	79.3	82.9	85.1
Sunshine (h)	9.0	10.2	7.7	10.3	5.5
Bed temp (C)	17.4	17	17.4	14.4	14.8
Radiation J m^{-2} s^{-1}	335.9	308.4	256.7	522.9	317.1
Wind (m s^{-1})	0.3	0.229	0.749	0.307	0.375
Air Temp (max)	25.7	24.7	24.1	21.7	29.9
Air Temp (mean)	21.7	20.2	21.7	17	24.35

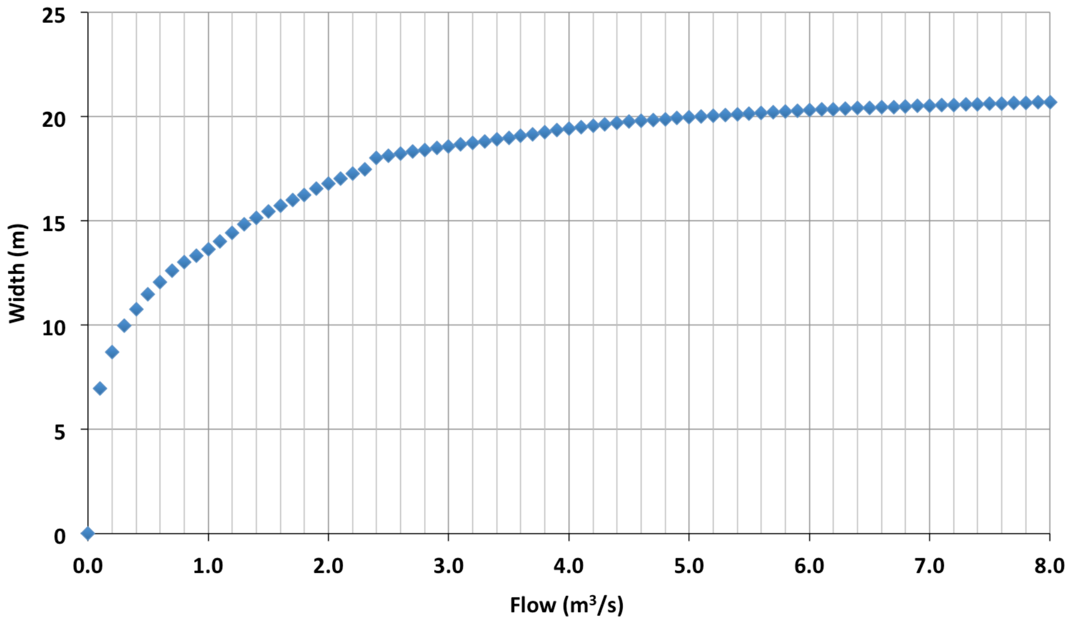
Table A5.3. Averaged (2008-2020) climate variables for the warmest month, January, input into the SEFA reach model.

Minimum Residual flow (L/s)	**700**
US temp (max)	18.7
US temp (mean)	16.9
DS temp (max)	21.5
DS temp (mean)	19.1
US flow (L/s)	4,800
DS flow (L/s)	3,803
Humidity (%)	81.2
Sunshine (h)	7.9
Bed temp (C)	16.3
Radiation (J m^{-2} s^{-1})	287.3
Wind m/s	0.5
Air Temp (mean)	18.0
Air Temp (max)	22.3

12. Appendix Six: Instream habitat model

Table A6.1. Habitat suitability curves used in IFIM analysis.

Common name	Life history stage	Habitat suitability curve
Benthic invertebrate density		Jowett (2019)
Food producing habitat		Waters (1976)
Brown trout	Adult (> 400 mm)	Hayes and Jowett (1994)
	Juvenile (7-170 mm)	Thomas and Bovee (1993)
	Yearling (< 100 mm)	Raleigh *et al.* (1986)
Crans bully		Jowett and Richardson (2008)
Inanga	Feeding	Jowett (2002)
Lamprey		Jowett and Richardson (2008)
Longfin eel	< 300 mm	Jowett and Richardson (2008)
	> 300 mm	Jowett and Richardson (2008)
Redfin bully		Jowett and Richardson (2008)
Shortfin eel	< 300 mm	Jowett and Richardson (2008)
	> 300 mm	Jowett and Richardson (2008)
Shortjaw kokopu		McDowall *et al.* (1996)
Torrentfish		Jowett and Richardson (2008)



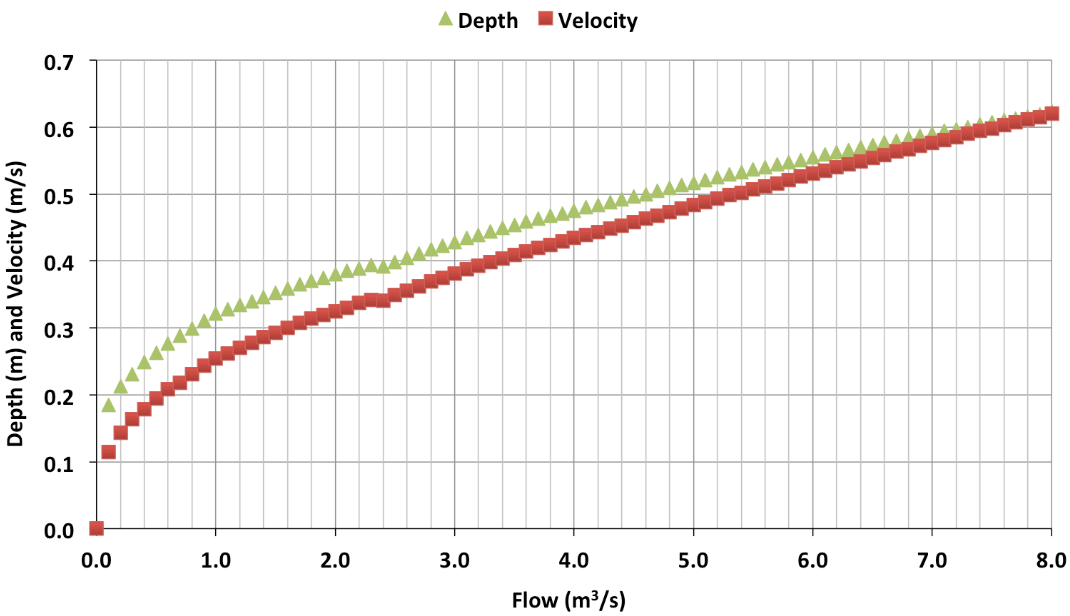


Figure A6.1. Variation in average width (m), depth (m), and velocity (m/s) with flow in the Waiwhakaiho River upstream of the Mangorei HEPS.