Water quality investigation Raumanga catchment 2021-2022

Northland REGIONAL COUNCIL
Te Kaunihera ā rohe o Te Taitokerau

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Executive Summary

Background

Raumanga Stream is one of major tributaries of the Hātea River estuary draining the suburbs of Maunu, Raumanga, and Horahora located in the western part of the Whangārei City. The last five years (2015-2019) of monthly SoE water quality monitoring shows higher concentration of dissolved inorganic nitrogen (DIN) and faecal pathogen (*Escherichia coli or E. coli*) in the Raumanga Stream compared to other main catchments contributing to the Hātea River estuary. A one-year water quality investigation programme was established by Northland Regional Council to ascertain the source of elevated nutrient concentration and microbial contamination observed in the Raumanga Stream.

Summary of Results

Five monitoring sites representing three major tributaries of the Raumanga catchment (Nihotetea Stream, Te Hihi Stream, and Waiponamu Stream) together with the Raumanga at Bernard Street SoE site were monitored between February 2021 and March 2022. The purpose of the monitoring was to identify the source of elevated nitrogen and *E. coli* concentrations at Raumanga SoE site. The results from this water quality investigation monitoring can be summarised as follows:

Nitrogen

- Comparatively high nitrate (NO_3-N) concentrations in the Nihotetea sub-catchment, which was exceptionally high in the unnamed tributary of Nihotetea Stream at Austin Road (Nihotetea Trib at Austin Road). NO_3-N constitutes the bulk of total nitrogen concentration for all Nihotetea Stream sites as well as the Raumanga SoE site at Bernard Street. High nitrate in Nihotetea and Raumanga Streams also contributed to their high Dissolved inorganic nitrogen (DIN) concentrations breaching the NPS-FM national bottom line most of the time over the monitoring period. The median NO_3-N and DIN concentrations at all sites except the Waiponamu Stream had also breached the Northland objective value (i.e., some of the worst results found in Northland's near-pristine reference streams). The high NO_3-N and DIN in Nihotetea Stream can be related to moderately well drained soil (i.e., greater surface water interactions with nitrate rich groundwater systems) and high oxidising environment i.e., more possibility of denitrification. This means there is a possible high risk of nitrate loss from agricultural activities through surface run-off as well as leaching into the shallow groundwater systems in Nihotetea Stream catchment as well as Raumanga mainstem.

- Ammoniacal nitrogen (NH_4-N) constituted the bulk of total nitrogen at Waiponamu Stream and to some extent at Te Hihi Stream, which might have been influenced by their poorly drained peat soil and its reducing geological properties. However, overall NH_4-N toxicity level was much lower at all sites, which was consistent with any other Northland rivers.

Phosphorous

- High Dissolved reactive phosphorus (DRP) was observed in Te Hihi Stream and Nihotetea Trib at Austin Road mostly during summer low flow and base flow conditions, but not in winter months perhaps because of dilution effect. The median DRP concentrations in Nihotetea Trib and Te Hihi Stream had breached the NPS-FM national bottom line mostly during summertime. The comparatively high DRP concentrations at these sites could be linked to volcanic geology and reduced peat soil exacerbated by their land-use impact. However, the DRP concentrations at all sites over the monitoring period were much lower than the Northland objective value.

Microbial contamination

- The *E. coli* median concentrations had breached the NPS-FM national bottom line at all sites, but did not breach the Northland objective value. The *E. coli* concentrations were comparatively high in Nihotetea Stream at Austin Road, Te Hihi Stream at Highfield Way and Raumanga at Bernard Street. It is to be noted that very few rivers in Northland meet the NPS-FM standards for *E. coli*. High *E. coli* concentrations in Nihotetea at Austin Road and Te Hihi Stream could be due to runoff from developed pastoral land-use, and faecal pathogens from animal pests and wildfowl. Further downstream in Raumanga mainstem the faecal pathogen can be related to old sewage, stormwater systems and lifestyle blocks. Previously, microbial source tracking results indicated that the primary source of contamination within the Whangārei Harbour catchment is ruminant but human markers have also been detected on several occasions at the Raumanga at Bernard Street site.

Other water quality attributes

- None of the sites had breached the NPS-FM national bottom line and Northland objective value for visual clarity (an indicator of suspended sediment). Overall visual clarity was not a major water quality issue for Raumanga catchment. However, it is to be acknowledged that the monitoring programme was not designed to focus on storm events when majority of the sediment load is generated because of catchment runoff and accelerated bank erosion process.

- Temperature and pH readings at all monitoring sites were within the acceptable range throughout the monitoring period. The median electrical conductivities at most sites were indicative of moderate pollution and land-use impact. However, the conductivity values in Waiponamu Stream were exceptionally high, even if nutrient concentration was comparatively lower than other monitoring sites, perhaps because of ion rich groundwater influence from shallow aquifers constituting bulk of its base flows.

- Dissolved oxygen (DO) concentrations were exceptionally low at Waiponamu Stream and Nihotetea Stream at Austin Road. Low DO values at Waiponamu Stream and Nihotetea Stream at Austin Road, mostly during summertime, could be influenced by deoxygenated groundwater movements as well as macrophyte growth in a very slow-moving channel. DO concentrations observed in Waiponamu, Te Hihi, and Raumanga Stream were indicative of healthy ecosystem. However, it is to be acknowledged that discrete DO measurements are not ideal to monitor the effects of seasonal and diurnal DO fluctuations on aquatic biota.

Benthic macroinvertebrates

- Annual stream invertebrate monitoring results undertaken in 2021 and 2022 suggest that the macroinvertebrate community (MCI, QMCI, and ASPM) at the Nihotetea Stream upstream of the Waiponamu Stream confluence were in better condition (mostly within NPS-FM band B) than the downstream sites (mostly NPS-FM band C or D) – Te Hihi at Highfield Way and Raumanga at Bernard Street. Below national bottom line macroinvertebrate community indices (QMCI, ASPM, and EPT abundance) at the Raumanga at Bernard Street site reflected its degraded water quality and poor habitat condition. The moderate MCI and poor QMCI values at Te Hihi Stream site can be linked to its limited instream habitat quality and impact from the sprawling urban, and lifestyle blocks in the surrounding catchment. The absence of stonefly species and abundance of pollution tolerant snail species *Potamopyrgus* was noticeable at all sit*es*, indicating degraded water quality in the catchment.

Conclusion

Overall, the water quality state in the upper reaches of Nihotetea Stream around Austin Road was poor with high nutrients compared to the Te Hihi and Waiponamu Stream sub-catchments, possibly because of developed pastures with no riparian vegetation and influence of legacy nutrients in the groundwater from old-time orchards in early 2000. The poor water quality in the upper reaches of Nihotetea Stream was also influenced by its physiographic control over water quality process (i.e., landscape characteristics such as underlying geology, and dominant hydrological pathway to oxidising shallow groundwater systems). As the water travels down the catchment along the Nihotetea mainstem upstream of the Waiponamu Stream confluence, the water quality slightly improved providing better life supporting capacity value (e.g., healthy dissolved oxygen and macroinvertebrate community) because of better in-stream habitat diversity and riparian habitat. The poor water quality state including the macroinvertebrate community in Raumanga Stream at Bernard Street could be partially attributed to the upper reaches of Nihotetea Stream but also the cumulative effects of semi-rural and urban land-use in its surrounding catchment.

Recommendations

- There is a continual risk of nitrogen leaching and release of phosphorus to surface waterways and shallow groundwater systems in the Nihotetea Stream headwater catchments because of its well-drained soil, geology type, underlying oxidising shallow aquifers and high risk of surface runoff particularly during winter months. Therefore, it is recommended to have a careful consenting process for any new or renewal of existing consents that would have the potential of accelerating this landscape process behind poor water quality state in this catchment.

- Also suggest compliance check of land use practices in the Nihotetea catchment and ways to minimise water qulity contamination. For example, if there is dairy farming ensuring that they are meeting consent requirements or if the consent conditions need to be reviewed.

- Undertake non-regulatory catchment intervention or mitigation measures (such as creation of thick riparian buffer) in the Nihotetea headwater catchments north of Pompallier Estate Drive, where currently the waterways are devoid of any healthy riparian buffer. Similar catchment interventions together with careful consenting process is also recommended in the headwater catchments of Te Hihi Stream and lower reaches of Raumanga mainstem.

- Undertake further water quality investigation following the implementation of catchment mitigations measures together with sampling of physiographic process attributes (e.g., Dissolved Organic Carbon or DOC, Iron, Manganese, Sulphate, Dissolved Silica, Alkalinity, Potassium, Sodium) in the upstream headwaters of Nihotetea. This will aid in better understanding of the water quality process and effectiveness of the mitigation measures in the Raumanga catchment.

Introduction

Background

Te Taitokerau (Northland) has an abundance of rivers and streams with relatively small catchments, which provide habitat for a range of native fish and invertebrates, as well as important natural resources and amenity values to our communities. Our rivers and streams can either be directly polluted from point-source discharges (such as, effluents and sewage) or indirectly from diffused discharges as a result of surface run-off draining modified pasture or urban land-use during rainfall events. As majority of Northland's rivers flow into harbours rather than open coastline, poor river quality can also affect the health of our estuaries and harbours.

Ecological health or integrity of river ecosystem is related to ensemble of environmental factors including climate, catchment geology, land-use, availability of suitable habitat types (instream and riparian) and water chemistry or water quality. Therefore, frequent sampling of water quality parameters (e.g., nutrients – nitrogen and phosphorous, suspended sediment, faecal pathogen, temperature, dissolved oxygen) together with biological monitoring (e.g., macroinvertebrates, periphyton or algae cover on riverbed substrates) helps to understand the complex causal effects relationship of ecosystem response to catchment water quality.

Since July 2014 Raumanga Stream has been monitored together with other long-term State of the Environment (SoE) river monitoring sites that flow into the Whangārei Harbour. The last five years (2015-2019) of monthly SOE water quality monitoring shows higher concentration of dissolved inorganic nitrogen (DIN) and faecal pathogen (*Escherichia coli or E. coli*) in the Raumanga Stream compared to other main catchments contributing to the Hātea River estuary. The 5-year median concentrations of DIN and *E. coli* in Raumanga Stream were above the national bottom line (National Policy Standard for Freshwater Management or NPS-FM 2020) and much higher than those observed at Waiarohia Stream a major tributary of Raumanga Stream. High DIN concentration (the sum of nitrate/nitrite-N and ammoniacal-N) can often be linked to prolific algal growth and therefore habitat degradation, while elevated *E. coli* indicates the infection risk of using a water body for recreational activities and drinking water source.

However, the above observations were based on only one SOE monitoring site located at the bottom of Raumanga catchment. Therefore, a one-year (summer 2021 – summer 2022) water quality monitoring programme was established by Northland Regional Council particularly to ascertain the source of the elevated nitrogen and microbial contamination in the Raumanga Stream.

Scope

The main purpose of this project was to identify sub-catchment(s) that is/are causing elevated nutrient and microbial contamination in Raumanga Stream, so that targeted catchment management interventions can be undertaken to mitigate water quality degradation in the catchment. To fulfil this purpose the project was broken into following smaller objectives:

- Analyse and understand the water quality characteristics (particularly, nitrogen species and microbial indicator) including seasonal pattern (i.e., pollution triggered by dry versus wet months) of the major tributaries of Raumanga Stream.
- Identify the tributary stream(s) with highest pollutants and relate that to catchment land-use and geology.
- Recommend for future monitoring and catchment interventions.

Methods

Catchment Description

Raumanga Stream is one of major tributaries of the Hātea River estuary draining the suburbs of Maunu, Raumanga, and Hora Hora located in the western part of the Whangārei City. The upstream catchment comprises an area of approximately 16 km^2, which is located in between the Pukenui Forest Park to the north and Otaika Valley to the south. The Raumanga Stream receives its flow from three major tributaries – Nihotetea Stream (7 km^2), Te Hihi Stream (5 km^2), and Waiponamu Stream (2 km^2) before joining the Waiarohia Stream further downstream (REC ver.2).

Catchments of the Nihotetea and Waiponamu Stream has a semi-rural landscape with mixed urban and pastoral landcover, while Te Hihi Stream has also catchment dominated by pastoral landcover with few headwaters flowing from the Pukenui Forest Park. The lower catchment of the Raumanga Stream mainstem is dominated by urban built ups. Overall, majority of the Raumanga catchment is dominated by agricultural pasture landcover (approx. 50%) with some horticulture and lifestyle blocks in the upstream catchment. The second largest landcover is impervious urban built ups (approx. 20%) along the lower reaches and some indigenous forest (approx. 20%) mainly on the ridge tops of Pukenui Forest Park.

Catchment geology is dominated by volcanic basalt rocks (Puhipuhi-Whangārei Volcanic Field and Kerikeri Volcanic Group) with some mix of sandstone, limestone and conglomerates (QMAP Whangārei 2009). The catchment is dominated by moderately-well to well drained soils and oxygen-rich underlying aquifer (i.e., oxidising environment). Therefore, deep drainage through slowly permeable soil layers to underlying aquifer is the main hydrological pathway (Landscape DNA[1]). Riverbed substrates in Raumanga Stream are predominantly rocky (coble and gravel) with some mix of sand, silt, and mud in upstream tributaries. According to NIWA virtual climate network the catchment receives a mean annual rainfall of 1400mm.

Table 1: Major landcover types in Raumanga catchment as classified in the Land Cover Database 5 (LCDB ver.5).

Landcover type	Area (km^2)	Percentage of catchment area
High producing exotic grassland (pasture)	7.31	47%
Indigenous forest	3.35	22%
Built-up area (urban settlement)	2.65	17%
Urban parkland/Open space	0.69	4%
Orchard, Vineyard or Other Perennial Crop	0.73	5%
Broadleaved indigenous hardwoods	0.20	1%
Manuka and/or Kanuka	0.27	2%
Exotic forest	0.23	2%

[1] https://www.landscapedna.org/science/physiographic-method/

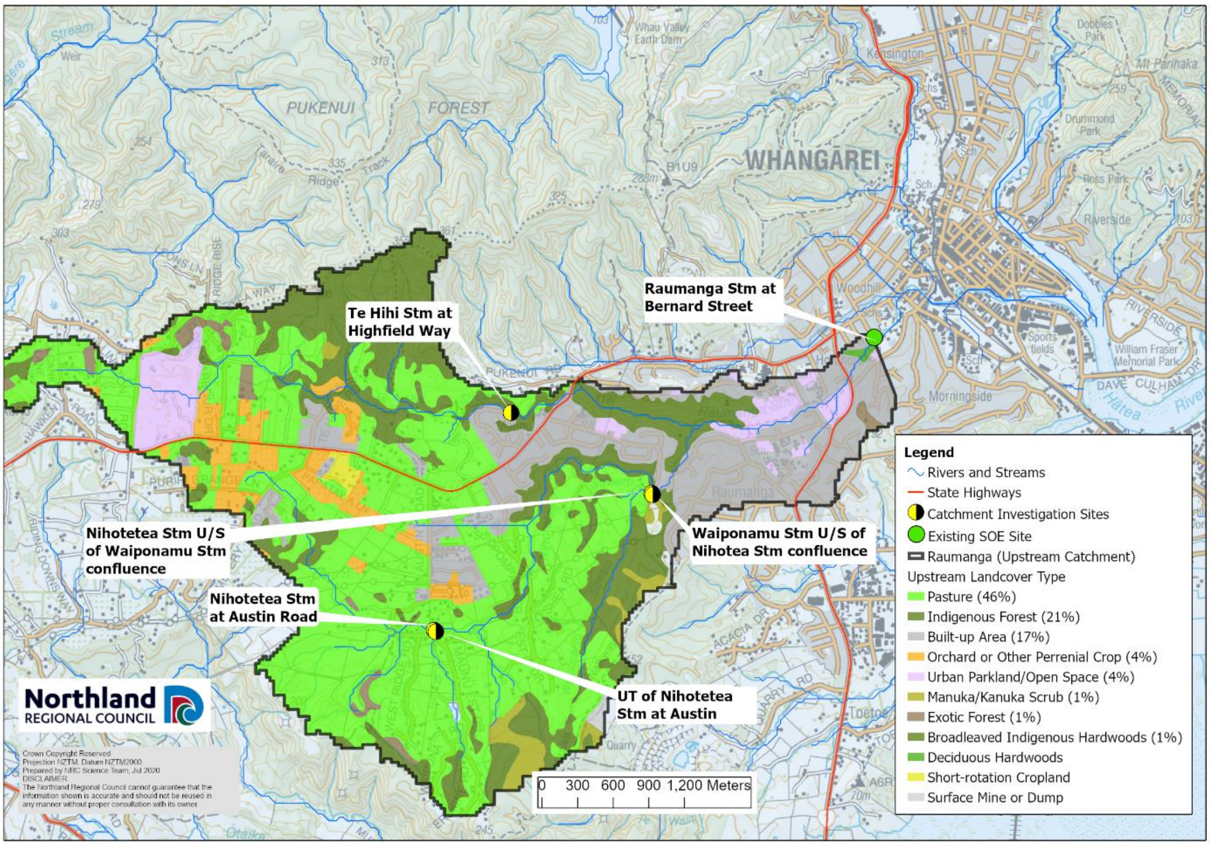


Figure 1: Map showing the distribution of major landcover types (LCDB 5) in the Raumanga catchment as well as the monitoring sites.

Monitoring Location

Five additional sites were chosen for sampling the major three tributaries along with the long-term SoE site in the Raumanga mainstem (i.e., Raumanga at Bernard Street). These monitoring sites are listed (from upstream to downstream order) in Table 2 with their approximate locations as shown in Figure 2.

Table 2: Monitoring sites (upstream to downstream order) for water quality investigation in Raumanga catchment.

Site Name	Site ID	Easting	Northing	Site Access
Nihotetea at Austin Road	LOC.328424	1715059	6042476	Access through private property - 179 Austin Road, Dallas Malcolm. Sample 2m above the confluence with an unnamed tributary.
Unnamed tributary of Nihotetea Stream at Austin Road (Nihotetea Trib at Austin Road)	LOC.328426	1715073	6042462	Same as above. Sample above the confluence with Nihotetea mainstem.
Nihotetea U/S of Waiponamu confluence	LOC.328433	1716892	6043632	Council land, park at the end of Kotuku Street off Puriri Park Road, walk through the grassland and head into the tree lines, sample 5m upstream of the Waiponamu Stream confluence.
Waiponamu U/S of Nihotetea confluence	LOC.328434	1716900	6043618	Similar access as above, sample just before it flows into Nihotetea Stream
Te Hihi at Highfield Way	LOC.328435	1715707	6044310	Access through public walkway (to the left) at the end of Highfield Way no exit

Site Name	Site ID	Easting	Northing	Site Access
				crescent off Maunu Road. Sample downstream of the wetland outlet.
Raumanga at Bernard Street	LOC.304709	1718769	6044944	Access through Bernard Street bridge.

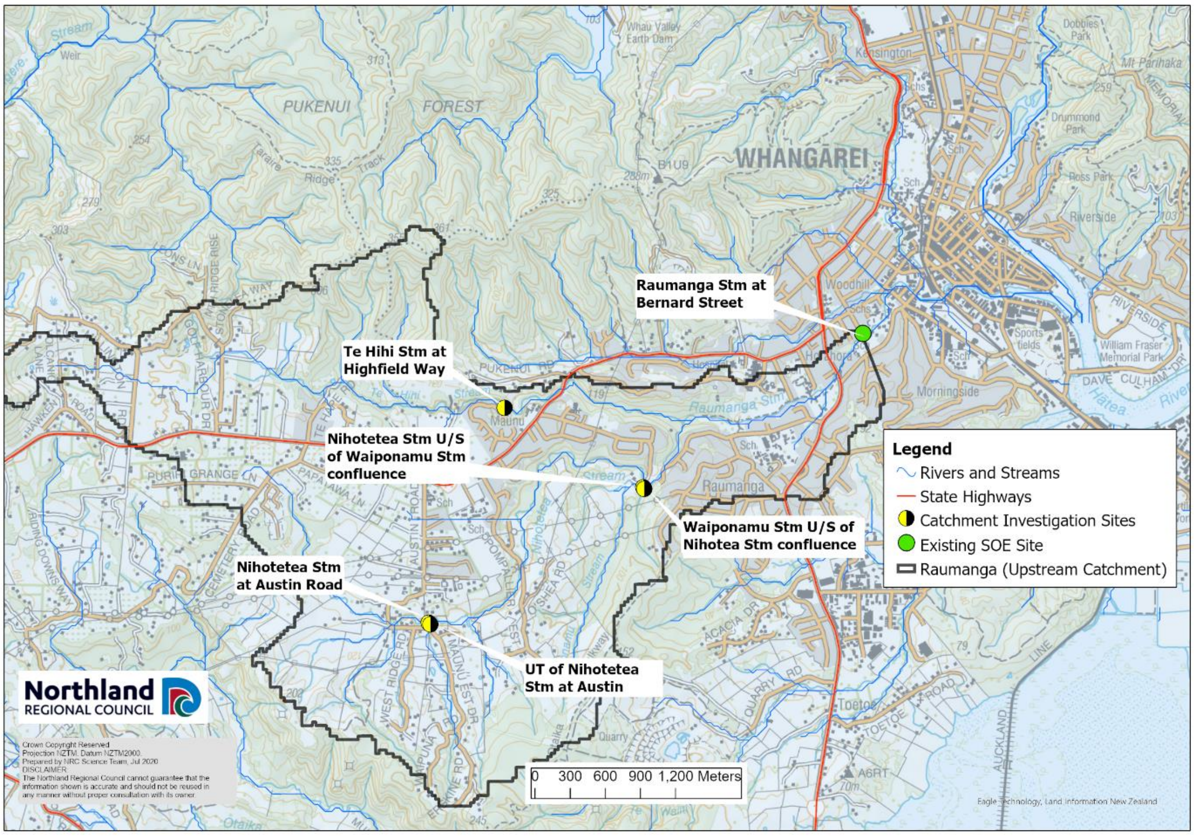


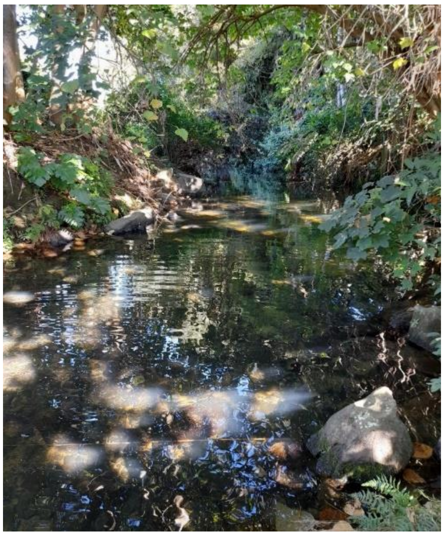
Figure 2: Locations of monitoring sites in the Raumanga catchment.

(a) Nihotetea Stream (to the left) and its unnamed tributary (to the right) at Austin Road.

(b) Nihotetea Stream upstream of Waiponamu Stream confluence at Kotuku Street Dam.

(c) Waiponamu Stream upstream of Nihotetea Stream confluence at Kotuku Street Dam.

(d) Te Hihi Stream at Highfield Way.



(e) Raumanga at Bernard Street

Figure 3: Photos of the water quality monitoring sites (in upstream to downstream order) that were selected for water quality investigation in the Raumanga catchment.

Sampling programme

Water quality monitoring

The sampling design included water quality monitoring of standard SoE suite of water quality tests on a monthly basis at the five additional monitoring sites covering a period of one year (i.e. starting from February 2021 to February 2022). The monthly monitoring at these sites were undertaken together with the long-term SoE site at Raumanga at Bernard Street between February 2021 and March 2022.

The following water quality parameters or attributes were analysed on a monthly basis by the Water Care Laboratory:

- Ammoniacal Nitrogen (NH4-N)
- Nitrate Nitrogen (NO3-N)

- Nitrite Nitrogen (NO2-N)
- Nitrate/Nitrite Nitrogen or Total Oxidised Nitrogen (TON)
- Dissolved Inorganic Nitrogen (DIN)
- Dissolved Reactive Phosphorous (DRP)
- Total Phosphorous (TP)
- Total and Volatile Suspended Solids
- Turbidity (NTU)
- *Escherichia Coli* (*E. coli*) by MPN

Field measures

Together with the water quality samples field parameters associated with standard SoE monitoring were also measured using handheld YSI meter. Visual clarity measurement was undertaken at each site using Black Disk (BD) and tape measure following the NEMS protocol[2]. Where BD readings could not be undertaken for practical reasons NIWA Clarity Tube (CT) was used estimate the BD readings. CT readings < 50 cm was considered equivalent to BD readings (using 20 cm diameter disk) because of strong 1:1 relationship. If Clarity Tube reading was > 50 cm and < 70 cm BD reading was estimated by using this equation:

$yBD = 7.28 \text{ X } 10^{[y\,CT\,/62\,.\,5]}$ (Kilroy & Biggs, 2002).

Biological parameter

Annual benthic macroinvertebrate monitoring was undertaken twice - once in February 2021 and then in February 2022, at the following sites. Macroinvertebrate monitoring was undertaken by following the C1 sampling (hard-bottom stream) and P3 sample processing protocol (Stark et. al. 2001). Samples were processed by the EOS Ecology.

- Nihotetea U/S Waiponamu confluence
- Te Hihi at Highfield Way
- Raumanga at Bernard Street

Macroinvertebrate community composition provides useful information on ecosystem health condition of the above two major contributing sub-catchments while identifying the source of elevated nutrients and microbial contamination in the Raumanga catchment.

Data analysis

Water quality

Side-by-side box plots a single axis were used to graphically display the distribution of the water quality data for each attribute throughout the monitoring period, which also helped us to compare between sites and understand whether one site differs from another. A box plot is based on a five-value summary – minimum (5th percentile), first quartile (25th percentile), median (50th percentile), third quartile (75th percentile), and maximum (95th percentile). The central rectangle of a box plot spans the first quartile to the third quartile covering the middle 50% of data. A segment inside the rectangle shows the median, and whiskers above and below the rectangle show the maximum and minimum values respectively, depending on the water quality attribute being measured.

[2] https://www.nems.org.nz/documents/water-quality-part-2-rivers/

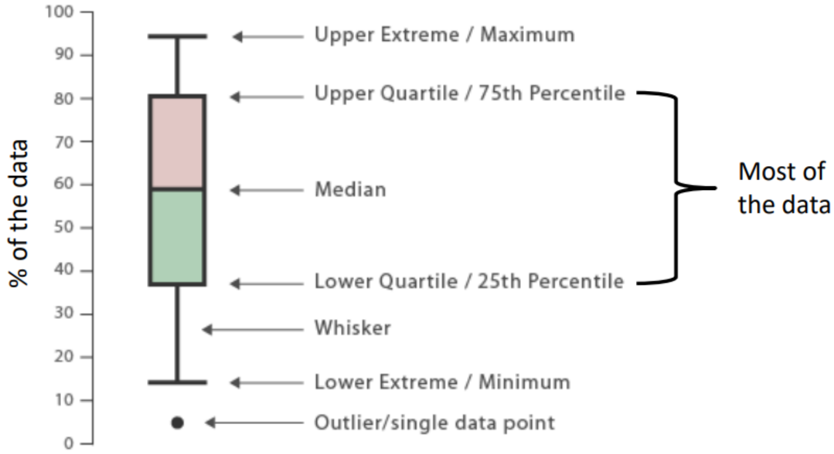


Figure 4: Explaining box plot.

The monthly water quality results for relevant attributes were analysed for estimating annual median and 95th percentile (or maximum values) to compare against their "national bottom lines" (considered as trigger values) as specified in the NPS-FM 2020. The NPS-FM 2020 (Appendices 2A and 2B) include several grades (band A to D) as well as "national bottom lines" for various water quality attributes. The national bottom line is the threshold of a water quality attribute which regional councils are obliged to prevent their waterways from reaching by undertaking good catchment management as well as regulatory and non-regulatory mitigation measures. The annual medians of water quality attributes were also compared to the worst water quality results (i.e., 92nd percentile for water quality contaminants and 8th percentile for visual clarity) observed at our reference sites with near-pristine condition which are considered as Northland objective values (Nicholson and Perquin 2019). See Table 3 with the list of trigger values used for assessing the water quality attributes for the purpose of this report.

Table 3: Trigger values used to assess the annual medians and maximums for various water quality attributes.

Water quality attributes		National bottom line (NPS-FM 2020)	Northland objective values
Ammoniacal nitrogen (toxicity) (mg/L)	Annual median	0.24	0.01
	Annual maximum	0.40	
Nitrate nitrogen (toxicity) (mg/L)	Annual median	2.4	0.10
	Annual 95th percentile	3.5	
Dissolved inorganic nitrogen or DIN (mg/L)	Annual median	1	0.10
	Annual 95th percentile	2.05	
Dissolved reactive phosphorous or DRP (mg/L)	Annual median	0.018	0.051
	Annual 95th percentile	0.054	
Escherichia coli (MPN/100mL)	Annual median	130	703
	Annual 95th percentile	1200	
Visual clarity (Black disk in m)	Annual median (For suspended sediment class 1)	1.34	0.87

Macroinvertebrates community indices

Several biotic indices were calculated from the raw macroinvertebrate data, which were used to give an indication of stream ecosystem health. These biotic indices (based on benthic invertebrate community composition) included Macroinvertebrate community index or MCI, Quantitative MCI or QMCI, EPT taxa richness, percent EPT abundance, and Average score per metric or ASPM. The scores of MCI, QMCI, and ASPM were compared to the NPS-FM 2020 standards (Table 14 and 15, Appendix 2B).

MCI – it is based on presence of macroinvertebrate taxa, which are assigned scores reflecting their tolerance to environmental pollution or organic enrichment (Stark & Maxted, 2007). These scores range between 1 and 10 (1 being highly tolerant and 10 being sensitive). The final score for each stream incorporates the sum of the MCI scores for each taxon with one or more individuals. A score of 120 or greater indicates a stream in pristine condition, a score between 80 and 120 indicate a moderately impacted stream, and a score lower than 80 indicate a severely polluted stream.

QMCI – it is the quantitative form of MCI and based on the abundance of individual taxa rather than number of taxa. The final score for each stream incorporates the sum of the MCI scores for each taxon weighted by the number of individuals. A score of 6 or greater indicates a stream in pristine condition, a score between 4 and 6 indicate a moderately impacted stream, and a score lower than 4 indicate a severely polluted stream.

EPT richness and percent EPT abundance – these are based on the taxa that belong in the Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddis fly) groups. These groups of insects are generally considered to be sensitive to pollution. The greater the proportion of these groups in the stream community, the healthier the stream is. The caddis flies *Oxyethira*, and *Paraoxyethira* are generally excluded from this calculation, as they are relatively tolerant to pollution.

ASPM - this is the average of three normalised metrics percent EPT abundance, EPT richness and MCI. When normalising scores for ASPM the following minima and maxima are used: %EPT-abundance (0-100), EPT-richness (0-29), MCI (0-200) by following the method of Kevin J Collier (2008).

Results and Discussion

Nutrients

Ammoniacal nitrogen

Results show that the annual medians as well as 95th percentiles (i.e., maximum concentrations) for ammoniacal nitrogen (NH_4-N) toxicity at all sites were much less than the NPS-FM band D value and therefore well above the national bottom line (Table 4). The NH_4-N median concentrations also satisfied the Northland objective values, which means 50% of the time NH_4-N concentrations were less than some of the worst results observed at the regional reference sites (Figure 5a). It was obvious from the box plots (Figure 5a) that the NH_4-N concentrations were slightly higher at the Waiponamu and Te Hihi Stream sites than the rest of the monitoring sites, which can be explained by looking at the main physiographic gradients that govern the water quality process (Pearson and Rissmann 2021) in these two sub-catchments i.e., moderately poor soil drainage (i.e., less chance of surface water interaction with shallow aquifer systems) and moderate reducing environment (i.e., less chance of oxidisation).

Nitrate nitrogen

Annual median concentrations for nitrate nitrogen (NO_3-N) toxicity satisfied the NPS-FM band D value at most sites except the Nihotetea Trib at Austin Road site where NO_3-N median concentration (2.1 g/m^3) was quite close to the national bottom line. The same site also breached the national bottom-line value for NO_3-N 95th percentile concentration (3.7 g/m^3) (Table 4). It important to note that NO_3-N concentrations at most samples were much higher than the Northland objective values except at Te Hihi and Waiponamu Stream sites (Figure 5b). It was obvious from the box plots that the NO_3-N concentrations in the Nihotetea Stream sites were much higher than the monitoring sites further downstream, which can, to some extent, be linked to moderately well drained soil (i.e., greater surface water interactions with nitrate rich shallow groundwater systems) and moderately high oxidised environment i.e., more possibility of denitrification. This means there is a high risk of nitrate loss from agricultural activities through surface run-off as well as leaching into the shallow groundwater systems in Nihotetea Stream catchment as well as Raumanga mainstem.

Dissolved inorganic nitrogen

The NPS-FM national bottom-line (draft NPS-FM 2019[3]) for dissolved inorganic nitrogen (DIN) was breached at most of the Nihotetea Stream sites for both annual median and 95th percentile concentrations. This was mostly due to high NO3-N concentrations at these sites (Table 4). The DIN concentration was particularly high (median = 2.13 g/m^3 and 95th percentile = 3.17 gm^3) at the Nihotetea Trib at Austin Road site (Figure 5c). The NO3-N median concentration at the Raumanga at Bernard Street site was very close to the national bottom-line. While looking at the monthly pattern of the DIN concentrations, we noticed consistently high NO3-N concentrations particularly in Nihotetea Stream sites during summer low-flow conditions, which was again exceptionally high in Nihotetea Trib at Austin Road compared to the other sites (Figure 6). This can be due to influence of groundwater movements from nitrate rich shallow aquifer systems, which makes up majority of the summertime low flows in Nihotetea sub-catchment. The last five-year median concentration of a groundwater bore site in Maunu (Site name - Maunu East GW at 507 SH14) was found to be 3.65 g/m^3.

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[3] NPS-FM 2020 does not have any thresholds for dissolved inorganic nitrogen (DIN), therefore national bottom-line values listed in draft NPS-FM 2019 were used for DIN.

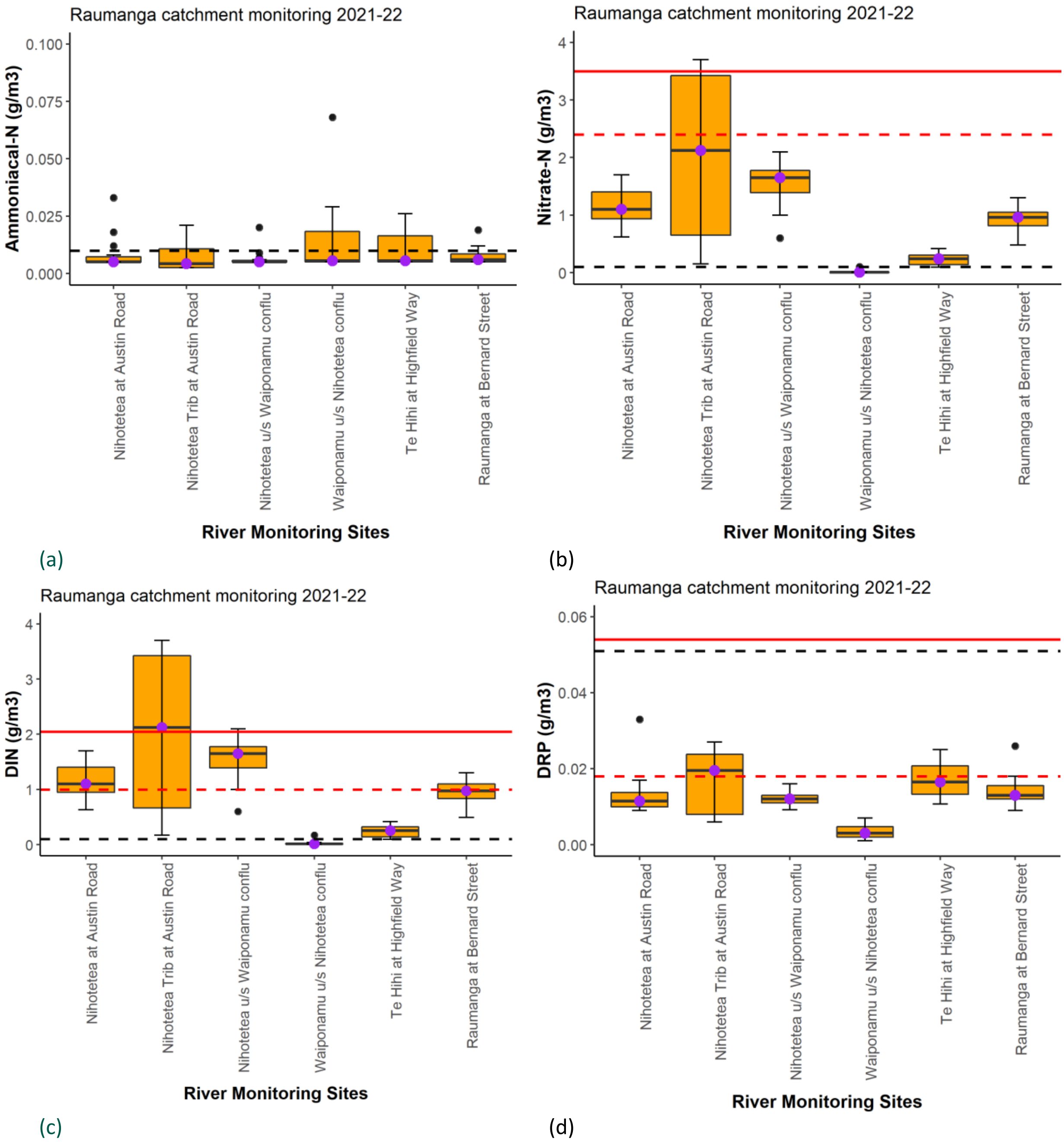


Figure 5: Box plots showing the distribution of Ammoniacal-N (a), Nitrate-N (b), Dissolved Inorganic Nitrogen or DIN (c), and Dissolved Reactive Phosphorus or DRP (d). **Purple dots** = median, **Red solid line** = NPS-FM national bottom line for annual 95th percentile concentration, Red hashed line = NPS-FM bottom line for annual median concentration, **Black hashed line** = Northland objective value.

It was noticed, a major proportion of the total nitrogen (Total N) concentrations in the Nihotetea and Raumanga Stream sites was comprised of inorganic nitrogen (DIN) as opposed to the Waiponamu Stream which had a very low proportion of DIN (Figure 7) mainly because of its high proportion of Total Kjeldahl Nitrogen (TKN) or organic nitrogen influenced by its moderately poor soil drainage properties and reducing (low oxidising potential) catchment geology.

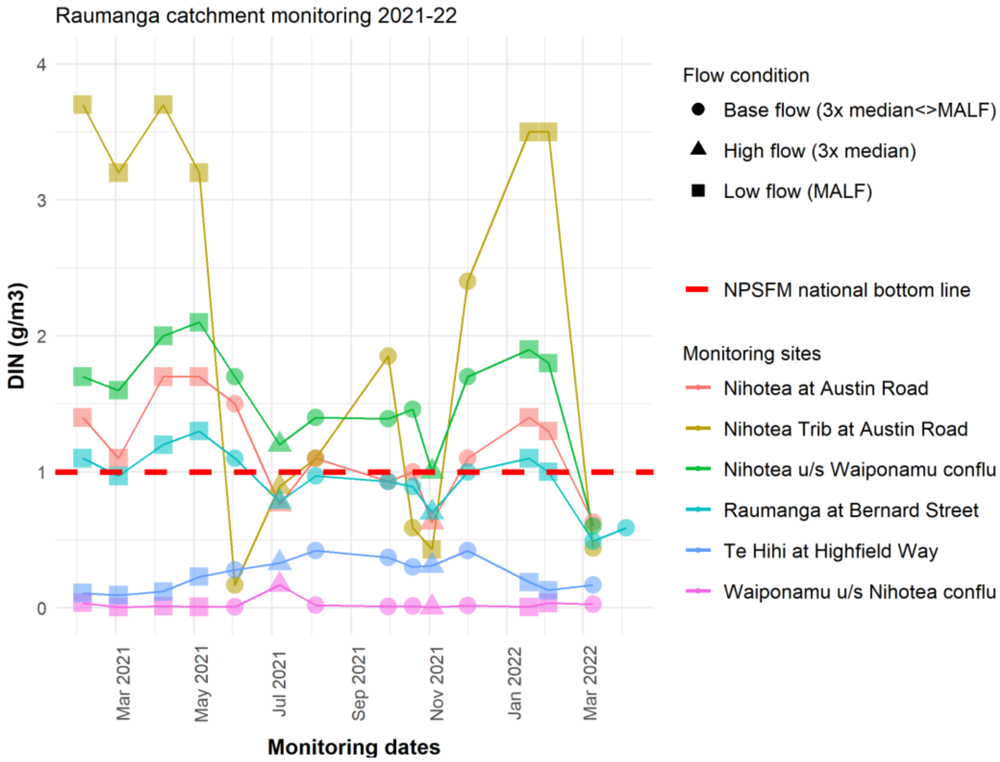


Figure 6: Comparing monthly results of Dissolved inorganic nitrogen (DIN) concentrations categorised by flow conditions across the monitoring sites over the whole monitoring period. Red hashed line = NPS-FM bottom line for annual median concentration. Flow categories are based on hydrological data at Raumanga site.

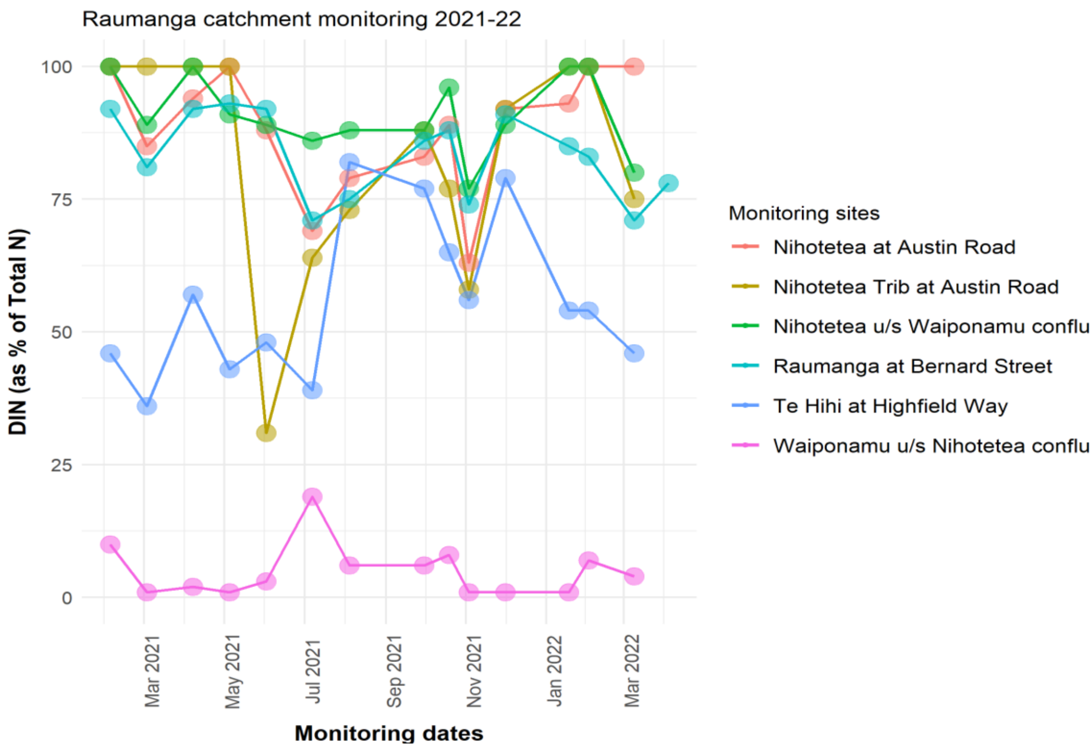


Figure 7: Comparing monthly results of Dissolved inorganic nitrogen (DIN) concentrations as proportion of total nitrogen (Total N) across the monitoring sites over the whole monitoring period.

On the other hand, a seasonal pattern was observed for Te Hihi Stream site where DIN as proportion of Total N was higher during winter wet months (perhaps due to surface run off and oxygen rich water) and comparatively low during summer low flows (perhaps due to decomposition of organic matter and moderately reducing environment, therefore less denitrification process). A recent study by Land & Water Science (Rissmann and Pearson 2020) on physiographic control over Northland's river water quality found organic nitrogen (TKN) together with NH4-N constituting the bulk of nitrogen loads at most of our rivers. This finding by Rissmann and Pearson 2020 did not match with the water quality results for Nihotetea Stream catchment for obvious variation in physiographic properties and their complex control on water quality process together with unknown land management practices at smaller sub-catchment scale.

Dissolved reactive phosphorus

Annual median concentrations of the Dissolved reactive phosphorus (DRP) were less than the NPS-FM national bottom line at most of the sites except at Nihotetea Trib at Austin Road (Table 4). The median DRP at Te Hihi Stream site, although did not breach, but was still close to the national bottom line (Figure 5c). The DRP concentrations at all sites satisfied the national bottom line for 95th percentile as well as the Northland objective value. While high DRP concentrations in Northland rivers are mostly associated with Basalt rocks from Tangihua Volcanic Complex and terrain ruggedness, the volcanic rocks from Kerikeri Volcanic Group unit, which is also found in Raumanga catchment, are less implicated in DRP generation (Rissmann and Pearson 2020). On the other hand, the Tauranga Group peat sediments in lowland floodplains (such as), particularly in developed lands, are also associated with high DRP generation, which could explain the high DRP in Te Hihi Stream and Nihotetea Trib at Austin Road. The monthly water quality results show that these high DRP concentrations in Te Hihi Stream and Nihotetea Trib at Austin Road mostly occur during summer low flow and base flow conditions, but not in winter months because of dilution effect.

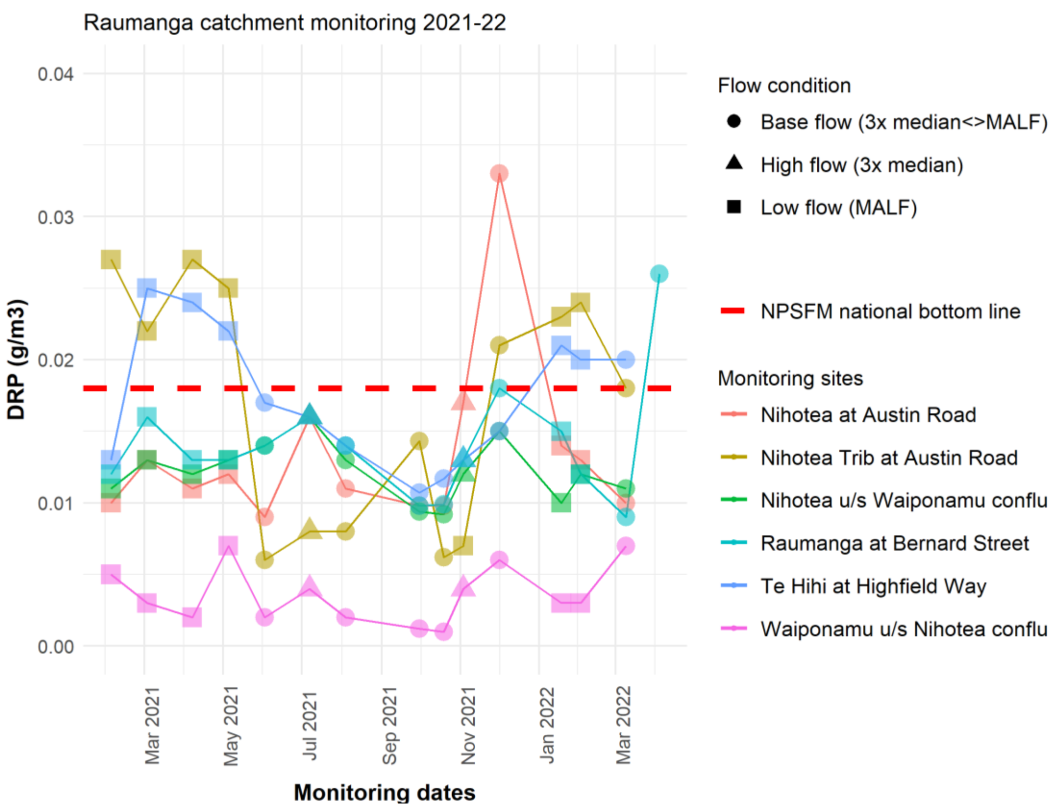
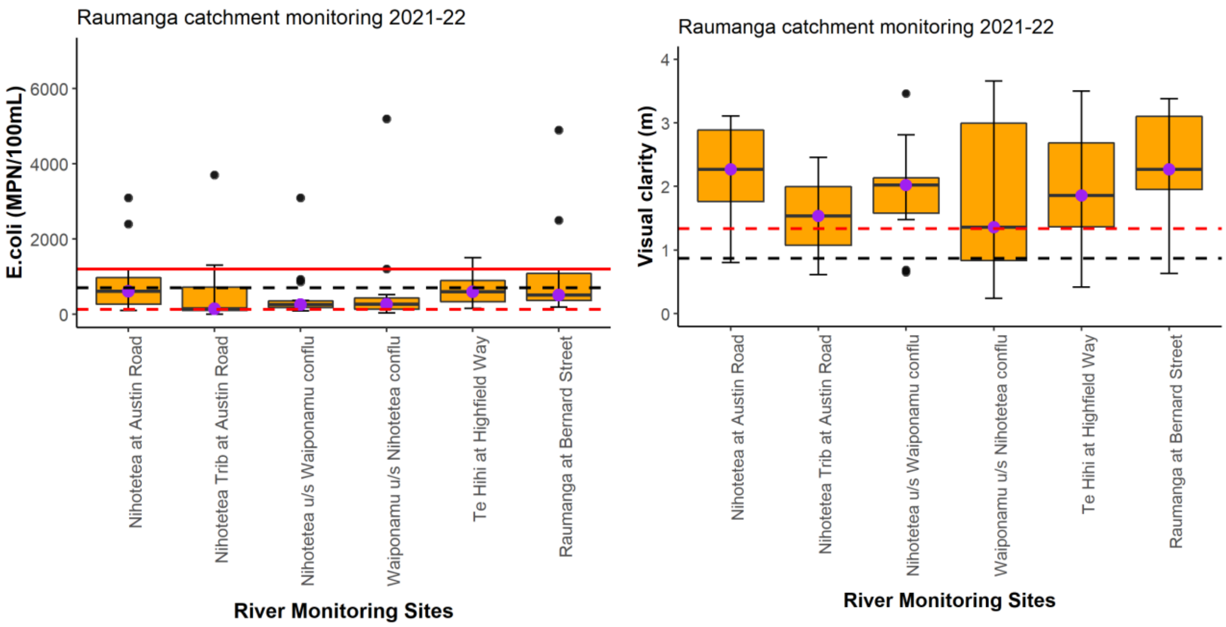


Figure 8: Comparing monthly results of Dissolved reactive phosphorus (DRP) concentrations categorised by flow conditions across the monitoring sites over the whole monitoring period. Red hashed line = NPS-FM bottom line for annual median concentration. Flow categories are based on hydrological data at Raumanga site.

Other water quality attributes

<u>Microbial contamination</u>

E. coli numbers (both annual median and 95th percentile) were much higher than the national bottom line values at all sites, however none of the median concentrations breached the Northland objective value of 703 MPN/100ml (Table 4, Figure 8a). This means still 50 percent of the time *E. coli* numbers were lower than the worst results observed in some of the regional reference sites. This trend of exceptionally high *E. coli* concentrations is quite similar throughout Northland rivers except in catchments with high natural state condition such as Waipoua Forest and Punaruku at Russell Road (Muirhead et al. 2023). Distribution of *E. coli* results from the box plots showed comparatively high *E. coli* concentrations in Nihotetea at Austin Road and Te Hihi Stream, which could be partially related to runoff from developed pastoral land-use, as well as the faecal pathogens from animal pests and wildfowls. Further downstream in Raumanga mainstem the faecal pathogen can also be related to old sewage and stormwater systems and lifestyle blocks. Even if there was no clear association between river flow conditions (as well as rainfall events) and high *E. coli* concentrations, most of the samples collected during low flow and base flow conditions satisfied the Northland objective value, while some of the high concentrations were particularly related to high flow conditions indicating the diffuse source of microbial contamination (Figure 9). Diffuse pollution source has been identified as a major source of microbial contamination in Northland's waterways by Muirhead et al. (2023). Previously, microbial source tracking results indicated that the primary source of contamination within the Whangārei Harbour catchment is ruminant but human markers have also been detected on several occasions at the Raumanga at Bernard Street site.



(a) (b)

Figure 9: Box plots showing the distribution of *E. coli* (a), and visual clarity (b). **Purple dots** = median, **Red solid line** = NPS-FM national bottom line for annual 95th percentile concentration, Red hashed line = NPS-FM bottom line for annual median concentration, **Black hashed line** = Northland objective value.

<u>Visual or water clarity (as indicator of suspended sediments)</u>

None of the sites failed the NPS-FM visual clarity standards, however the annual median black disk readings (measure of horizontal visibility through water column) were close to the national bottom line at the two sites - Waiponamu Stream and Nihotetea Trib at Austin Road site. Annual medians of visual clarity were also higher than the Northland objective value for all sites monitored. Low visual clarity is mainly influenced by elevated suspended sediments in the water column because of large rainfall events causing high turbidity. We found that overall visual clarity was not a big water quality issue for Raumanga catchment. However, it is to be acknowledged that this monitoring programme was not designed to focus on storm events when majority of the sediment load is generated because of catchment runoff and accelerated erosion process and therefore visual clarity is impacted by elevated suspended sediments (Hicks et.al. 2004). An analysis of the automated sediment data from stormflow events showed that 90% of the 2020 annual sediment load from the Hātea River was generated by the July 2020 flood event (Chakraborty 2022).

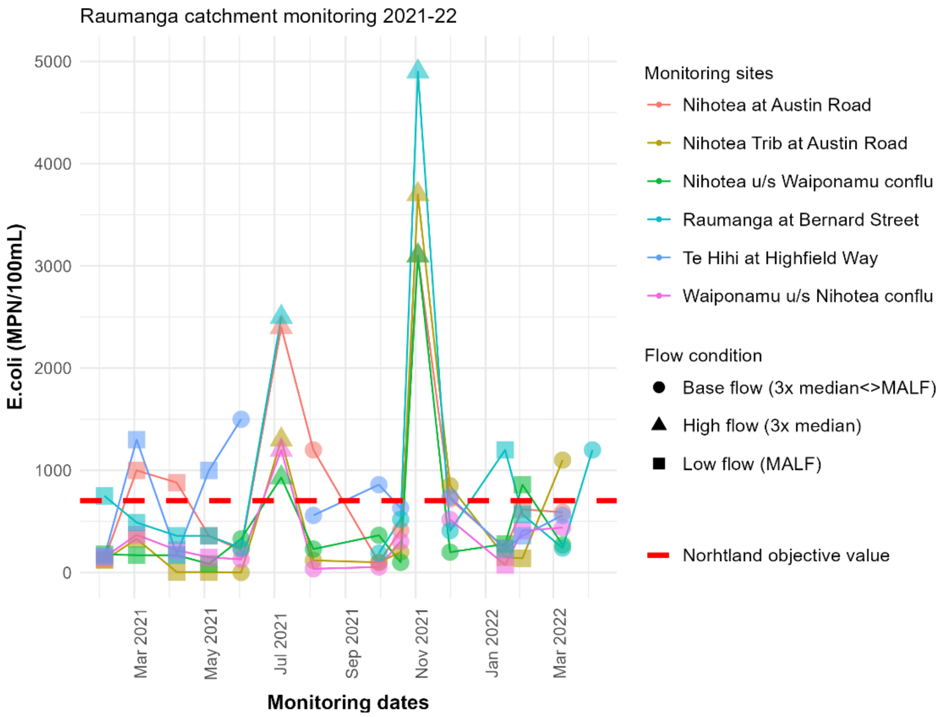


Figure 10: Comparing monthly results of *E. coli* concentrations among sites over the whole monitoring period. Here **Red hashed line** = Northland objective value. Flow categories are based on hydrological data at Raumanga site.

Table 4: Summary of the water quality results for each site assessed against the NPS-FM national bottom lines and Northland objective values. Highlighted cells indicate numeric values triggered by the national bottom line, while numbers in ***bold and italics*** indicate numeric values that failed to meet the Northland objective values.

Water quality attributes		Nihotetea at Austin Road	Nihotetea Trib at Austin Road	Nihotetea u/s Waiponamu confluence	Waiponamu u/s Nihotetea confluence	Te Hihi at Highfield Way	Raumanga at Bernard Street
Ammoniacal-N (toxicity) (mg/L)	Annual median	0.005	0.004	0.005	0.006	0.006	0.006
	Annual maximum	0.033	0.021	0.02	0.068	0.026	0.019
Nitrate-N (toxicity) (mg/L)	Annual median	***1.1***	***2.13***	***1.65***	0.01	***0.24***	***0.96***
	Annual 95th percentile	1.7	3.7	2.03	0.05	0.41	1.23
Dissolved inorganic nitrogen or DIN (mg/L)	Annual median	***1.1***	***2.13***	***1.65***	0.01	***0.26***	***0.97***
	Annual 95th percentile	1.7	3.7	2.04	0.08	0.42	1.23
Dissolved reactive	Annual median	0.012	0.020	0.012	0.003	0.017	0.013

Water quality attributes		Nihotetea at Austin Road	Nihotetea Trib at Austin Road	Nihotetea u/s Waiponamu confluence	Waiponamu u/s Nihotetea confluence	Te Hihi at Highfield Way	Raumanga at Bernard Street
phosphorous or DRP (mg/L)	Annual 95th percentile	0.023	0.027	0.015	0.007	0.024	0.020
Escherichia coli (MPN/100mL)	Annual median	605	145	250	263	686	521
	Annual 95th percentile	2645	2140	1689	2600	15050	6430
Visual clarity (Black disk in m)	Annual median	2.27	1.54	2.02	1.36	1.86	2.27

Physicochemical attributes

The discrete Temperature and pH readings at all monitoring sites were within the acceptable range throughout the monitoring period and well outside extremes observed elsewhere in Northland rivers. The maximum temperatures observed during summer months were between 18 to 20˚C, while maximum pH readings were between 6.9 to 8 (Appendix 1). It is important to acknowledge that the discrete measurements of Temperature might not have exhibited the actual extremes experienced by these sites during the late afternoon as samplings mostly occurred in the morning. The median electrical conductivities at most sites were around 230 µS/cm with the 95th percentile values approximately around 240 to 290 µS/cm, which were expected in any lowland rivers with moderate level of pollution and land-use impact. However, the conductivity values (median = 369 µS/cm, min. = 341 µS/cm, 95th percentile = 481 µS/cm) in Waiponamu Stream were exceptionally high while nutrient concentrations at this site were comparatively lower than other monitoring sites, which can only be explained by cation and anion rich (such as chloride) groundwater movements from shallow aquifers constituting bulk of its base flows (Figure 11).

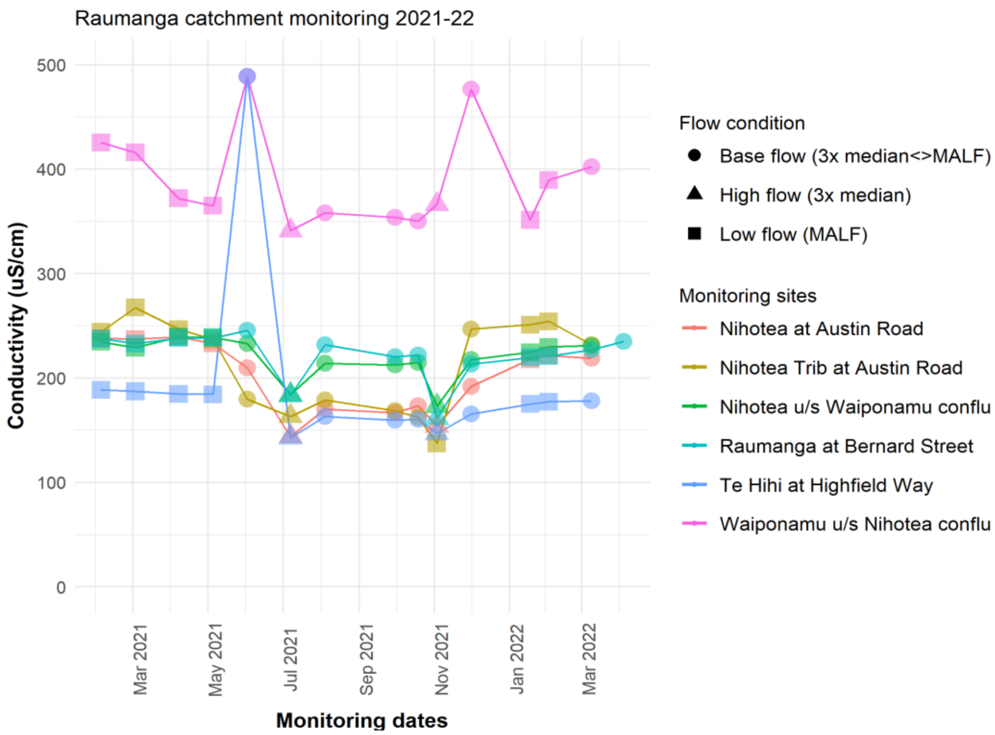


Figure 11: Comparing monthly results of electrical conductivity among sites over the whole monitoring period. Flow categories are based on hydrological data at Raumanga site.

Dissolved oxygen (DO) is an important water quality attribute, which provides life supporting capacity value to fish and freshwater invertebrates. The seasonal and diurnal (day vs night-time) fluctuation in DO level is generally influenced by water temperature, stream characteristics, in-stream biological activities and atmospheric pressure. Biological activities include photosynthesis and respiration by aquatic plants and algae and decomposition of organic matter such as sewage effluent, decaying vegetation and animal manures. Therefore, high fluctuation in DO maxima and minima, particularly during summer months, often indicate poor river water quality and imbalanced biological activities. The DO concentrations (min., median and 5th percentiles) observed at Nihotetea Stream upstream of Waiponamu confluence, Te Hihi Stream at Highfield Way and Raumanga Stream at Bernard Street were indicative of healthy ecosystem. However, the DO values were exceptionally low at Waiponamu Stream (min. = 0.2 mg/L, median = 4.2 mg/L, 5th percentile = 0.7 mg/L) and Nihotetea Stream at Austin Road (min. = 3.9 mg/L, median = 7.3 mg/L, 5th percentile = 4 mg/L) (Appendix 1). The low DO values at Waiponamu Stream and Nihotetea Stream at Austin Road, mostly during summertime (Figure 12), could be linked to deoxygenated groundwater movements constituting the bulk of their base flows as well as macrophyte growth in a very slow-moving channel.

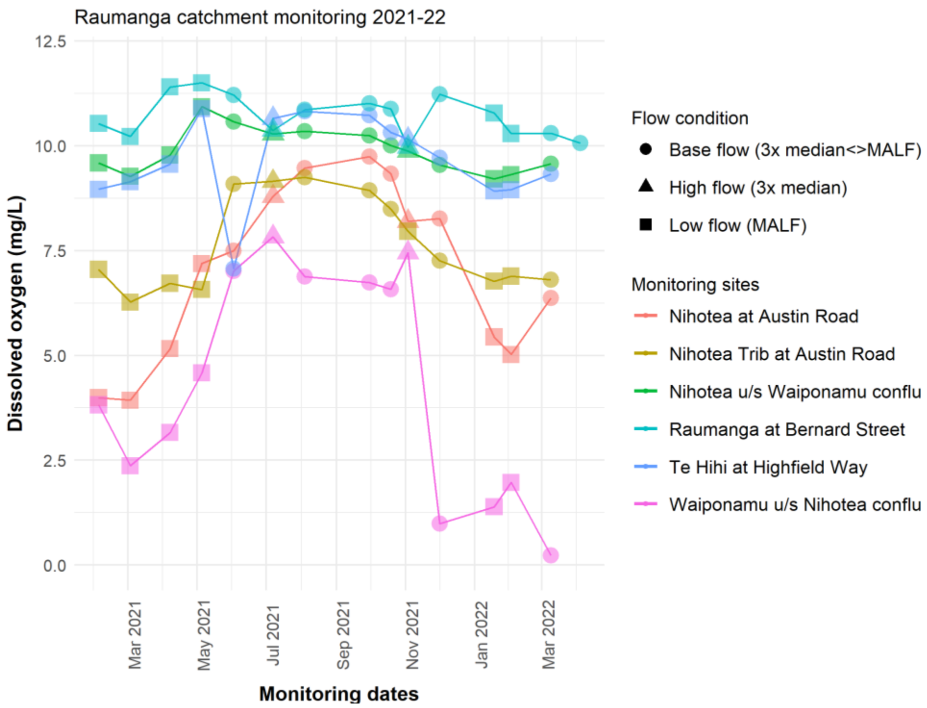


Figure 12: Comparing monthly results of dissolved oxygen (mg/L) among sites over the whole monitoring period. Flow categories are based on hydrological data at Raumanga site.

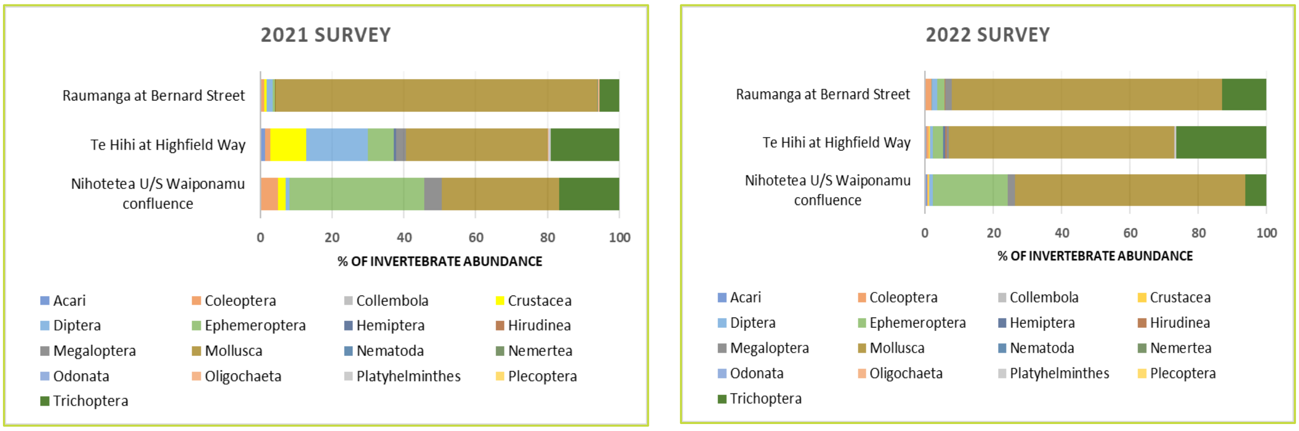
Benthic macroinvertebrates

Annual stream invertebrate monitoring results undertaken in 2021 and 2022 suggest that the macroinvertebrate community (MCI, QMCI, and ASPM) at the Nihotetea Stream upstream of the Waiponamu Stream confluence were in better condition (mostly within NPS-FM band B) than the downstream sites (mostly NPS-FM band C or D) – Te Hihi at Highfield Way and Raumanga at Bernard Street (Table 5). This was not surprising as the instream and riparian habitat conditions at the Nihotetea mainstem upstream of Waiponamu Stream were much healthier with riparian shades provided by the matured regenerating vegetation and rocky bed substrates forming sequence of riffle and run habitats than its downstream sites. Although total scores of the Rapid Habitat Assessment (RHA) survey were similar (approx. 70 out of 100) at the three invertebrate sampling sites, the invertebrate habitat abundance score was much higher (9 out of 10) in Nihotetea Stream than the other two sites (3 out of 10). On the other hand, band D QMCI and ASPM indices (i.e., below national bottom line) together with low EPT abundance at the Raumanga at Bernard Street site reflected its degraded water quality and poor habitat condition (Table 5). The moderately poor MCI and QMCI values at Te Hihi Stream site can be linked to its limited instream and riparian habitat quality and impact from the sprawling urban, and lifestyle blocks in the surrounding catchment. The EPT abundance in Te Hihi Stream was still higher than Raumanga Stream perhaps because of the drifted sensitive taxa from some of its forested headwaters.

Table 5: Macroinvertebrate community indices assessed against the NPS-FM 2020 Table 14 and 15 standards. Cells highlighted in green = band B, orange = band C, and red = band D or national bottom line.

Macroinvertebrate community indices	**Monitoring sites** (upstream to downstream order)					
	Nihotetea U/S Waiponamu confluence		Te Hihi at Highfield Way		Raumanga at Bernard Street	
	Yr. 2021	**Yr. 2022**	**Yr. 2021**	**Yr. 2022**	**Yr. 2021**	**Yr. 2022**
MCI	125	115	101	101	90	92
QMCI	6.1	5.2	4.4	4.3	4	4
ASPM	0.4	0.5	0.4	0.4	0.3	0.3
EPT richness	9	8	11	13	10	8
%EPT abundance	54	28	26	29	5	15

Note: There is no NPS-FM standards or quality bands for EPT indices. EPT indices include sensitive taxa comprising Ephemeroptera, Plecoptera, and Trichoptera (i.e., mayfly, stonefly, and caddisfly).



(a) (b)

Figure 13: Various insect groups as percentage of macroinvertebrate community abundance observed at the three Raumanga catchment investigation sites during 2021 (a) and 2022 (b) annual invertebrate survey.

From the analysis of macroinvertebrate community structures at these sites it was obvious that the presence of abundant high scoring (MCI tolerance value) mayfly species (Ephemeroptera) such as *Austorclima*, *Deleatidium*, *Nesameletus*, *Zephlebia*, and *Coloburiscus* (a sensitive species adapted to forested streams) at the Nihotetea mainstem site contributed to its good macroinvertebrate scores compared to the other sites. On the other hand, caddisflies were abundant at the Te Hihi Stream site, which was mainly dominated by *Aoteapsyche*, a low scoring EPT tolerant to moderate pollution. However, the absence of stonefly species (Plecoptera) and abundance of pollution tolerant snail species (insect group - Mollusca) *Potamopyrgus* was noticeable at all sites, indicating degraded water quality in the catchment (Figure 13).

Summary and conclusion

Five monitoring sites representing three major tributaries of the Raumanga catchment (Nihotetea Stream, Te Hihi Stream, and Waiponamu Stream) together with the Raumanga at Bernard Street SoE site were monitored between February 2021 and March 2022. The purpose of the monitoring was identify the source of elevated nitrogen and *E. coli* concentrations at Raumanga SoE site. The results from this water quality investigation monitoring can be summarised as follows:

Nitrogen -

- Comparatively high nitrate (NO_3-N) concentrations in the Nihotetea sub-catchment, which was exceptionally high in the unnamed tributary of Nihotetea Stream at Austin Road (Nihotetea Trib at Austin Road). NO_3-N constitutes the bulk of total nitrogen for all Nihotetea Stream sites as well as the Raumanga SoE site at Bernard Street. High nitrate in Nihotetea and Raumanga Streams also contributed to their high Dissolved inorganic nitrogen (DIN) concentrations breaching the NPS-FM national bottom line most of the time over the monitoring period. The median NO_3-N and DIN concentrations at all sites except the Waiponamu Stream had also breached the Northland objective value (i.e., some of the worst results found in Northland's near-pristine reference streams). The high NO_3-N and DIN in Nihotetea Stream can be related to moderately well drained soil (i.e., greater surface water interactions with nitrate rich groundwater systems) and high oxidising environment i.e., more possibility of denitrification. This means there is a possible high risk of nitrate loss from agricultural activities through surface run-off as well as leaching into the shallow groundwater systems in Nihotetea Stream catchment as well as Raumanga mainstem.

- Ammoniacal nitrogen (NH_4-N) constituted the bulk of total nitrogen at Waiponamu Stream and to some extent at Te Hihi Stream, which might have been influenced by their poorly drained peat soil with high reduction potential. However, overall NH_4-N toxicity level was much lower at all sites, which was consistent with any other Northland rivers.

Phosphorous –

- High Dissolved reactive phosphorus (DRP) was observed in Te Hihi Stream and Nihotetea Trib at Austin Road mostly during summer low flow and base flow conditions, but not in winter months perhaps because of dilution effect. The median DRP concentrations in Nihotetea Trib and Te Hihi Stream had breached the NPS-FM national bottom line mostly during summertime. The comparatively high DRP concentrations at these sites could be linked to volcanic geology and reduced peat soil exacerbated by their land-use impact. However, the DRP concentrations at all sites over the monitoring period were much lower than the Northland objective value.

Microbial contamination –

- The *E. coli* median concentrations had breached the NPS-FM national bottom line at all sites, but did not breach the Northland objective value. The *E. coli* concentrations were comparatively high in Nihotetea Stream at Austin Road, Te Hihi Stream at Highfield Way and Raumanga at Bernard Street. It is to be noted that very few rivers in Northland meet the NPS-FM standards for *E. coli*. High *E. coli* concentrations in Nihotetea at Austin Road and Te Hihi Stream could be due to runoff from developed pastoral land-use, and faecal pathogens from animal pests and wildfowl. Further downstream in Raumanga mainstem the faecal pathogen can be related to old sewage, stormwater systems and lifestyle blocks. Previously, microbial source tracking results indicated that the primary source of contamination within the Whangārei Harbour catchment is ruminant but human markers have also been detected on several occasions at the Raumanga at Bernard Street site.

Other water quality attributes -

- None of the sites had breached the NPS-FM national bottom line and Northland objective value for visual clarity (an indicator of suspended sediment). Overall visual clarity was not a major water quality issue for Raumanga catchment. However, it is to be acknowledged that the monitoring programme was not designed to focus on storm events when majority of the sediment load is generated because of catchment runoff and accelerated bank erosion process. Whangārei harbour sedimentation report by Swales et al. (2013) identified Raumanga catchment as a major source of deposited sediment from bank erosion and slips.

- Temperature and pH readings at all monitoring sites were within the acceptable range throughout the monitoring period. The median electrical conductivities at most sites were indicative of moderate pollution and land-use impact. However, the conductivity values in Waiponamu Stream were exceptionally high, even if nutrient concentration was comparatively lower than other monitoring sites, perhaps because of ion rich groundwater influence from shallow aquifers constituting bulk of its base flows.

- Dissolved oxygen (DO) concentrations were exceptionally low at Waiponamu Stream and Nihotetea Stream at Austin Road. Low DO values at Waiponamu Stream and Nihotetea Stream at Austin Road, mostly during summertime, could be influenced by deoxygenated groundwater movements as well as macrophyte growth in a very slow-moving channel. DO concentrations observed in Waiponamu, Te Hihi, and Raumanga Stream were indicative of healthy ecosystem respiration. However, it is to be acknowledged that discrete DO measurements are not ideal to monitor the effects of seasonal and diurnal DO fluctuations on aquatic biota.

Benthic macroinvertebrates -

- Annual stream invertebrate monitoring results undertaken in 2021 and 2022 suggest that the macroinvertebrate community (MCI, QMCI, and ASPM) at the Nihotetea Stream upstream of the Waiponamu Stream confluence were in better condition (mostly within NPS-FM band B) than the downstream sites (mostly NPS-FM band C or D) – Te Hihi at Highfield Way and Raumanga at Bernard Street. Low QMCI and ASPM indices (i.e., below national bottom line) together with low EPT abundance at the Raumanga at Bernard Street site reflected its degraded water quality and poor habitat condition. The moderate MCI and poor QMCI values at Te Hihi Stream site can be linked to its limited instream habitat quality and impact from the sprawling urban, and lifestyle blocks in the surrounding catchment. The absence of stonefly species and abundance of pollution tolerant snail species *Potamopyrgus* was noticeable at all sit*es*, indicating degraded water quality in the catchment.

Overall, the water quality state in the upper reaches of Nihotetea Stream around Austin Road was poor with high nutrients compared to the Te Hihi and Waiponamu Stream sub-catchments, possibly because of developed pastures with no riparian vegetation and influence of legacy nutrients in the groundwater from old-time orchards in early 2000. The poor water quality in the upper reaches of Nihotetea Stream was also influenced by its physiographic control over water quality process (i.e., landscape characteristics such as underlying geology, and dominant hydrological pathway to oxidising shallow groundwater systems). As the water travels down the catchment along the Nihotetea mainstem upstream of the Waiponamu Stream confluence, the water quality slightly improved providing better life supporting capacity value (e.g., healthy dissolved oxygen and macroinvertebrate community) because of better in-stream habitat diversity and riparian habitat. The poor water quality state including the macroinvertebrate community in Raumanga Stream at Bernard Street could be partially attributed to the upper reaches of Nihotetea Stream but also the cumulative effects of semi-rural and urban land-use in its surrounding catchment. Also, there might be some negative ecological impacts of the Hopua te Nihotetea dam (completed in 2015) downstream of the Waipounamu stream confluence, however investigating that was beyond the scope of this report. It is to be acknowledged that improving the water quality in Raumanga catchment even with an integrated catchment management initiatives might take years because of the effect of legacy nutrients, challenging landscape settings with natural contribution and complicated socio-economic factors.

Recommendations

- There is a continual risk of nitrogen leaching and release of phosphorus to surface waterways and shallow groundwater systems in the Nihotetea Stream headwater catchments because of its well-drained soil, geology type, underlying oxidising shallow aquifers and high risk of surface runoff particularly during winter months. Therefore, it is recommended to have a careful consenting process for any new or renewal of existing consents that would have the potential of accelerating this landscape process behind poor water quality state in this catchment.

- Also suggest compliance check of land use practices in the Nihotetea catchment and ways to minimise water qulity contamination. For example, if there is dairy farming ensuring that they are meeting consent requirements or if the consent conditions need to be reviewed.

- Undertake non-regulatory catchment intervention or mitigation measures (such as creation of thick riparian buffer) in the Nihotetea headwater catchments north of Pompallier Estate Drive, where currently the waterways are devoid of any healthy riparian buffer. Similar catchment interventions together with careful consenting process is also recommended in the headwater catchments of Te Hihi Stream and lower reaches of Raumanga mainstem.

- Undertake further water quality investigation following the implementation of catchment mitigations measures together with sampling of physiographic process attributes (e.g., Dissolved Organic Carbon or DOC, Iron, Manganese, Sulphate, Dissolved Silica, Alkalinity, Potassium, Sodium) in the upstream headwaters of Nihotetea. This will aid in better understanding of the water quality process and effectiveness of the mitigation measures in the Raumanga catchment.

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Appendix

Appendix 1: Summary statistics of major water quality parameters measured across the Raumanga catchment investigation sites.

Water quality attributes		Nihotetea at Austin Road	Nihotetea Trib at Austin Road	Nihotetea u/s Waiponamu confluence	Waiponamu u/s Nihotetea confluence	Te Hihi at Highfield Way	Raumanga at Bernard Street
Temperature (degree C)	Median	16.2	16.0	16.2	14.8	15.4	17.3
	Min.	12.3	10.9	11.4	9.9	10.4	11.6
	Max.	18.8	16.8	18.9	17.9	19.6	20.3
	SD	2.5	1.8	2.5	2.9	3.5	3.2
	Q95	18.7	16.7	18.6	17.4	19.5	20.1
pH	Median	6.8	6.5	7.9	6.8	7.6	7.8
	Min.	6.6	6.4	7.7	6.6	6.8	7.4
	Max.	6.9	6.9	8.1	7.2	8.0	8.4
	SD	0.1	0.1	0.2	0.1	0.3	0.3
	Q95	6.9	6.7	8.1	7.0	7.9	8.3
Conductivity (µS/cm)	Median	214	234	227	369	176	227
	Min.	144	138	173	341	143	161
	Max.	240	268	239	489	489	246
	SD	34	44	20	47	86	22
	Q95	239	259	239	481	294	241
Dissolved oxygen (mg/L)	Median	7.3	7.2	9.8	4.2	9.6	10.8
	Min.	3.9	6.3	9.2	0.2	7.1	10.0
	Max.	9.7	9.3	10.9	7.8	10.9	11.5
	SD	2.0	1.1	0.5	2.7	1.0	0.5
	Q05	4.0	6.5	9.2	0.7	8.3	10.0
Ammoniacal Nitrogen (mg/L)	Median	0.01	0.00	0.01	0.01	0.01	0.01
	Min.	0.01	0.00	0.01	0.01	0.01	0.01
	Max.	0.03	0.02	0.02	0.07	0.03	0.02
	SD	0.01	0.01	0.00	0.02	0.01	0.00
	Q95	0.02	0.02	0.01	0.04	0.02	0.01
Nitrate Nitrogen (mg/L)	Median	1.1	2.1	1.7	0.0	0.2	1.0
	Min.	0.6	0.2	0.6	0.0	0.1	0.5
	Max.	1.7	3.7	2.1	0.1	0.4	1.3
	SD	0.4	1.4	0.4	0.0	0.1	0.2
	Q95	1.7	3.7	2.0	0.1	0.4	1.2
Dissolved Inorganic Nitrogen or DIN (mg/L)	Median	1.1	2.1	1.7	0.0	0.3	1.0
	Min.	0.6	0.2	0.6	0.0	0.1	0.5
	Max.	1.7	3.7	2.1	0.2	0.4	1.3
	SD	0.4	1.4	0.4	0.0	0.1	0.2
	Q95	1.7	3.7	2.0	0.1	0.4	1.2
	Median	0.16	0.17	0.15	0.48	0.16	0.17
	Min.	0.10	0.05	0.10	0.15	0.10	0.11

Water quality attributes		Nihotetea at Austin Road	Nihotetea Trib at Austin Road	Nihotetea u/s Waiponamu confluence	Waiponamu u/s Nihotetea confluence	Te Hihi at Highfield Way	Raumanga at Bernard Street
Total Kjeldahl Nitrogen or TKN (mg/L)	Max.	0.43	0.55	0.27	1.06	0.54	0.35
	SD	0.12	0.16	0.06	0.26	0.12	0.07
	Q95	0.43	0.45	0.24	0.88	0.40	0.32
Total Nitrogen (mg/L)	Median	1.30	2.35	1.75	0.49	0.47	1.20
	Min.	0.63	0.55	0.75	0.16	0.21	0.69
	Max.	1.80	3.70	2.30	1.10	0.85	1.40
	SD	0.31	1.26	0.37	0.27	0.18	0.20
	Q95	1.74	3.70	2.11	0.96	0.67	1.33
Dissolved Reactive Phosphorous or DRP (mg/L)	Median	0.012	0.020	0.012	0.003	0.017	0.013
	Min.	0.009	0.006	0.009	0.001	0.011	0.009
	Max.	0.033	0.027	0.016	0.007	0.025	0.026
	SD	0.006	0.008	0.002	0.002	0.005	0.004
	Q95	0.023	0.027	0.015	0.007	0.024	0.020
Total Phosphorous or TP (mg/L)	Median	0.017	0.029	0.018	0.031	0.032	0.023
	Min.	0.010	0.019	0.010	0.006	0.023	0.015
	Max.	0.074	0.053	0.045	0.086	0.084	0.053
	SD	0.020	0.010	0.010	0.026	0.018	0.012
	Q95	0.064	0.045	0.040	0.078	0.074	0.050
***Escherichia coli* or *E. coli* (MPN/100mL)**	Median	605	145	250	263	686	521
	Min.	100	1	86	37	160	190
	Max.	3100	3700	3100	5200	17000	10000
	SD	878	993	786	1340	5431	2631
	Q95	2645	2140	1690	2600	15050	6430
Visual clarity (Black disk in m)	Median	2.27	1.54	2.02	1.36	1.86	2.27
	Min.	0.80	0.61	0.65	0.24	0.42	0.63
	Max.	3.11	2.46	3.46	3.66	3.50	3.38
	SD	0.93	1.31	0.73	1.30	0.94	0.86
	Q05	0.99	0.70	0.68	0.30	0.42	0.67

Note: Q95 = 95th percentile, Q05 = 5th percentile.

Appendix 2: Results from annual macroinvertebrate surveys (2021 and 2022) and calculated macroinvertebrate community indices.

			Site name					
			Nihotetea U/S Waipounamu confluence		Te Hihi at Highfield Way		Raumanga at Bernard Street	
		Site no.	328433		238435		304709	
		Date	5/02/2021	26/01/2022	5/02/2021	26/01/2022	2/02/2022	13/01/2021
Taxa grouping	**Taxa name**	**TV score (HB)**						
Acari	Acari	5		4	15	8	2	8
Coleoptera	*Elmidae (L)*	6	40	1	16	12	14	112
Crustacea	*Phreatogammarus*	5	16	1				
	Paracalliope	5	1	1	106	8	1	64
	Paratya	5						1
Diptera	*Aphrophila*	5			3			
	Austrosimulium	3		1	52	4		8
	Harrisius	6	8					
	Mischoderus	4	1					1
	Muscidae	3					2	1
	Orthocladiinae	2			33	1	2	32
	Paradixa	4		4				
	Polypedilum	3		1	14	8	4	32
	Psychodidae	1						8
	Tanypodinae	5			4		1	
	Tanytarsini	3			80		5	88
Ephemeroptera	*Austroclima*	9	8	14		8		
	Coloburiscus	9	112	71	21	24	18	16
	Deleatidium	8	80	7	8	12	2	16
	Nesameletus	9	8	18	3	1		
	Zephlebia	7	96	12	44	8		16
Hemiptera	*Diaprepocoris*					4		

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			Site name					
			Nihotetea U/S Waipounamu confluence		Te Hihi at Highfield Way		Raumanga at Bernard Street	
		Site no.	328433		238435		304709	
		Date	5/02/2021	26/01/2022	5/02/2021	26/01/2022	2/02/2022	13/01/2021
Taxa grouping	**Taxa name**	**TV score (HB)**						
	Microvelia	5			8			
	Sigara	5				8		
Hirudinea	*Hirudinea*	3				8	1	
Megaloptera	*Archichauliodes*	7	40	12	29	8	16	16
Mollusca	*Ferrissia*	3					2	
	Gyraulus	3			18	32		
	Latia	3					13	
	Pseudosuccinea	3				1		
	Potamopyrgus	4	264	376	407	1132	675	8912
Nemertea	Nemertea	3						8
Oligochaeta	Oligochaeta	1			3	1	1	48
Platyhelminthes	*Dalyellidae*	3				1		
	Platyhelminthes	3			6	8		
Trichoptera	*Hydropsyche (Aoteapsyche)*	4	8	12	50	180	58	256
	Costachorema	7			1			
	Hudsonema	6				1	2	16
	Hydrobiosis	5	8	1		1		8
	Olinga	9			2	8		
	Oxyethira	2			4		2	56
	Plectrocnemia	8				1		
	Polyplectropus	8					2	
	Pycnocentria	7	40		8	8	5	80
	Pycnocentrodes	5	80	22	139	236	44	128
	Triplectides	5			1	32		1

			Site name					
			Nihotetea U/S Waipounamu confluence		Te Hihi at Highfield Way		Raumanga at Bernard Street	
		Site no.	328433		238435		304709	
		Date	5/02/2021	26/01/2022	5/02/2021	26/01/2022	2/02/2022	13/01/2021
Taxa grouping	**Taxa name**	**TV score (HB)**						
		Total abundance	810	558	1075	1764	872	9932
		Taxonomic richness	16	17	26	29	22	25
		MCI	125	115	101	101	92	90
		QMCI	6.1	5.2	4.4	4.3	4.2	4
		EPT richness	9	8	11	13	8	10
		EPT abundance	440	157	281	520	133	593
		%EPT abundance	54	28	26	29	15	5
		ASPM	0.5	0.4	0.4	0.4	0.3	0.3

Note: TV = Tolerance value; HB = hard-bottomed stream

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